

Effect of Positive End Expiratory Pressure on Central Venous Pressure in Mechanically Ventilated Patients

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Abstract Background: Central venous pressure (CVP) monitoring remains in common use as an index of circulatory filling and cardiac preload. Positive end-expiratory pressure (PEEP) in mechanically ventilated patients can affect CVP via increasing intra-thoracic pressure. Critical care nurses should be able to measure the CVP competently and identify the factors affecting its readings. **Aim:** The current study was conducted to determine the effect of PEEP on the CVP readings in mechanically ventilated patients. **Methods:** a descriptive design used in this study. A convenient sample of 200 adult critically ill patients of both sex, hemodynamically and respiratory stable, having a central venous catheter (CVC) in place, and attached to a mechanical ventilator and pulse oximeter were included in the study. The patient's baseline CVP was recorded while the patient connected to the mechanical ventilator, then the patients were temporary disconnected from the mechanical ventilator and the CVP measured again without the effect of PEEP. **Results:** About 40% of the study sample aged 45 to 64 years, 52.5% were males, 50 % suffered from respiratory disorders, and 49% were overhydrated. Eighty eight percent of the study sample was on PEEP levels between 5 to < 10 cmH₂O. The CVP readings while the patients connected to MV were higher than CVP reading while the patients without PEEP, but these differences were not significant. **Conclusion:** CVP readings are not significant affected by the PEEP up to 15 cmH₂O. The CVP can be reliably measured while patients are connected to MV. **Recommendations:** Measurement of CVP can be obtained while the patient is connected to MV.

Keywords: PEEP, mechanical ventilation, central venous pressure, critically ill patients

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1. Introduction

Hemodynamic monitoring plays an important and central role in the management of critically ill patients [1,2,3]. Hemodynamic monitoring aims to guide medical management, to prevent and/or treat organ failure, and to improve the outcomes of patients. Hemodynamic monitoring itself includes several different techniques [4]. In spite of the availability of several newer monitoring techniques, central venous pressure (CVP) monitoring remains in common use as an index of circulatory filling and cardiac preload [3]. CVP measurement is the most widely and frequently used variable in the intensive care

unit (ICU). It provides important information about the cardio circulatory status, guide fluid resuscitation in critically ill patients, and should not be abandoned [5,6]. CVP is an indicator of right ventricular and, to a lesser extent, left ventricular preload and it also reflects the venous return and informs about right ventricular function [7].

CVP may be affected by intra-thoracic, pericardial, and intra-abdominal pressures [8]. Positive end-expiratory pressure (PEEP) in mechanically ventilated patients can affect CVP via increasing intra-thoracic pressure. Various reports exist on the direct relationship between the 2 pressures [7]. PEEP is the pressure above atmospheric pressure maintained throughout the respiratory cycle to prevent alveolar collapse at end-expiration [9]. The

transmission of PEEP into the thoracic cavity depends on the properties of the lungs and the chest wall. When chest wall elastance is high, PEEP can significantly increase pleural pressure [10]. Shubin et al [11] suggested temporary disconnecting the patient from mechanical ventilator for valid CVP readings. However, disconnection the patient from MV may result in hypoventilation, hypoxia, bradycardia and hypotension [12]. A number of studies have now been conducted to determine if PEEP produces clinical changes in hemodynamic pressures or not. The researchers concentrate their attention on the effect of PEEP on the pulmonary artery pressure which is limited in use in our country.

2. Aim of the Study

The current study was conducted to determine the effect of positive end expiratory pressure on the central venous pressure in mechanically ventilated patients.

3. Research Question

Does the positive end expiratory pressure affect the central venous pressure readings in mechanically ventilated patients?

4. Methods

4.1. Design and Settings

A descriptive correlational research design was used to conduct the study in the ICUs of Alexandria Main University Hospital namely; the Casualty Intensive Care Unit (Unit I) and the General Intensive Care Unit (Unit III).

4.2. Study Sample

A convenient sample of 200 critically ill males and females patients with intrapulmonary and extrapulmonary disorders were enrolled in study. Patients were eligible for inclusion in the study if they were ≥ 18 years old, having a central venous catheter (CVC) in place; attached to a mechanical ventilator and pulse oximeter; and hemodynamically and respiratory stable (heart rate of 50–130 beats/minute, mean arterial pressure (MAP) > 55 mmHg, respiratory rate of 8–30 breaths/minute). Hemodynamically unstable patients (i.e. patients who have changes in systolic, mean, or diastolic blood pressure of ≥ 20 mm Hg; have changes in heart rate of ≥ 20 beats/minute; have changes in CVP of ≥ 4 mmHg; have changes in infusion rate of cardiovascular drugs), patients on high levels PEEP (>15 cmH₂O), and patients who have oxygen saturation (SpO₂) $< 93\%$ were excluded from the study.

4.3. Tools and Data Collection

The researchers used a predesigned sheet to record the patient's characteristics (including the patient's age,

sex, diagnosis, and hydration status), the PEEP level (from the mechanical ventilator settings), and the CVP levels while the patient connected to the mechanical ventilator and while the patient disconnected from the mechanical ventilator. The CVP was measured by a disposable water manometer which is the device applied for CVP monitoring in the settings of the study.

4.3.1. Preparatory Phase (before obtaining the CVP readings)

When the patient met the predetermined inclusion criteria and he/his family member agreed to take part in the study, the patency of the CVC and the efficiency of the bed (for rising and falling) were checked. When the patient needs any therapeutic interventions that could potentially affect the CVP readings such as tracheal suction or the nebulizer setting, it was done before CVP measurement and a 10-minutes stabilization period was allowed after suction. In addition, the nasogastric tube feeding must be given at least one hour before measuring the CVP to prevent aspiration that could be occurred in flat position.

The patient's characteristics and the PEEP level were recorded. Then the patient was placed in supine position in the middle of the bed in proper body alignment for 10 minutes stabilization period. The phlebostatic axis (4th intercostals space at mid axillary line) was used as a reference point on the body and it was marked with ink on the side of the patient's chest to ensure accurate measurements [13,14,15]. The manometer zero point was leveled at the patient's phlebostatic axis and then the manometer was connected to the distal lumen of the CVC, after removing any air bubbles in the manometer.

4.3.2. Implementation Phase (obtaining the CVP readings)

The CVP was measured at the end of expiration while the patient was connected to mechanical ventilator using a water manometer with the zero point leveled at the phlebostatic axis. After that the patient was disconnected from mechanical ventilator and the CVP was measured at the end of expiration. Finally the patient was reconnected to mechanical ventilator immediately after measuring the CVP. During the CVP measurement, the blood pressure, heart rate, and SpO₂ were monitored for any changes; if unacceptable changes occurred, the CVP measurement stopped, the patients reconnected to mechanical ventilator and excluded from the study.

The above steps were repeated three times (every two hours for 6 consecutive hours) and the mean of the three CVP readings was calculated and recorded. Any therapeutic interventions that could potentially raise or lower the CVP reading (such as suctioning, turning and volume replacement) were not carried out during measurement of the CVP or 10 minutes before [16]. The ventilator setting remained consistent throughout the 6 hours period of data collection. However, patients were excluded from the study in case of changing the ventilatory settings and also if the patient become hemodynamically unstable and need therapeutic interventions.

A pilot study was conducted on 10 critically ill mechanically ventilated patients to test the feasibility and

applicability of the tools and methodology. The data was collected over period of thirteen months.

4.4. Ethical Considerations

Ethical approval was obtained from the research ethical committee at the faculty of nursing, Alexandria University. Approval to conduct the study was obtained from the responsible authority after explanation of the aim of the study. Informed consent was obtained from conscious patients or from the family members for unconscious patients before conducting the study. The patients and family members received an explanation of the research and its objectives before obtaining their consent. Patient and their family members were assured that their consents are voluntary and they can withdraw from the study at any time without any harmful consequences. Patient and family members who agreed to participate in the study were provided with more verbal information about the study and they signed a consent form.

4.5. Statistical Analysis

Statistical analysis was done using the software Statistical Package for Social Sciences (SPSS) version 10. Data were expressed as frequencies, percentages, means, and standard deviations. For each patient the mean of the three CVP readings while the patient was connected to mechanical ventilator and the mean of the three CVP readings while the patient disconnected from mechanical ventilator were calculated and used for comparison. F-test (ANOVA) was used for analysis of variance and comparison between the means of more than two group means. P value of 0.05 was used to assess the significance of the result.

5. Results

The results in [Table 1](#) reveals that more than one third of the studied sample (39.5%) aged 45 to less than 65 years, 26.5% aged 25 to less than 45 years, and 24.5% aged 65 years and more, while only 10% were below 25 years. More than half of the sample (52.5%) was males. One half of the studied sample suffered from respiratory disorders while the other half suffered from extrapulmonary disorders: 32% cardiovascular disorders, 9.5 % central nervous system disorders, 6.5% renal disorders, while only 2% suffered from other disorders (gastrointestinal and metabolic disorders). About half of the studied sample (49%) were overhydrated (i.e. had signs and symptoms of fluid overload, positive fluid balance, normal or low sodium level, decreased hematocrit value, and normal or low blood urea), 38.5% were adequately hydrated (had no signs and symptoms of fluid overload or deficit), while only 12.5% were dehydrated (had signs and symptoms of fluid volume deficit, negative fluid balance, increased or normal sodium level, and increased or normal blood urea). The majority of the studied sample (88%) was on PEEP 5 to < 10 cmH₂O, and 6% were on PEEP < 5 cmH₂O, and

6% were on PEEP10 cmH₂O or more.

Table 1. Characteristics of the studied sample

Characteristics	Number (n=200)	%
Age in years		
• < 25	20	10.0
• 25- < 45	53	26.5
• 45- < 65	79	39.5
• ≥ 65	48	24.0
Gender		
• Male	105	52.5
• Female	95	47.5
Body systems alteration		
• Intrapulmonary (respiratory).	100	50.0
• Extrapulmonary:		
- Cardiovascular	64	32.0
- CNS	19	9.5
- Renal	13	6.5
- Others	4	2.0
Hydration status		
• Overhydrated	98	49.0
• Adequately hydrated	77	38.5
• Dehydrated	25	12.5
PEEP (cmH₂O)		
• 0 - < 5	12	6.0
• 5 - < 10	176	88.0
• 10- 15	12	6.0

[Table 2](#) shows the effect of PEEP and body systems alterations on the CVP readings. The CVP readings increased as the PEEP level increased, but the difference between the mean CVP readings while the patients on different PEEP levels was not significant. Similarly there was no significant difference between the mean CVP readings of the same patients when they were disconnected from MV (i.e. without PEEP). The mean CVP readings while the patients connected to MV was higher than the mean CVP readings while the patients without PEEP, but this difference was not significant.

When patient on PEEP, the mean CVP reading of patients having CNS disorders was significantly lower than the mean CVP reading of the patients having pulmonary, cardiovascular, renal, and other systems disorders (10.85 VS 17.0, 18.66, and 18.83, respectively, $P < 0.001$). Same significant difference existed while the patients without PEEP. When comparing the mean differences between mean CVP while patients on PEEP and the mean CVP while the patients without PEEP, the mean difference of patients with other body systems disorders was significantly higher than the mean difference of patients with pulmonary, cardiovascular, CNS, and renal disorders (-5.00 VS -1.50, -1.48, -2.53, and -2.41, respectively, $P = 0.001$).

Table 2. Effect of PEEP and body systems alterations on the CVP readings

	Mean CVP when patient on PEEP (mean \pm SD)	Mean CVP when patient without PEEP (mean \pm SD)	Mean Difference
PEEP (cm H₂O)			
• 0 - < 5	16.82 \pm 6.33	15.06 \pm 6.00	-1.75
• 5 - <10	17.14 \pm 7.77	15.31 \pm 8.71	-1.83
• 10- 15	19.03 \pm 2.03	18.08 \pm 2.69	-0.94
F	0.704	1.063	1.293
P	0.496	0.347	0.277
Systems alterations			
• Intrapulmonary (respiratory)	17.0 \pm 6.080 ^a	15.50 \pm 6.84 ^a	-1.50 ^a
• Cardiovascular	18.66 \pm 5.90 ^b	17.18 \pm 6.39 ^b	-1.48 ^b
• CNS	10.85 \pm 3.67 ^c	8.32 \pm 4.23 ^c	-2.53 ^c
• Renal	18.83 \pm 5.96 ^d	16.42 \pm 6.42 ^d	-2.41 ^d
• Others	8.17 \pm 0.00 ^e	3.17 \pm 0.00 ^e	-5.00 ^e
F	6.364	7.101	4.116
P	<0.001* (c#a,b,d) [†]	<0.001* (c#a,b,d) [†]	0.001* (e#a,b,c,d) [‡]
Extrapulmonary	16.94 \pm 6.45 ^a	15.02 \pm 7.07 ^a	-1.91 ^a
Intrapulmonary			
• Obstructive	20.49 \pm 8.20 ^b	19.64 \pm 9.07 ^b	-0.85 ^b
• Restrictive	15.88 \pm 4.70 ^c	14.53 \pm 4.99 ^c	-1.35 ^c
• Vascular	17.89 \pm 4.52 ^d	17.44 \pm 4.86 ^d	-0.45 ^d
• Others	15.19 \pm 4.52 ^e	12.61 \pm 5.27 ^e	-2.58 ^e
F	3.087	4.146	5.588
P	0.017* (e#b,c,d) [•]	0.003* (a#b,d) ^{••}	<0.001* (b#e) ^{•••}

*p-value indicates significant difference between the subgroups; [†]Significance difference existed between c and a,b,d; [‡]Significance difference existed between e and a,b,c,d. [•]Significance difference existed between e and b,c,d; ^{••}Significance difference existed between a and b,d; and ^{•••}Significance difference existed between b and e.

When the patients on PEEP, the mean CVP of patients having other pulmonary disorders was significantly lower than the mean CVP of patients having obstructive, restrictive, or vascular pulmonary disorders (15.19 VS 20.49, 15.88, and 17.89, respectively, $P = 0.017$). While the patients without PEEP, the mean CVP of patients having extrapulmonary disorders was significantly lower than the mean CVP of patients having obstructive and vascular pulmonary disorders (15.02 VS 19.64, and 17.44, respectively, $P = 0.003$). When comparing the mean differences between mean CVP while patient on PEEP and the mean CVP while the patients without PEEP, there mean difference of patients with other pulmonary disorders was significantly higher than the mean difference of patients with obstructive pulmonary disorders (-2.58 VS -0.85, $P = <0.001$).

6. Discussion

Critically ill patients with the need for mechanical ventilation (MV) show complex interactions between respiratory and cardiovascular physiology. These interactions are important as they may guide the clinician's therapeutic decisions and, possibly, affect

patient outcome [17]. Positive end-expiratory pressure (PEEP) ventilation is used to prevent alveolar collapse and improve oxygenation [18]. However, increased intrathoracic pressure from PEEP decreases venous return and lowers cardiac preload. Mechanically, the PEEP-mediated increase in intrathoracic pressure is transmitted to the right atrium, increasing right atrial pressure (RAP) [19,20]. The predicted or estimated RAP is known to be equal to the central venous pressure (CVP) [8]. Therefore, CVP consequently will be increased with increased RAP.

Findings of the current study revealed that high PEEP levels produce high CVP readings. The mean CVP readings while the patients on PEEP (i.e. connected to MV) were higher than the mean CVP readings while the patients without PEEP (i.e. disconnected from MV). However, these differences were not statistically significant. This finding inconsistent with Shojaee et al (2017) [7] finding that the application of PEEP was associated with statistically significant increase in CVP. Our finding could be attributed to low (physiological level) and moderate level of PEEP used in the majority of the current study sample. Another possible reason for this finding is the hypervolemic status of the majority of the sample which can alter the hemodynamic effect of PEEP on the CVP.

Patients in ICU have instability in at least one of the vital body systems (cardiovascular, neurological, or respiratory systems) or at risk for this to develop. If these vital systems are not functioning appropriately, death can occur. The current study findings show that body system disorders that could affect the intravascular volume and the preload (renal and cardiovascular disorders) affect the CVP readings while the patient on PEEP or without PEEP. The effect of renal and cardiovascular impairment on the CVP readings could be due to its pathophysiological effects and impaired pumping action of the heart and its consequences, sodium and water retention, in addition to the effect of positive pressure ventilation (PPV).

7. Conclusions

Central venous pressure readings are not significantly affected by the PEEP up to 15 cm H₂O. The CVP can be reliably measured while patients are connected to MV. Body systems alteration is among the factors affecting the CVP readings.

8. Recommendations

The critical care nurse does not need to disconnect the patient from MV for accurate CVP measurement as the change in the mean CVP in relation to different level of PEEP is small and a wide variation in CVP readings was not found.

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