Original Article

Optimizing Positive End-Expiratory Pressure Based on Intra-Abdominal Pressure in Patients with Acute Respiratory Failure

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ABSTRACT

Background: Positive end-expiratory pressure (PEEP) is a crucial component of mechanical ventilation to improve oxygenation in critically ill patients with respiratory failure. The interaction between abdominal and thoracic compartment pressures is known well. Especially in intra-abdominal hypertension, lower PEEP may cause atelectotrauma by repetitive opening and closing of alveoli. **Aim:** In this study, it was aimed to investigate the effect of PEEP adjustment according to the intra-abdominal pressure (IAP) on oxygenation and clarify possible harms. **Method:** Patients older than 18 were mechanically ventilated due to hypoxemic respiratory failure and had normal IAP (<15 mmHg) included in the study. Patients with severe cardiovascular dysfunction were excluded. The following PEEP levels were applied: PEEPzero of 0 cmH2O, $PEEP_{IAP/2}$ = 50% of IAP, and $PEEP_{IAP}$ = 100% of IAP. After a 30-minute equilibration period, arterial blood gases and mean arterial pressures were measured. **Results:** One hundred thirty-eight patients (mean age 66.5 ± 15.9, 56.5% male) enrolled on the study. The mean IAP was 9.8 ± 3.4. Seventy-nine percent of the patients' PaO_2/FiO_2 ratio was under 300 mmHg. Figure 1 shows the change in PaO_2/FiO_2 ratio, $PaCO_2$, PPlato, and MAP of the patients according to the PEEP levels. Overall increases were detected in the PaO_2/FiO_2 ratio ($P < 0.001$) and Pplato ($P < 0.001$), while $PaCO_2$ and MAP did not change after increasing PEEP gradually. Pairwise analyses revealed differences in PaO_2/FiO_2 between PEEPzero (186.4 [85.7–265.8]) and $PEEP_{IAP/2}$ (207.7 [101.7–292.9]) (t = -0.77, $P < 0.001$), between baseline and $PEEP_{IAP}$ (236.1 [121.4–351.0]) (t = -1.7, $P < 0.001$), and between $PEEP_{IAP/2}$ and $PEEP_{IAP}$ (t = -1.0, $P < 0.001$). Plato pressures were in the safe range (<30 cmH_2O) at all three PEEP levels (PEEPzero = 12 [10–15], $PEEP_{IAP/2}$ = 15 [13–18], $PEEP_{IAP}$ = 17 [14–22]). **Conclusion:** In patients with acute hypoxemic respiratory failure and mechanically ventilated, PEEP adjustment according to the IAB improves oxygenation, especially in the settings of the limited source where other PEEP titration methods are absent.

Keywords: *Intra-abdominal pressure, mechanical ventilation, positive-end expiratory pressure, respiratory failure*

Introduction

Mechanical ventilation is an essential tool utilized in critical care settings to support patients with respiratory failure. To maintain alveolar recruitment, prevent lung collapse, and enhance gas exchange in mechanically ventilated patients, positive end-expiratory pressure (PEEP) adjustment is crucial.[1,2] However, determining the right PEEP level for each patient can be a complex and challenging task for healthcare professionals.

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It is critical to determine the appropriate amount of PEEP to prevent any harm to patients. An insufficient PEEP can result in atelectrauma, whereas an excessive PEEP can cause barotrauma, increase pulmonary vascular resistance, and reduce preload.[2] Therefore, optimizing PEEP settings has become a significant research focus to enhance patient care and clinical outcomes in the intensive care unit (ICU). The PEEP/FIO_2 tables of the ARDS/FiO_2 Network or best compliance can be used for PEEP selection. However, personalizing care for each patient can provide more significant benefits.[3] Hospitals with the necessary equipment and expertise can utilize advanced methods, such as stress index, end-expiratory lung volume, esophageal manometry, ultrasound, and electrical impedance tomography for improved patient care.[4]

The human body consists of an abdomen and a thorax, forming a closed physical system that obeys the laws of closed containers for pressure changes. Despite the presence of the diaphragm muscle separating the abdomen and thorax, the diaphragm is flexible. This elasticity leads to a two-way pressure interaction in which intra-abdominal pressure (IAP) affects ventilation of the lungs and oxygenation. Intra-abdominal hypertension (IAH) has been shown to reduce lung volumes by decreasing chest wall compliance and causing atelectasis.[5-7] This effect is particularly significant in patients with respiratory failure and limited respiratory capacity. It impacts the ideal PEEP setting for those who require mechanical ventilation. Increased levels of PEEP could potentially reverse changes in airway mechanics and oxygenation caused by IAH.[5,8,9] This is due to the equalization of thoracic and intra-abdominal pressures on expiration and the prevention of atelectotrauma by keeping the alveoli open in the dependent lung fields. This phenomenon may help determine the optimal PEEP level in mechanically ventilated patients with acute respiratory failure without IAH.

The objective of this study was to explore the impact of adjusting PEEP based on IAP on the oxygenation of patients with acute respiratory failure who are on mechanical ventilation while also identifying any potential risks.

Method

This single-center study was conducted in. Hospital Medical Intensive Care Units and included patients admitted between January 2015 and December 2019. This study was approved by …. Clinical Research Ethics Committee (-----BAEK 2020/421). Written informed consent was obtained from either the patient or their relatives.

Patients

The study enrolled patients who were over 18 years old and admitted to the ICU for acute hypoxemic respiratory failure and subsequently intubated and mechanically ventilated. Those who had IAH (IAP > 15 cmH_2O), were pregnant, had severe cardiovascular dysfunction (malign arrhythmia, ejection fraction < 50%, cardiac index < 2.1 L/min/m^2 where available), or required inotropic/vasopressor therapy (noradrenaline≥0.20 mcg/kg/min, dopamine>5 mcg/kg/min, or dual therapy) were excluded.

Intra-abdominal pressure measurement

To measure IAP, the intravesical technique was used.[10] First, the drainage tube of the patient's Foley catheter was clamped. Then, 50 mL of sterile saline was infused into the bladder through the aspiration port of the catheter, and the catheter was filled with fluid. Next, an 18-gauge needle attached to a pressure transducer was inserted into the aspiration port. The transducer was zeroed at the midaxillary line prior to insertion. Finally, IAP was measured by performing an expiratory hold manoeuver at the mechanical ventilator in the supine position with a 5 cmH_2O PEEP level.

Mechanical ventilation

Patients were ventilated with volume-assist controlled ventilation. Respiratory rate and inspiratory/expiratory ratio (I/E) were adjusted based on the results of arterial blood gas analysis (pH and $PaCO_2$). Tidal volume arranged 6–8 ml/kg of ideal body weight as plateau pressure (P_{Plato}) remains ≤ 30 cmH_2O. The flow was individualized by analyzing peak pressure, flow/time, and pressure/time waves. The level of sedation was modified, and an intravenous bolus of neuromuscular agents was given as required to eliminate any spontaneous breathing during the intervention.

Data and intervention

Patient demographics [age, gender, ideal body weight, Sequential Organ Failure Assessment (SOFA)], baseline mean arterial pressure (MAP), IAP, PaO_2/FiO_2 ratio, $PaCO_2$, P_{Plato} at the admission during mechanical ventilation with 5 cmH_2O PEEP, and outcomes (ICU and hospital length of stay, hospital mortality) were recorded.

After the initial measurement of IAP, the following PEEP levels were applied in this order $PEEP_{zero}$ of 0 cmH2O, $PEEP_{IAP/2}$ = 50% of IAP, and $PEEP_{IAP}$ = 100% of IAP. Arterial blood gases, MAP, and P_{Plato} measurements were repeated after a 30-minute equilibration period following a change in PEEP. The intervention was planned to be terminated in case of new hemodynamic instability or desaturation during the gradual increase in PEEP and measurements. However, no adverse events developed in any patient.

Statistical analysis

Statistical analyses were performed using the IBM SPSS software version 26. Descriptive analyses are presented using medians [25–75 percentile] for ordinal variables and n (%) for categorical variables. Friedman tests were conducted to test whether a significant change in the PaO_2/FiO_2 ratio, P_{Plato}, $PaCO_2$ and MAP variables were noted. An overall 5% type 1 error level was used to infer statistical significance. The Wilcoxon test was performed to test the significance of pairwise differences using Bonferroni correction to adjust for multiple comparisons.

Results

One hundred thirty-eight patients enrolled on the study. Baseline characteristics are shown in Table 1. The mean age of the patients was 66.5 ± 15.9. The majority of them were male (56.5%). The mean IAP was 9.8 ± 3.4 cmH_2O. Seventy-nine percent of the patients' PaO_2/FiO_2 ratio was under 300 mmHg. The median ICU length of stay was 12 days [9–16]. The ICU mortality was 27.5%, while the hospital mortality rates was 28.9%.

Figure 1 shows the change in PaO_2/FiO_2 ratio, $PaCO_2$, P_{Plato} and MAP of the patients according to the PEEP levels. Overall increases were detected in the PaO_2/FiO_2 ratio ($P < 0.001$) and P_{Plato} ($P < 0.001$), while there was no significant change in $PaCO_2$ and MAP after increasing PEEP gradually. Pairwise analyses revealed differences in PaO_2/FiO_2 between PEEPzero (186.4 [85.7-265.8]) and $PEEP_{IAP/2}$ (207.7 [101.7-292.9]) (t = -0.77, $P < 0.001$), between baseline and $PEEP_{IAP}$

Table 1: Baseline characteristics of the patients

	Characteristic and data
Patients, *n*	138
Age, years	68 [58-77]
Gender, Male	78 (56.5)
Cause of ICU admission	
Medical	108 (78.3)
Surgical	30 (21.7)
SOFA	6 [4-9]
Mean arterial pressure, mmHg	67.5 [61-76]
Intraabdominal Pressure, cmH_2O	9 [8-12]
PaO_2/FiO_2, mmHg	186.4 [85.7-265.8]
$PaCO_2$, mmHg	39.2 [34.9-46.0]
Plato pressure, cmH_2O	12 [10-15]
ICU length of stay	12 [9-16]
ICU mortality	38 (27.5)
Hospital mortality	40 (28.9)

ICU=Intensive Care Unit; SOFA=Sequential Organ Failure Assessment. Data is expressed as *n* (%) and median [25-75 percentile]

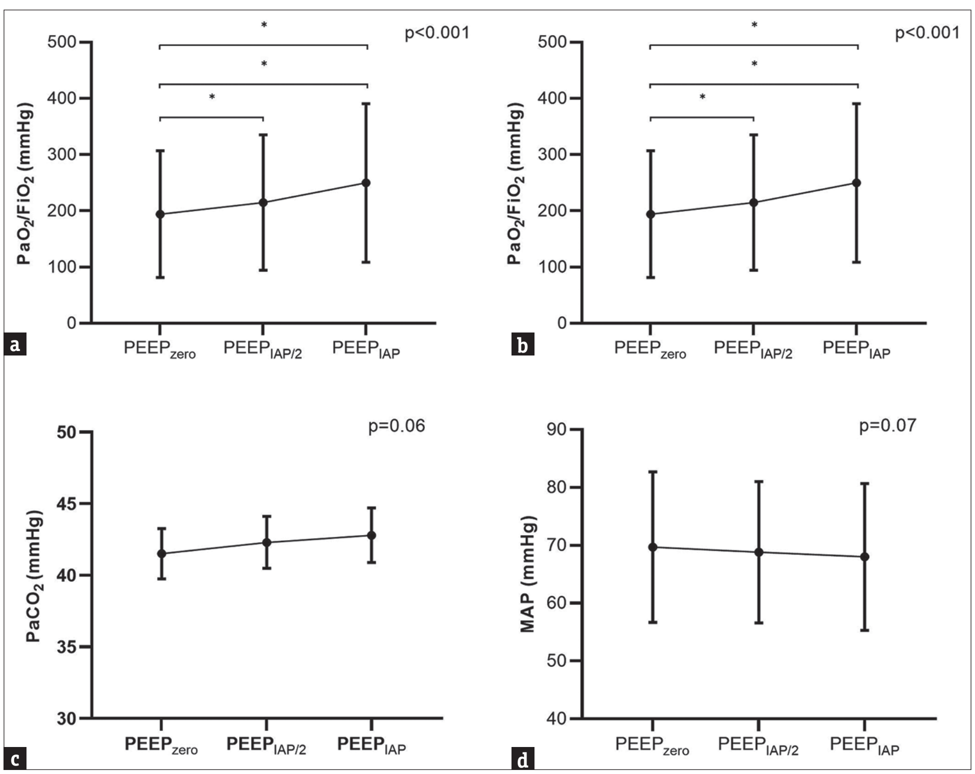

Figure 1: PaO_2/FiO_2 ratio (a), Plato pressure (b), $PaCO_2$ (c), and mean arterial pressure (MAP) (d) at $PEEP_{baseline}$, $PEEP_{IAP/2}$, and $PEEP_{IAP}$. Data points show mean ± SD. The Friedman test assessed *P*-values. *: $P < 0.05$ in pairwise analysis with the Wilcoxon test. Significance values were adjusted by the Bonferroni correction

(236.1 [121.4-351.0]) (t = -1.7, $P < 0.001$), and between $PEEP_{IAP/2}$ and $PEEP_{IAP}$ (t = -1.0, $P < 0.001$). Plato pressures were in the safe range (<30 cmH_2O) at all three PEEP levels (PEEPzero = 12 [10-15], $PEEP_{IAP/2}$ = 15 [13-18], $PEEP_{IAP}$ = 17 [14-22]).

Discussion

The results of this study revealed that adjusting PEEP according to IAP improved oxygenation without causing cardiorespiratory deterioration in mechanically ventilated patients with acute hypoxemic respiratory failure.

Acute respiratory failure poses a critical challenge in intensive care units, necessitating mechanical ventilation to provide essential respiratory support. One crucial aspect of mechanical ventilation is the application of PEEP, which maintains lung recruitment and alveolar stability. However, the optimal PEEP setting remains a subject of ongoing research. Optimizing PEEP based on individual patient characteristics, such as lung compliance and recruitability, can enhance alveolar ventilation and gas exchange.[11] By customizing PEEP settings, clinicians can mitigate ventilator-induced lung injury and improve patient outcomes.[12] Besides lung and rib cage properties, the interaction with the abdominal cavity affects lung mechanics and influences PEEP optimisation.[13] When the IAP is higher than the end-expiratory thoracic cavity pressure, it may cause a decrease in end-expiratory lung volume and respiratory system compliance by decreasing chest wall compliance.[6] In the study by Malbrain *et al*.,[14] a very good correlation was found between intrapleural pressure, IAP, and the lower inflection point on the PV curve. This concept has led to the necessity of considering IAPs when adjusting PEEP in mechanical ventilation.

Studies showing the importance of IAP in determining the optimum PEEP were primarily performed in cases with IAH. In the study of Regli *et al*., which is similar to our study in terms of method, patients hospitalized in intensive care and mechanically ventilated were screened for IAH and 50 enrolled. Oxygenation, respiratory system compliance, and tolerance were evaluated by applying three levels of PEEP at 30-minute intervals. While compliance increased with moderate (IAP/2) PEEP application, oxygenation improved with high PEEP (IAP) application, but tolerance and compliance decreased. Unlike this study, our patient group was ARF patients, most of whom had p/f below 300 mmHg. Since we did not enrol patients with IAH, applied PEEP levels were lower than those of Reglin's study, and we had not done any recruitment manoeuvers in any step. However, we observed a significant increase in oxygenation at all steps. The lower PEEP level can explain why we did not detect intolerance at any step. We focused on patients with normal IAPs (<15 cmH_2O) and excluded those with severe cardiovascular dysfunction, ensuring a more targeted investigation into the effect of PEEP adjustments on oxygenation. However, it is noteworthy that patients with elevated IAP were not included in the study, which limits the generalizability of the findings to a broader population, particularly those with IAH.

While mechanical ventilation is essential for ARF, it can pose risks, such as ventilator-induced lung injury (VILI). The concept of lung protective mechanical ventilation has emerged as a strategy to mitigate VILI, optimize gas exchange, and improve patient outcomes in ARDS.[15] Lung protective ventilation minimizes VILI by reducing mechanical stress and strain on lung tissues during ventilation. Low tidal volumes (4–8 mL/kg of predicted body weight) are recommended to reduce alveolar overdistension.[1] Plateau pressure is the airway pressure measured at the end of an inspiratory pause. It directly reflects alveolar distension and is a critical determinant of lung overstretching. Elevated Pplato (≥30 cmH_2O) indicates an increased risk of barotrauma and volutrauma, potentially contributing to VILI.[15] Monitoring P_{Plato} is essential to prevent alveolar damage and optimize ventilation strategies. The observed increase in P_{Plato} with the gradual rise in PEEP levels is a notable finding, suggesting potential concerns regarding alveolar overdistension. In our study, despite the increase in PPlato, the pressures remained within safe limits (<30 cmH_2O), indicating that the chosen PEEP adjustments did not lead to excessive lung stress or potential harm. The study's approach of considering both oxygenation improvement and P_{Plato} safety provides a comprehensive assessment of the impact of PEEP adjustments.

While the study provides valuable insights into PEEP adjustment based on IAP, it is essential to acknowledge certain limitations. The study's single-center design and the exclusion of patients with IAH and severe cardiovascular dysfunction may limit the external validity of the findings. There were various causes for acute respiratory failure, and not all criteria for diagnosing ARDS were considered. If only patients with ARDS had been studied, the effect of PEEP might have been different. However, different levels of PEEP were only maintained for 30 minutes each, so we could not investigate their impact on mortality. We did not compare PEEP adjustment according to the IAP with other physiological methods such as EELV, transpulmonary pressure, or PV curve. Additionally, the absence of direct measurement of alveolar recruitment and potential lung injury markers restricts a more comprehensive understanding of the underlying physiological mechanisms.

In conclusion, according to the IAP, PEEP adjustment improves oxygenation in patients with acute hypoxemic respiratory failure and mechanically ventilated. The findings of this study add to the existing literature by proposing a novel approach to PEEP titration based on IAP, which may be particularly relevant in situations where alternative PEEP titration methods are unavailable or suboptimal. These findings contribute to the ongoing dialog on optimizing mechanical ventilation and warrant further exploration in more significant, diverse patient populations.

Current knowledge

The proper adjustment of PEEP is pivotal in ensuring optimal alveolar recruitment, lung stability, and efficient gas exchange. However, determining the right PEEP level for each patient is a complex and often challenging task for healthcare professionals, with significant consequences if not arranged correctly.

What this paper contributes to our knowledge

The results of this study revealed that adjusting PEEP according to IAP improved oxygenation without causing cardiorespiratory deterioration in mechanically ventilated patients with acute hypoxemic respiratory failure. The findings of this study add to the existing literature by proposing a novel approach to PEEP titration based on IAP, which may be particularly relevant in situations where alternative PEEP titration methods are unavailable or suboptimal.

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Conflicts of interest

There are no conflicts of interest.

References

1. Fan E, Del Sorbo L, Goligher EC, Hodgson CL, Munshi L, Walkey AJ, *et al*. An Official American Thoracic Society/ European Society of Intensive Care Medicine/Society of Critical Care Medicine Clinical Practice Guideline: Mechanical ventilation in adult patients with acute respiratory distress syndrome. Am J Respir Crit Care Med 2017;195:1253-63.
2. Millington SJ, Cardinal P, Brochard L. Setting and titrating positive end-expiratory pressure. Chest 2022;161:1566-75.
3. El-Khatib MF, Chatburn RL. Selecting optimum positive end-expiratory pressure: Seeing the forest instead of the trees*. Crit Care Med 2013;41:2050-1.
4. Hess DR. Recruitment maneuvers and PEEP titration. Respir Care 2015;60:1688-704.
5. Regli A, Ahmadi-Noorbakhsh S, Musk GC, Reese DJ, Herrmann P, Firth MJ, *et al*. Computed tomographic assessment of lung aeration at different positive end-expiratory pressures in a porcine model of intra-abdominal hypertension and lung injury. Intensive Care Med Exp 2021;9:52.
6. Fiedler MO, Deutsch BL, Simeliunas E, Diktanaite D, Harms A, Brune M, *et al*. Effect of moderate elevated intra-abdominal pressure on lung mechanics and histological lung injury at different positive end-expiratory pressures. PLoS One 2020;15:e0230830.
7. Fiedler MO, Simeliunas E, Deutsch BL, Diktanaite D, Harms A, Brune M, *et al*. Impact of different positive end-expiratory pressures on lung mechanics in the setting of moderately elevated intra-abdominal pressure and acute lung injury in a porcine model. J Clin Med. 2021;10:306.
8. Suwanvanichkij V, Curtis JR. The use of high positive end-expiratory pressure for respiratory failure in abdominal compartment syndrome. Respir Care 2004;49:286-90.
9. Krebs J, Pelosi P, Tsagogiorgas C, Alb M, Luecke T. Effects of positive end-expiratory pressure on respiratory function and hemodynamics in patients with acute respiratory failure with and without intra-abdominal hypertension: A pilot study. Crit Care 2009;13:R160.
10. Kirkpatrick AW, Roberts DJ, De Waele J, Jaeschke R, Malbrain ML, De Keulenaer B, *et al*. Intra-abdominal hypertension and the abdominal compartment syndrome: Updated consensus definitions and clinical practice guidelines from the world society of the abdominal compartment syndrome. Intensive Care Med 2013;39:1190-206.
11. Rollas K, Hanci P, Topeli A. Effects of end-expiratory lung volume versus PaO (2) guided PEEP determination on respiratory mechanics and oxygenation in moderate to severe ARDS. Exp Lung Res 2022;48:12-22.
12. Pelosi P, Ball L, Barbas CSV, Bellomo R, Burns KEA, Einav S, *et al*. Personalized mechanical ventilation in acute respiratory distress syndrome. Crit Care 2021;25:250.
13. Scheidt M, Hyatt RE, Rehder K. Effects of rib cage or abdominal restriction on lung mechanics. J Appl Physiol Respir Environ Exerc Physiol 1981;51:1115-21.
14. Malbrain MLNG, Deeren D, Nieuwendlijk R, Darquennes R, Verbrugghe W, Daelemans R, *et al*. Partitioning of respiratory mechanics in intra-abdominal hypertension. Intensive Care Med 2003;29:S85.
15. Brower RG, Matthay MA, Morris A, Schoenfeld D, Thompson BT, Wheeler A. Ventilation with lower tidal volumes as compared with traditional tidal volumes for acute lung injury and the acute respiratory distress syndrome. N Engl J Med 2000;342:1301-8.