HEMODYNAMIC TOLERANCE OF SHORT-DURATION PRONE VENTILATION IN MECHANICALLY VENTILATED ARDS PATIENTS

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ABSTRACT
Background: Acute Respiratory Distress Syndrome is a critical pulmonary condition characterized by severe hypoxemia and impaired respiratory mechanics requiring intensive ventilatory support. Prone positioning has gained importance as an adjunctive intervention in ARDS because of its beneficial effects on pulmonary recruitment and ventilation–perfusion matching. While its role in improving oxygenation is well recognized, information regarding the cardiovascular response to short-duration prone ventilation remains limited.
Aim: To assess the hemodynamic alterations occurring during 8-hour prone ventilation in mechanically ventilated patients with ARDS.
Methodology: This prospective observational study was conducted among 95 invasively ventilated ARDS patients admitted to the Intensive Care Unit of a tertiary care hospital. Patients fulfilling the Berlin criteria for ARDS were recruited consecutively during the study period. Baseline hemodynamic variables and oxygenation parameters were recorded in the supine position prior to prone positioning. Patients were subsequently maintained in the prone position for eight hours under continuous monitoring and standard ICU care. Pulse rate, systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP) were assessed at predefined intervals during proning and after repositioning to supine. Oxygen saturation and arterial oxygenation parameters were also evaluated. Statistical analysis was performed using paired t-test, and a p value <0.05 was considered statistically significant.
Results: Eight-hour prone ventilation resulted in significant improvement in oxygenation parameters. Mean SpO_2 increased from $90.89 \pm 1.67\%$ to $93.35 \pm 1.83\%$ ($p < 0.001$), while arterial oxygenation also demonstrated favorable improvement following proning. Hemodynamic evaluation revealed a mild increase in pulse rate during prone positioning. SBP, DBP, and MAP showed gradual reductions over the observation period; however, these changes remained within clinically acceptable limits without evidence of major cardiovascular instability or interruption of prone ventilation. The MAP trend demonstrated progressive decline during proning followed by stabilization after returning to the supine position.
Conclusion: Short-duration prone ventilation significantly improves oxygenation while maintaining acceptable hemodynamic stability in mechanically ventilated ARDS patients. The findings support the safety, feasibility, and clinical utility of 8-hour prone positioning as an adjunctive therapeutic strategy in critical care settings when appropriate monitoring is ensured.

KEYWORDS: Acute Respiratory Distress Syndrome; Prone Ventilation; Hemodynamic Changes; Mechanical Ventilation; Mean Arterial Pressure; Oxygenation; Critical Care; Arterial Blood Gas Analysis.

INTRODUCTION

Acute Respiratory Distress Syndrome is a severe form of acute hypoxemic respiratory failure characterized by diffuse alveolar damage, impaired pulmonary gas exchange, and reduced lung compliance. The syndrome results from widespread inflammatory injury to the alveolar–capillary membrane, leading to pulmonary edema, ventilation–perfusion mismatch, and refractory hypoxemia. ARDS remains a major cause of morbidity and mortality in critically ill patients despite considerable advances in intensive care management and ventilatory support strategies. Reported mortality rates range from 30% to 45%, depending on disease severity and associated comorbid conditions. (1,2)
The global significance of ARDS became more pronounced during the COVID-19, where severe viral pneumonia frequently progressed to acute respiratory failure requiring invasive mechanical ventilation and prolonged ICU admission. (3) Management of ARDS primarily relies on lung-protective mechanical ventilation strategies aimed at minimizing ventilator-induced lung injury while optimizing oxygenation. However, conventional ventilation in the supine position may contribute to dependent alveolar collapse, heterogeneous distribution of ventilation, and worsening shunt physiology. (4)
Prone positioning has emerged as an important adjunctive intervention in the management of moderate-to-severe ARDS. Physiologically, prone ventilation improves oxygenation by enhancing dorsal alveolar recruitment, reducing compression

of dependent lung regions, improving ventilation–perfusion matching, and promoting more uniform distribution of transpulmonary pressure. (5,6) Several landmark trials and meta-analyses have demonstrated that prolonged prone positioning can improve oxygenation and reduce mortality in severe ARDS patients when combined with lung-protective ventilation strategies. (7,8)

Despite its established respiratory benefits, the hemodynamic consequences of prone ventilation continue to be an area of clinical concern. Changes in body position during proning may influence venous return, cardiac preload, right ventricular afterload, intrathoracic pressure, and systemic vascular resistance, thereby affecting cardiovascular stability. (9) Critically ill ARDS patients are often hemodynamically unstable because of sepsis, systemic inflammation, sedation, vasopressor use, and severe hypoxemia, making continuous cardiovascular assessment during prone positioning clinically important. (10)

Most previous studies have focused predominantly on prolonged proning sessions lasting 12–16 hours or more. However, shorter-duration prone ventilation protocols are increasingly being adopted in many ICUs because of improved feasibility, reduced manpower requirements, and lower risk of complications related to prolonged positioning. Nevertheless, evidence regarding the hemodynamic effects and safety profile of short-duration prone ventilation remains limited, particularly in resource-constrained critical care settings.

Understanding the cardiovascular adaptations occurring during short-duration prone ventilation is important for optimizing patient monitoring and ensuring safe implementation of prone positioning protocols. Therefore, the present study was undertaken to evaluate the hemodynamic changes associated with 8-hour prone ventilation in mechanically ventilated ARDS patients.

METHODOLOGY

Study design and setting: This prospective observational study was conducted in the Intensive Care Unit (ICU) of a tertiary care teaching hospital over a period of 18 months after obtaining approval from the Institutional Ethics Committee. The study was carried out in accordance with the ethical principles outlined in the Declaration of Helsinki. Written informed consent was obtained from the patient's legally authorized representative prior to enrolment.

Study population and sampling: A total of 95 patients diagnosed with ARDS and requiring invasive mechanical ventilation were enrolled in the study using a consecutive sampling method. All eligible patients admitted to the Intensive Care Unit (ICU) during the study period who fulfilled the Berlin criteria for ARDS and met the inclusion criteria were consecutively recruited until the desired sample size was achieved.

Inclusion Criteria

- Patients aged ≥18 years
- Mechanically ventilated patients diagnosed with ARDS according to Berlin criteria
- Hemodynamically stable patients are considered suitable for prone ventilation

Exclusion Criteria

- Patients with unstable spinal injury or recent thoracoabdominal surgery
- Severe hemodynamic instability requiring escalating vasopressor support
- Pregnancy
- Raised intracranial pressure
- Facial or pelvic fractures contraindicating prone positioning
- Patients with cardiac arrhythmias or conditions preventing safe proning
- prone Ventilation Protocol

All enrolled patients were initially maintained in the supine position under lung-protective mechanical ventilation strategies as per ICU protocol. Baseline hemodynamic parameters and arterial blood gas (ABG) measurements were recorded prior to prone positioning. Patients were subsequently turned to the prone position by a trained multidisciplinary ICU team using standard safety precautions to avoid accidental extubation, pressure injuries, or displacement of monitoring lines and catheters. Adequate sedation and ventilatory support were ensured throughout the procedure. Prone ventilation was maintained continuously for eight hours. During the proning period, patients were closely monitored for oxygenation status, ventilatory parameters, and hemodynamic stability. At the completion of the eight-hour period, patients were repositioned to the supine posture and reassessed.

Hemodynamic Assessment: The following hemodynamic parameters were recorded:

- Pulse rate (beats/minute)
- Systolic blood pressure (SBP)
- Diastolic blood pressure (DBP)
- Mean arterial pressure (MAP)

Measurements were obtained at baseline before proning, immediately after proning, hourly during the proning period, at the 8th hour of proning, and after returning to the supine position.

Statistical Analysis:

Data was entered into Microsoft Excel and analyzed using appropriate statistical software. Descriptive statistics were used for demographic variables. Continuous variables were expressed as mean ± standard deviation (SD) along with 95% confidence intervals (CI). Comparisons between pre-proning and post-proning measurements were performed using paired t-test. A p value <0.05 was considered statistically significant. In addition to paired t-test analysis, percentage change from baseline was calculated to assess the clinical magnitude of hemodynamic variation during prone ventilation. Hemodynamic trends during prone ventilation were assessed using repeated time-point observations to evaluate cardiovascular stability throughout the intervention period. Repeated measures analysis was not performed because individual patient-level serial data were not available for all time points.

RESULTS

Table 1: Baseline profile of patients with ARDS undergoing eight-hour prone ventilation (N = 95)

Variable	Category / Value	n (%) / Mean ± SD	95% CI
Age group (years)	30-39	10 (10.5)	4.4% to 16.7%
	40-49	30 (31.6)	22.2% to 40.9%
	50-59	43 (45.3)	35.3% to 55.3%
	60-69	12 (12.6)	6.0% to 19.3%
Age (years)	Mean age	49.98 ± 7.61	48.43 to 51.53
Gender	Male	58 (61.0)	51.2% to 70.9%
	Female	37 (39.0)	29.1% to 48.8%

Table 1 summarizes the demographic characteristics of the study participants. Most patients were within the 50–59 years age category, comprising 43 individuals (45.3%) of the total study population. This was followed by the 40–49 years age group, which included 30 patients (31.6%). Comparatively fewer participants were observed in the 60–69 years group (12.6%) and the 30–39 years group (10.5%). The overall mean age of the participants was 49.98 ± 7.61 years, with a 95% confidence interval of 48.43–51.53 years, suggesting that ARDS predominantly affected middle-aged adults in the present study cohort.

With respect to gender distribution, male patients were more frequently represented than females. Out of the 95 study participants, 58 (61.0%) were males, whereas 37 (39.0%) were females. The estimated 95% confidence interval for the proportion of male participants was 51.2%–70.9%, while that for female participants ranged from 29.1% to 48.8%. These findings indicate a male predominance among mechanically ventilated ARDS patients included in the study.

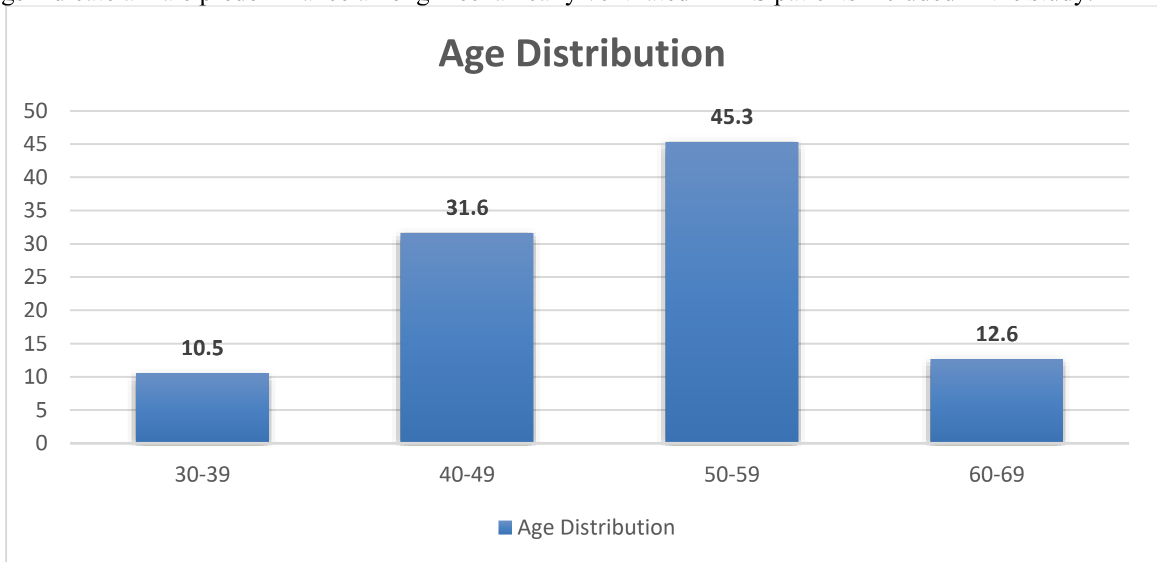

Figure 1: Age Distribution

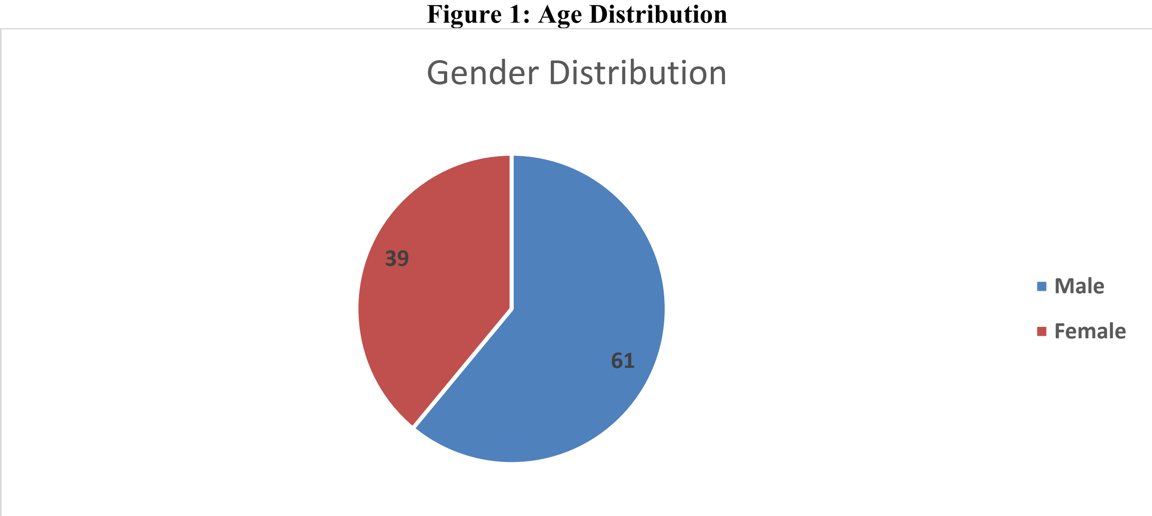

Figure 1B: Gender distribution

Table 2: Effect of eight-hour prone ventilation on oxygenation parameters (N = 95)

Parameter	Before proning Mean ± SD	95% CI	After 8 hours of proning Mean ± SD	95% CI	Mean difference	p value

SpO_2 (%)	90.89 ± 1.67	90.55 to 91.23	93.35 ± 1.83	92.98 to 93.72	-2.450	<0.001

Table 2 demonstrates the effect of eight-hour prone ventilation on oxygen saturation in ARDS patients. The mean SpO_2 significantly improved from 90.89 ± 1.67% before proning to 93.35 ± 1.83% after 8 hours of prone ventilation. The mean difference was statistically highly significant on paired t-test analysis ($p < 0.001$), indicating improved oxygenation during prone positioning.

Table 3: Hemodynamic changes during prone ventilation (N = 95)

Parameter / Time point	Mean ± SD	95% CI	Mean difference	p value
Pulse rate before proning (bpm)	82.00 ± 10.75	79.81 to 84.19		
Pulse rate immediately after proning (bpm)	85.65 ± 11.28	83.35 to 87.95	-3.65	<0.001
Pulse rate after 8 hours / after supine (bpm)	86.65 ± 10.07	84.60 to 88.70	-4.65	<0.001
Pulse rate at 8th hour of proning (bpm)	85.02 ± 7.94	83.40 to 86.64	-1.63*	<0.006
SBP before proning (mmHg)	123.30 ± 7.60	121.75 to 124.85		
SBP immediately after proning (mmHg)	124.93 ± 7.55	123.39 to 126.47	-1.67	<0.001
SBP after 8 hours / after supine (mmHg)	115.43 ± 6.26	114.16 to 116.70	7.82	<0.001
DBP before proning (mmHg)	74.56 ± 6.71	73.19 to 75.93		
DBP immediately after proning (mmHg)	74.25 ± 5.59	73.11 to 75.39	0.305	0.597
DBP after 8 hours / after supine (mmHg)	67.93 ± 4.68	66.98 to 68.88	6.630	<0.001

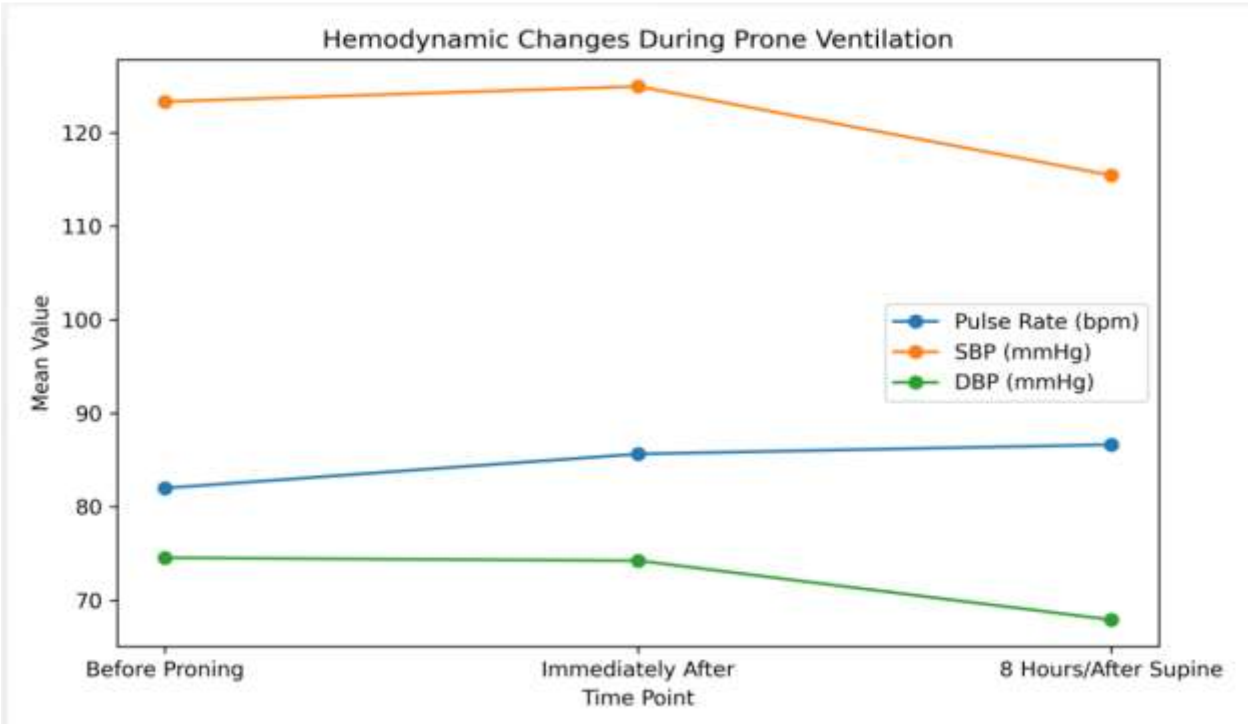

Figure 3: Hemodynamic changes during prone ventilation among study participants (N = 95). The graph illustrates the mean pulse rate, systolic blood pressure (SBP), and diastolic blood pressure (DBP) measured before proning, immediately after proning, and after 8 hours of prone ventilation/supine repositioning. Pulse rate showed a significant increase following proning and remained elevated after 8 hours. SBP demonstrated a slight increase immediately after proning, followed by a significant decrease after 8 hours. DBP remained relatively unchanged immediately after proning but decreased significantly after prolonged prone positioning. These findings suggest that prone ventilation is associated with significant hemodynamic alterations over time.

Table 4: Mean arterial pressure (MAP) trend during proning

Time point	Mean MAP (mmHg)
Before proning	90.79
Immediately after proning	91.14
1st hour after proning	88.80
2nd hour after proning	87.34
3rd hour after proning	85.92
4th hour after proning	84.92
5th hour after proning	83.88
6th hour after proning	83.68

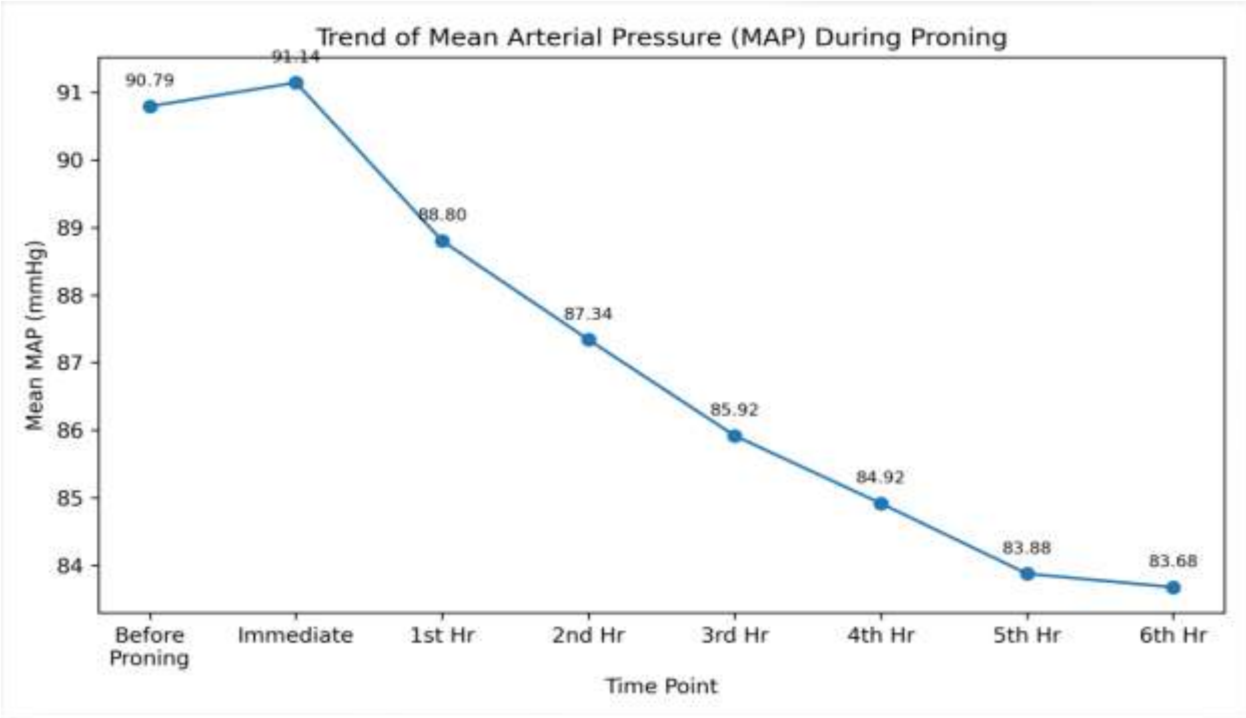

Figure 4: Trend of mean arterial pressure (MAP) during prone ventilation among study participants. The mean MAP showed a slight increase immediately after proning (91.14 mmHg) compared to the baseline value before proning (90.79 mmHg). Thereafter, a gradual and consistent decline in MAP was observed over the subsequent hours of prone positioning, reaching 83.68 mmHg by the 6th hour. This trend suggests progressive hemodynamic adaptation during prolonged prone ventilation, with the most notable reduction occurring between the immediate post-proning period and the 5th hour of monitoring.

Table 5: Percentage Change of Hemodynamic Parameters During Prone Ventilation

Parameter	Baseline	Post-proning / Final value	Mean change	Percentage change
Pulse rate bpm	82	86.65	+4.65	+5.67%
SBP mm Hg	123.30	115.43	−7.82	−6.34%
DBP mm Hg	74.56	67.93	−6.63	−8.89%
MAP mm Hg	90.79	83.57	−7.22	−7.95%

Tables 3,4 & 5 demonstrate the hemodynamic alterations observed during 8 hours of prone ventilation in ARDS patients. The mean pulse rate increased significantly from 82.00 ± 10.75 bpm before proning to 85.65 ± 11.28 bpm immediately after proning ($p < 0.001$). Following 8 hours of prone ventilation, pulse rate further increased to 86.65 ± 10.07 bpm, while the pulse rate recorded at the 8th hour of proning was 85.02 ± 7.94 bpm ($p < 0.006$). Additional analysis demonstrated that the immediate increase in pulse rate represented a mean rise of 3.65 bpm, corresponding to approximately 4.45% from baseline. After completion of the proning period, the pulse rate showed an overall increase of 4.65 bpm, equivalent to a 5.67% rise from baseline values. Although statistically significant, these elevations remained within clinically acceptable limits and did not indicate clinically relevant tachycardia.

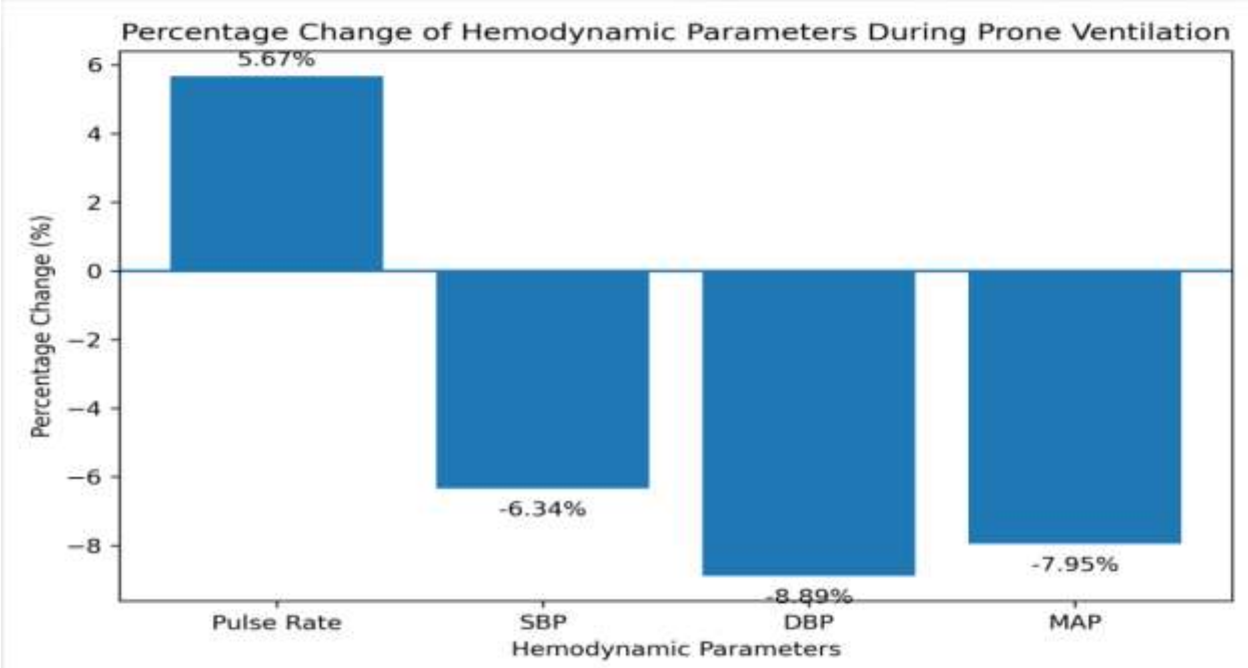

Figure 5. Percentage change in hemodynamic parameters during prone ventilation. Pulse rate demonstrated a modest increase of 5.67% from baseline to the final measurement. In contrast, systolic blood pressure (SBP), diastolic blood pressure (DBP), and mean arterial pressure (MAP) showed decreases of 6.34%, 8.89%, and 7.95%, respectively. Among the measured parameters, DBP exhibited the greatest percentage reduction, followed by MAP and SBP. These findings indicate that prolonged prone ventilation was associated with a mild increase in heart rate and a concurrent reduction in blood pressure parameters.

Systolic blood pressure (SBP) demonstrated a mild but statistically significant increase immediately after proning, rising from 123.30 ± 7.60 mmHg to 124.93 ± 7.55 mmHg ($p < 0.001$). This change represented a mean increase of 1.67 mmHg, corresponding to only 1.35% above baseline values. However, after 8 hours of prone ventilation and repositioning to supine posture, SBP decreased significantly to 115.43 ± 6.26 mmHg ($p < 0.001$), with an overall mean reduction of 7.82 mmHg, representing a 6.34% decline from baseline. Despite statistical significance, the reduction remained within physiologically tolerable limits without evidence of severe hypotension.

Diastolic blood pressure (DBP) remained relatively stable immediately after proning, changing minimally from 74.56 ± 6.71 mmHg to 74.25 ± 5.59 mmHg ($p = 0.597$). The mean difference was only 0.31 mmHg, suggesting preservation of immediate hemodynamic stability following prone positioning. Following prolonged prone ventilation, DBP decreased significantly to 67.93 ± 4.68 mmHg ($p < 0.001$), corresponding to a mean reduction of 6.63 mmHg or 8.89% from baseline values. Nevertheless, these changes remained clinically acceptable and did not necessitate interruption of prone ventilation.

The trend in mean arterial pressure (MAP) revealed a gradual decline during the proning period. MAP decreased from 90.79 mmHg before proning to 91.14 mmHg immediately after proning, followed by progressive reductions during subsequent hourly measurements, reaching 83.57 mmHg at the 8th hour of proning. After repositioning to supine posture, MAP stabilized at 83.76 mmHg. Additional analysis showed that the reduction in MAP at the 8th hour represented a mean decrease of 7.22 mmHg, equivalent to a 7.95% reduction from baseline. Importantly, MAP remained consistently above the critical threshold of 65 mmHg throughout the observation period, indicating preserved systemic perfusion and absence of clinically significant circulatory compromise.

Collectively, these findings indicate that short-duration prone ventilation produces mild hemodynamic alterations that are statistically significant but clinically well tolerated. The observed changes in pulse rate, blood pressure, and MAP did not result in major cardiovascular instability, thereby supporting the safety and feasibility of 8-hour prone positioning in mechanically ventilated ARDS patients.

DISCUSSION

Prone ventilation has emerged as an important adjunctive intervention in the management of ARDS because of its beneficial effects on oxygenation, alveolar recruitment, and ventilation–perfusion matching. The physiological rationale for prone positioning involves redistribution of transpulmonary pressure, recruitment of dependent lung regions, reduction in dorsal alveolar collapse, and improvement in pulmonary perfusion homogeneity. (6,11) These mechanisms collectively contribute to enhanced gas exchange and reduction in intrapulmonary shunting in mechanically ventilated ARDS patients. In the present study, eight-hour prone ventilation resulted in significant improvement in oxygenation parameters while maintaining overall hemodynamic stability, supporting the clinical utility of prone positioning in critically ill patients.

The improvement in oxygenation observed in the present study is consistent with previous investigations demonstrating favorable respiratory effects of prone positioning. Guérin et al., in the landmark PROSEVA trial, reported that prolonged prone ventilation significantly improved oxygenation and reduced mortality among severe ARDS patients managed with lung-protective ventilation strategies.(7) Similarly, Munshi et al., in a systematic review and meta-analysis, demonstrated that prone positioning improves oxygenation and survival outcomes when applied early and for prolonged durations in moderate-to-severe ARDS (8) Scholten et al. also emphasized that prone positioning enhances alveolar recruitment and improves ventilation–perfusion matching, thereby optimizing oxygen delivery. (5) Although the increase in oxygen saturation observed in the present study was modest, even small improvements in oxygenation may be clinically beneficial in critically ill patients by reducing hypoxemic burden and improving tissue oxygen delivery.

The present study demonstrated statistically significant changes in pulse rate during prone ventilation, with an approximate increase of 5.67% from baseline after eight hours. This mild rise in heart rate may represent a compensatory autonomic response to positional changes and altered cardiopulmonary interactions during prone positioning. Increased intrathoracic and intra-abdominal pressures during proning may transiently reduce venous return and cardiac preload, resulting in mild sympathetic activation to preserve cardiac output. (12) Similar findings were reported by Douglas et al., who observed improvement in oxygenation accompanied by mild hemodynamic adaptations during prone positioning in patients with acute respiratory failure. (13) Kallet also reported that prone ventilation may cause modest elevations in heart rate without clinically significant arrhythmias or cardiovascular compromise. (14)

Systolic and diastolic blood pressures demonstrated gradual reductions during the proning period in the present study. However, these changes remained within physiologically acceptable limits and did not result in clinically significant hypotension. The observed reductions in blood pressure may be related to improved oxygenation, decreased hypoxic pulmonary vasoconstriction, redistribution of intrathoracic pressure, and sedative effects during prolonged mechanical ventilation. Importantly, the immediate post-proning period did not demonstrate significant deterioration in diastolic blood pressure, suggesting preservation of initial cardiovascular stability following repositioning.

The trend in mean arterial pressure (MAP) showed a gradual decline throughout the proning period, with an overall reduction of approximately 7.95% from baseline. Despite this decline, MAP remained consistently above the critical perfusion threshold of 65 mmHg throughout the study duration, indicating preserved systemic perfusion and absence of clinically significant circulatory compromise. These findings are consistent with the observations of Jozwiak et al., who demonstrated that prone positioning generally preserves systemic hemodynamics and may improve right ventricular function in selected ARDS patients. (9) Gattinoni et al. similarly reported that prone positioning does not adversely affect cardiovascular function when adequate monitoring and fluid management are maintained. (15) Furthermore, Vieillard-Baron et al. demonstrated that prone positioning may reduce right ventricular afterload by improving pulmonary vascular recruitment and reducing hypoxic pulmonary vasoconstriction. (16)

An important finding of the present study is that although several hemodynamic variables reached statistical significance, the magnitude of these changes remained clinically modest. Additional percentage-change analysis demonstrated that pulse rate increased by only 5.67%, while reductions in SBP, DBP, and MAP remained below 10% from baseline values. These findings highlight the distinction between statistical significance and clinical significance in critically ill populations undergoing repeated hemodynamic measurements. None of the observed hemodynamic alterations necessitated interruption of prone ventilation or escalation of cardiovascular support, thereby supporting the hemodynamic tolerability of short-duration prone positioning.

The findings of the present study are particularly relevant because most previous studies have focused predominantly on prolonged prone ventilation sessions lasting 12–16 hours or more. (17,18) In contrast, the present study specifically evaluated the cardiovascular effects of short-duration prone ventilation over eight hours. Short-duration proning protocols may offer practical advantages in resource-constrained ICUs by reducing manpower burden, minimizing pressure-related complications, and improving feasibility without substantially compromising therapeutic benefit.

A major strength of the present study is the serial assessment of hemodynamic parameters at multiple time points during prone ventilation, allowing evaluation of temporal cardiovascular adaptations associated with prone positioning. However, certain limitations should be acknowledged. The study was observational and single-centered in design with a relatively modest sample size. Advanced hemodynamic monitoring techniques such as echocardiography, cardiac output monitoring, or pulmonary artery catheterization were not utilized, limiting detailed assessment of cardiac performance during proning. Additionally, subgroup analyses based on ARDS severity, vasopressor requirement, or underlying etiology were not performed.

Overall, the present study demonstrates that eight-hour prone ventilation produces favorable oxygenation responses with mild and clinically acceptable hemodynamic alterations in mechanically ventilated ARDS patients. The findings support the safety, feasibility, and clinical applicability of short-duration prone positioning as an adjunctive therapeutic strategy in intensive care management when careful monitoring and supportive care are ensured.

CONCLUSION

Eight-hour prone ventilation significantly improved oxygenation in mechanically ventilated Acute Respiratory Distress Syndrome patients while maintaining overall hemodynamic stability. Although mild variations in pulse rate and blood pressure were observed, these changes remained clinically tolerable without evidence of major cardiovascular compromise. The findings support short-duration prone ventilation as a safe, feasible, and effective adjunctive strategy in the intensive care management of ARDS patients.

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