



EVALUATION OF EFFECT OF POSITIVE END-EXPIRATORY PRESSURE (PEEP) OPTIMIZATION IN ADULT ACUTE RESPIRATORY DISTRESS SYNDROME PATIENTS ON CENTRAL VENOUS PRESSURE (CVP) AND RIGHT VENTRICLE (RV) SYSTOLIC FUNCTION

Cardiology

Dr Mohit Somani	Department of Critical care Medicine, Mahatma Gandhi Medical College and Hospital, Jaipur
Dr Himanshu Dodeja	Department of Critical care Medicine, Mahatma Gandhi Medical College and Hospital, Jaipur
Dr Ayush Gupta*	Senior Resident, Department of Critical care Medicine, Mahatma Gandhi Medical College and Hospital, Jaipur *Corresponding Author
Dr Srishti Jain	Professor, Department of Critical care Medicine, Mahatma Gandhi Medical College and Hospital, Jaipur

ABSTRACT

Background: ARDS impairs oxygenation and affects cardiovascular dynamics. PEEP, while improving oxygenation, may influence CVP and RV function. **Objective:** To assess the impact of PEEP optimization on CVP and RV systolic function in mechanically ventilated ARDS patients. **Methods:** A prospective observational study conducted over 6 months on 40 ARDS patients under mechanical ventilation. PEEP was adjusted to 5 and 10 cmH₂O sequentially. Parameters including PaO₂/FiO₂, CVP, and TAPSE were measured. **Results:** PEEP increase from 5 to 10 cmH₂O significantly improved oxygenation (PaO₂/FiO₂, p<0.001) and increased CVP (p<0.05). TAPSE changes were not statistically significant. **Conclusion:** PEEP elevation improves oxygenation with a concurrent rise in CVP, but no major deterioration in RV systolic function.

KEYWORDS

PEEP, ARDS, CVP, Right Ventricular Function, Mechanical Ventilation

INTRODUCTION

Acute respiratory distress syndrome (ARDS) is a severe form of respiratory failure characterized by inflammatory lung injury, resulting in non-hydrostatic pulmonary edema. It leads to profound hypoxemia, reduced lung compliance, and an increased intrapulmonary shunt. Patients typically present with respiratory distress, which can progress to respiratory failure, necessitating ventilatory support.¹

ARDS has been defined by a working group in collaboration with the European Society of Intensive Care Medicine.¹ Central venous pressure (CVP) reflects the pressure in the right atrium, making it a valuable parameter for assessing right heart failure, volume status, and cardiac preload. As a result, CVP monitoring is commonly performed in operating rooms and intensive care units (ICUs). However, inaccurate CVP measurements may occur due to factors such as cannula malposition, zeroing errors, the patient's poor general condition, or the use of vasopressors.^{1,2}

An increase in alveolar pressure due to PEEP can elevate right ventricular (RV) afterload and right atrial pressure, leading to a reduction in RV preload. Consequently, increased RV afterload and decreased RV preload, resulting from higher PEEP, have been associated with a decline in cardiac output. However, it is hypothesized that the significant pulmonary edema and reduced lung compliance observed in ARDS patients may mitigate the impact of high PEEP on the cardiac index.

Positive end-expiratory pressure (PEEP) influences CVP in mechanically ventilated patients by increasing intrathoracic pressure. However, there is no precise formula to determine the optimal PEEP value for CVP adjustment in these patients. The current study investigates the effect of PEEP optimization in adult Acute respiratory distress syndrome patients on CVP and RV systolic function.

Methodology

A Prospective Observational Study was conducted in the Department of Critical Care Medicine, Mahatma Gandhi Medical College, Jaipur. Approval from the Institutional Ethical Committee was taken. The study period was 6 months (01/04/2023-31/10/2023).

40 Patients were enrolled who were known cases of acute respiratory distress syndrome and endotracheally intubated on mechanical ventilation, in the ICU. They were evaluated with the aim of evaluation of effect of PEEP optimization in Acute respiratory distress syndrome patients on CVP and RV systolic function. The method of titrating PEEP and rescue treatments were decided by the primary physician. Patients under 16- 75 years of age with ARDS meeting the diagnostic criteria of the 2012 Berlin definition of ARDS and were

Endotracheally intubated and mechanically ventilated we included in the study.

During the study, mechanical ventilation was administered sequentially with PEEPs of 5 cmH₂O and 10 cmH₂O to patients diagnosed with moderate-to-severe ARDS. Data on their ventilation oxygenation status and cardiac function, parameters were collected after 4 hours of pressure change.

Patients excluded from the study were those not meeting the inclusion criteria, including individuals with preexisting right heart failure, cor pulmonale, or cardiogenic pulmonary edema. Also excluded were those with contraindications to high PEEP, such as pneumothorax. Pregnant or lactating women, hemodynamically unstable patients who died within 24 hours of ventilator use, and individuals with chronic respiratory diseases like COPD were not considered. Additionally, patients with previous congenital heart disease or right heart dysfunction were excluded.

Sample Size

The sample size needed for the present study was calculated based on a previously done study by Shojae M et. al.³ using a standard deviation to estimate the minimum sample size needed. Therefore, by considering $Z_{\alpha} = 0.5\%$, $p = 95\%$, minimum clinically considerable CVP difference of 1 cm H₂O ($d = 1$), and the minimum detectable difference between the means of CVP in PEEP 10 of 4.06 cm H₂O assuming the Standard deviation of 5.99 cm H₂O, the sample size needed was calculated to be 34 cases.

Quantitative data were reported as mean and standard deviation and qualitative ones as frequency and percentage. To compare CVP before and after applying various PEEPs, paired t- test or non-parametric Wilcoxon test were used. In all tests, $p < 0.05$ was considered as significance level.

RESULTS

Table 1: Baseline Characteristics of Patients with ARDS

Studied variables	Mean $\pm$ SD (range)
Systolic BP (cmH ₂ O)	122.56 $\pm$ 20.3 (100 - 170)
Diastolic BP (cmH ₂ O)	75.58 $\pm$ 12.21 (60 - 100)
Heart rate/minute	93.91 $\pm$ 16.31 (60 - 120)
Age (year)	Frequency (%)
16-30	0 (0%)
31-45	5 (12.50%)
46-60	17 (42.50%)
60-75	18 (45%)

Hx of cardiac failure	
Yes	8 (20%)
No	32 (80%)
Hx of hypertension	
Yes	29 (72.50%)
No	11 (27.50%)
Cause of admission	
Pneumosepsis	8 (20%)
Urosepsis	9 (22.50%)
Cerebrovascular accident	8 (20%)
Metastatic cancer	1 (2.50%)
Other	14 (35%)

40 patients with the mean age of 66.45 ± 8.55 years (46 - 75) were evaluated (72.5% male). The most frequent cause of ICU admission was sepsis with 42.50%. Table 1 shows the baseline characteristics of the studied patients. Table 2 shows the relationship between various PEEP measures and CVP. 5 cmH₂O increase in PEEP led to 2.99 ± 1.31 mean difference in CVP level. Evaluation of the relationship between changes in PEEP and CVP measures based on different levels of CVP are summarized in table 3. The relationship between CVP and 5 cmH₂O ($p = 0.199$), and 10 cmH₂O ($p = 0.199$) PEEP changes were not dependent on the baseline level of CVP.

Table 2: Effect of PEEP on Cardiac Function

Parameter	PEEP 5 cm H ₂ O	PEEP 10 cm H ₂ O	P value
PaO ₂ (cmH ₂ O) (median [IQR])	85.5 [77.0, 94.0]	89.0 [82.0, 96.0]	<0.001
PaO ₂ / FiO ₂ ratio (x $\pm$ s)	161.0 [140.4, 173.0]	172.0 [146.1, 174.0]	<0.001
TAPSE mm (median [IQR])	15.0 [13.0, 18.0]	16.0 [15.0, 17.0]	>0.05
CVP cmH ₂ O (median [IQR])	10.1 $\pm$ 5.23	11.96 $\pm$ 5.92	<0.05

All 40 patients underwent cardiac ultrasound at various PEEPs without experiencing significant hemodynamic deterioration during the study. A statistically significant increase in the PaO₂/FiO₂ ratio was observed with higher PEEP levels.

Regarding cardiac function, when PEEP was set at 10 cmH₂O, CVP demonstrated significant increases, while TAPSE showed a no notable increase. These differences were statistically insignificant except CVP which increased with the increase in PEEP levels. All patients had hypoxemia with a low PaO₂/FiO₂ ratio at PEEP level 5cm. The PaO₂ and PaO₂/FiO₂ ratios improved with increasing levels of PEEP.

DISCUSSION

The findings of this study showed that an increase in PEEP has a direct relationship with CVP increase. Approximately, a 5 cmH₂O increase in PEEP will be associated with about 2 cm H₂O raise in CVP. It seems that sex, history of cardiac failure, hypertension, and baseline CVP do not significantly affect CVP increase rate. In a study by Yang et al.⁴ 1 cmH₂O increase in PEEP, led to 0.38 cm H₂O increase in CVP, which is approximately in line with the present study. A study on the effect of PEEP in patients under mechanical ventilation showed a significant direct relationship between 0, 5, and 10 cmH₂O PEEPs with CVP. The CVP increase was related to mean PEEP during mechanical ventilation when PEEP was set 10 or less, in a study by Cao et al.⁷ which is in line with this study. Evaluating the effect of PEEP on CVP and stroke volume in 20 patients with cardiac diseases, revealed that PEEP significantly affects CVP, while no significant relationship was detected between heart rate and mean arterial pressure.⁶ In the present study, 5 cm H₂O increase in PEEP, led to 1.5 - 2.5 cm H₂O increase in CVP. Currently, trends in CVP can be used as a guide for fluid therapy and monitoring the effects of volume on cardiovascular system. Many current treatment protocols, especially regarding septic shock patient management, define the aim of the treatment as achieving a CVP of 8 - 12 cmH₂O in patients without ventilator and 12 - 16 cmH₂O in those under mechanical ventilation. However, the study by Cao et al.⁷ showed that in patients under ventilator and PEEP, CVP alone is not a good reference for estimation of circulatory volume and required fluid volume for resuscitation.

Many studies have shown correlation and relationship between PEEP and CVP in different set of patients. Positive end-expiratory pressure (PEEP) increases intra thoracic pressure, in patients under mechanical ventilation, thus affecting CVP. Yet, there are no guidelines or accurate formula for setting of optimal PEEP levels, to adjust CVP in such patients.

Papazian et. al.⁸ suggested that one of the essential component of the management of ARDS includes PEEP, thus, using a value above 5 cmH₂O in all patients presenting with ARDS, has been suggested. Studies have suggested that utilization of high PEEP should be reserved for patients in whom it improves oxygenation without marked deterioration of respiratory system compliance or hemodynamic status. PEEP settings should be individualized. Zhou et. Al.⁹ concluded that Traditional static index CVP cannot accurately reflect changes in cardiac preload with positive pressure ventilation. Similarly, Al-Sayaghi et. al.¹⁰ suggested that PEEP up to 15 cm H₂O, does not affect Central venous pressure readings. They also suggested, that the CVP measurement, while patients are connected to Mechanical Ventilation, may also be reliable.

In this study it was found that indicators directly influenced by pressure transmission, as CVP, exhibited a positive correlation with PEEP. When PEEP increased from 5 cmH₂O to 10 cmH₂O, there was no significant change in right ventricular systolic function. This is likely because the increased pressure restricted venous return and alleviated right ventricular preload, thereby decreasing the right ventricular end-diastolic volume. However, with PEEP further increasing to 10 cmH₂O, right ventricular systolic function significantly decreased, leading to pronounced right ventricular dilation together with an increased afterload pressure. Meanwhile, TAPSE initially decreased with increasing PEEPs, demonstrating optimal performance at moderate PEEP. This phenomenon aligns with the results of an animal study, where researchers found that in ARDS-induced beagle dogs receiving mechanical ventilation at various PEEPs, static lung compliance peaked at a PEEP of 6-8 cmH₂O, and TAPSE and SVI increased within a certain PEEP range. However, with further PEEP increases, pulmonary vascular resistance escalated, and SVI declined. In this study, when PEEP was elevated to 10 cmH₂O, TAPSE does not significantly increase. This finding is similar to the findings of a previous study, where compared to low PEEPs, high PEEPs improved oxygenation and promoted alveolar recruitment but also led to hypercapnia and respiratory acidosis, as well as right ventricular dilation, left ventricular deformation, and a significant decrease in cardiac index. Thus, appropriate PEEP settings are crucial for maintaining oxygenation, right ventricular function and hemodynamic stability in ARDS patients.^{11,12}

Nevertheless, further research is needed to determine how to titrate PEEP to balance oxygenation, right ventricular function, and circulatory stability. Theoretically, from a right ventricular function perspective, the ideal PEEP may requires maintaining right ventricular afterload at the lowest level, that is, ensuring minimal pulmonary vascular resistance and optimal lung compliance in ARDS patients. This necessitates dynamic monitoring of the patient's respiratory mechanics, pulmonary artery pressure, and pulmonary vascular resistance.

Limitations The study is focused on only one primary disease processes. Additionally, the sample size was small, which may impact the generalizability of the findings. Furthermore, PEEP values were limited to 5 cm and 10 cm of water, and higher PEEP values were not analyzed. Lastly, ultrasound measurements of the heart are operator-dependent, which could introduce variability in the results.

CONCLUSION

This study found a direct relationship between PEEP and CVP, with an approximate 2 cm H₂O increase in CVP for 5 cm H₂O rise in PEEP. Additionally, factors such as sex, history of cardiac failure, baseline CVP levels, and hypertension do not appear to significantly influence this relationship. Higher PEEP enhances oxygenation without impacting right ventricular systolic function. Further prospective studies with larger sample sizes are needed to evaluate the effects of PEEP optimization on CVP and right ventricular systolic function.

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