Journal of Mechanical Ventilation

Effects of the prone position on gas exchange and ventilatory mechanics and their correlations with mechanical power in burn patients with ARDS

Claudio Luciano Franck, [1] Ehab G. Daoud [2]

DOI: https://doi.org/10.53097/JMV.10095

Cite: Franck CL, Daoud EG. Effects of the prone position on gas exchange and ventilatory mechanics and their correlations with mechanical power in burn patients with ARDS. J Mech Vent 2024; 5(1):21-29.

Abstract

Background

Prone position has many documented benefits on severe ARDS patients especially on mortality. The benefits in ARDS secondary to severe burns have not been fully documented.

Aim

To quantify the effects of prone positioning on gas exchange, ventilatory mechanics and their correlations with mechanical power in burn subjects with ARDS.

Methods

Cross-sectional observational analytical study that took place between January 2023 and October 2023 in Burns ICU in Brazil on subjects with moderate to severe ARDS ventilated with the volume controlled mode. Data were collected in the first prone positioning lasting 24 hours in the first 30 minutes after changing position and 30 minutes before returning to the supine position. The parameters of the components of mechanical ventilation and mechanical power calculated by the Gatinoni's formula (respiratory rate, tidal volume, driving pressure, PEEP, peak and plateau pressures) were collected to evaluate ventilatory mechanics, and the values of the FiO_2, PaO_2, PaO_2/FiO_2 ratio, SpO_2, $EtCO_2$, $PaCO_2$, $PaCO_2$ - $EtCO_2$ gradient to assess gas exchange.

Mean, minimum and maximum values, 1st and 3rd quartiles, median and standard deviation are calculated. To compare the results obtained at the two evaluation moments, the student's t-test for dependent samples and non-parametric Wilcoxon tests were considered. To evaluate the association between the variation between the two moments of each variable, and the variation in mechanical power, the Pearson correlation coefficient was calculated. The normality of the variables was assessed using the Jarque-Béra test. P values <0.05 indicated statistical significance.

Results

Except for $EtCO_2$ (P 0.939) and $PaCO_2$ (P 0.391) all other variables presented statistical significance in relation to their variations with reduction in FiO_2 (P <0.001), reduction in $PaCO_2$ - $EtCO_2$ gradient (P 0.011), and increases in PaO_2 (P 0.008), PaO_2/FiO_2 (P <0.001), SpO_2 (P 0.004).

In the analysis of variables, reduction in respiratory rate (P 0.142), VT (P 0.385), peak pressure (P 0.085), plateau pressure (P 0.009), PEEP (P 0.032), driving pressure (P 0.083), elastance (P 0.180), mechanical power (P < 0.001) with increase static compliance (P 0.414) and resistance pressure (P 0.443). Among the ventilatory mechanics variables, only the reductions in plateau pressure, PEEP, and mechanical power showed statistical significance.

Conclusion

The prone position in burns induced ARDS improved oxygenation and reduced arterial partial pressure to end tidal CO_2 gradient, furthermore, reducing plateau pressures and PEEP, which in turn reduced mechanical power.

Keywords: mechanical power, burns, ARDS, prone position

Authors

1. MD, PhD. Mackenzie Evangelical College of Paraná, Brazil
2. MD, Associated professor of Medicine, John A Burns School of Medicine, Hawaii, USA

Corresponding author: claudiolfranck@hotmail.com

Conflict of interest/Disclosures: None
Funding: None

Introduction

Severe burns can cause systemic inflammatory response syndrome (SIRS), [1] and as a pulmonary consequence, Acute Respiratory Distress Syndrome (ARDS) [2] can occur with hypoxemia and changes in lung mechanics. [3] ARDS can result from inhalation injury, and it becomes more serious when it is combined with SIRS generated by extensive and deep burns. [4]

Mechanical ventilation is an essential support for severely burned patients [5] with the intention of ensuring sufficient hematosis (the conversion of venous into arterial blood, i.e. oxygenation and CO_2 removal i.e. ventilation in the lungs) with adjustments of mechanical ventilation components that minimize the chances of developing ventilator-induced injury (VILI). [6]

Represented by tidal volume, respiratory frequency , pressures and flow, the components of mechanical ventilation influence VILI in distinct but intricate proportions [7] and none of them can be attributed separately as responsible, as it results from the set combination of ventilation parameters and the condition of the lung parenchyma itself related to its size , vascular pressure and heterogeneity. [8]

Mechanical power unifies the set of ventilation components that determine VILI, [9] and it represents the energy transferred to the respiratory system by the ventilator in joules per minute. [10] In ARDS, the mechanical power values tend to increase as the disease progresses. [11] VILI depends on the interdependence between current energy and its components, such as driving pressure and plateau pressure, which represents the importance of refining its adjustments and reducing each component. [12]

Facial and ventral burns are considered relative contraindications to prone positioning. [13] The prone position has been proven successful in severe ARDS for over 40 years [14] with proven oxygenation and mortality benefits. [15] In a previous case report [16] we illustrated the significant improvements in oxygenation, ventilatory parameters and mechanical power in a pregnant patient with severe ARDS. The benefits result from improved ventilation in the posterior lung regions which receive the larger portion of the blood flow, homogenizing aeration, and ventilation-perfusion (V/Q) distribution with consequent reduction of shunt and derecruitment, along improvements in pulmonary circulation and right ventricular function. [17]

However, the impairment of respiratory mechanics is associated with the severity and etiology of ARDS, but the effects of prone positioning on ventilatory mechanics in burns associated ARDS remain uncertain and doubts need to be clarified. [18]

The aims of this research were to verify the effects of prone positioning on the gas exchange and ventilatory mechanics and their correlations with mechanical power in burn patients with ARDS. Identify the values of the inspired fraction of oxygen (F_iO_2), arterial partial pressure of Oxygen (P_aO_2), P_aO_2/F_iO_2 ratio, Oxygen saturation (SpO_2), expired fraction of Carbon Dioxide gas ($EtCO_2$), partial pressure of carbon dioxide ($PaCO_2$), arterial partial pressure to end tidal CO_2 gradient ($PaCO_2$ - $EtCO_2$ gradient) initially and at the end of the prone positioning. Identify the values of respiratory rate (RR), tidal volume (VT), peak pressure (Ppeak), plateau pressure (Pplateau), resistance pressure (Presistance), driving pressure (ΔP), positive end-expiratory pressure (PEEP), elastance (E), compliance (C), initially and at the end of prone positioning, and whether they had significant effects on ventilatory mechanics. Identify the values of mechanical power, initially and at the end of prone positioning, and whether they had significant effects and which components correlated with the results.

Methods

This research was approved by the Research Ethics Committee of Mackenzie Evangelical College of Paraná, in the process numbered 5,580,044. This is a cross-sectional observational analytical study that took place between January 2023 and October 2023 in the Burns ICU of Hospital Evangélico Mackenzie in Curitiba , PR, Brazil. Informed Consent was obtained from the legal guardians of the selected patients during the hospitalization period.

Prone positioning was required in 20% of severe burn victims undergoing mechanical ventilation with an average age of 42 years and 60% were males. Burns were classified as second and third degree with an average body surface area of 44.5%, average third degree burn of 19.5% and inhalation injury in 68.75% of subjects triggered by alcohol combustion (7), gasoline combustion (1), high voltage (1) and house fire (1). Abbreviated Burn Severity Index Score (ABSI) average of 10 [19] The length of stay in the intensive care unit was 34 days with an average mortality of 50%, predicted mortality by the ABSI score is 65%.

Data were collected from ten adult severely burned subjects with moderate to severe ARDS who were placed at least once in the prone position . All patients were under analgesia and deep sedation and a neuromuscular blocker. The Magnamed®

FlexiMag$^{Max\ 700}$ ventilator was used in the volume-controlled ventilation (VCV) mode. Data were collected in the first prone positioning lasting 24 hours in the first 30 minutes after changing position and 30 minutes before returning to supine positioning. The parameters of the components of mechanical ventilation and mechanical power were recorded to evaluate ventilatory mechanics, and the values of the FiO_2, PaO_2, PaO_2/F_iO_2 ratio, SpO_2, $PaCO_2$, $EtCO_2$, and $PaCO_2$ - $EtCO_2$ gradient to assess oxygenation and ventilation.

The mechanical power was calculated using the simplified Gatinoni formula [20]

$$0.098 \text{ X RR X } V_T \text{ (Peak Inspiratory pressure – (Plateau pressure - PEEP) / 2}$$

In the statistical analysis to describe quantitative variables, at each evaluation moment, the mean, minimum, maximum values, 1st and 3rd quartiles, median and standard deviation were recorded. To compare the results obtained at the two evaluation moments, the Student's t-test for dependent samples and non-parametric Wilcoxon tests were used. To evaluate the association between the variation between the two moments of each variable, and the variation in mechanical power, the Pearson correlation coefficient was used. The normality of the variables was assessed using the Jarque-Béra test. Values of $P < 0.05$ were considered significant.

Results

In the analysis of variables related to gas exchange, the null hypothesis of equal means of F_iO_2 (%), P_aO_2 (mmHg), $EtCO_2$ (mmHg), SpO2 (%) and the P_aO_2/F_iO_2 ratio at the two assessment moments versus the alternative hypothesis of different means. Except for $EtCO_2$ (P 0.939), $PaCO_2$ (P 0.391) all others variables presented statistical significance in relation to their variations with reduction in FiO_2 ($P < 0.001$), reduction in $PaCO_2$ - $EtCO_2$ gradient (P 0.011), and increases in PaO_2 (P 0.008), PaO_2/FiO_2 ($P < 0.001$), SpO_2 (P 0.004) (Table 1).

In the analysis of variables related to ventilation mechanics, the null hypothesis of equal medians of RR (1/minute), tidal volume (L), peak pressure (cmH_20), plateau pressure (cmH_20), resistance pressure (cmH_20), PEEP (cmH_20), ΔP (cmH_2O), Elastance (cmH_2O/L), Compliance (L/cmH_2O) and mechanical power (J/minute) was tested, at the two evaluation moments versus the alternative hypothesis of different medians

The variations presented were: reduction in respiratory rate (P 0.142), V_T (P 0.385), peak pressure (P 0.085), plateau pressure (P 0.009), PEEP (P 0.032), driving pressure (P 0.083), elastance (P 0.180), mechanical power (P 0.001) with increase static compliance (P 0.414) and resistence pressure (P 0.443). Among the ventilatory mechanics variables, the reductions in Pplateau, PEEP, and mechanical power showed statistical significance (Table 2).

To verify which components of mechanical ventilation were correlated to produce the effects of reducing current energy, the null hypothesis of no linear association (Pearson's linear correlation equal to zero) between the variation of this variable between the two components was tested for each component. moments and the variation in mechanical power between the two moments versus the alternative hypothesis of the existence of a linear association (non-zero Pearson linear correlation). There was a moderate positive correlation between PEEP (P 0.023) and plateau pressure (P 0.037) with mechanical power (Table 3).

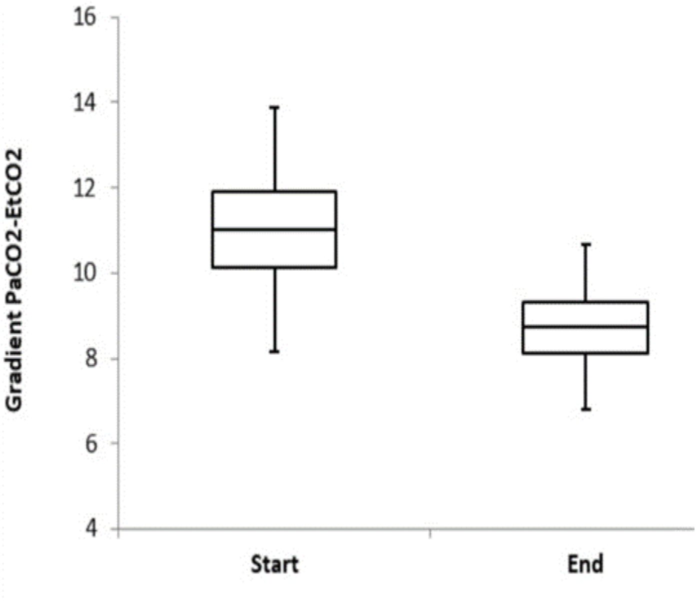

Figure 1: Box and whisker plot for the $PaCO_2$ -$EtCO_2$ from the beginning to the end of the prone position.

Table 1: Initial values and at the end of prone positioning on gas exchange variables.

Prone	N	Mean	Min.	1º quartile	Median	3º quartile	Max.	Standard Deviation	P value
F_iO_2 (%) Start	10	62.00	60.00	60.00	60.00	63.75	70.00	3.50	
F_iO_2 (%) End	10	40.00	25.00	31.25	40.00	48.75	55.00	10,00	
Δ End-Start	10	-22.00	-35.00	-28.75	-22.50	-16.25	-5.00	10.06	<0.001
PaO_2 (mmHg) Start	10	62.90	51.00	57.25	62.00	65.00	88.00	10.17	
PaO_2 (mmHg) at End	10	91.60	62.00	77.25	91.00	101.75	126.00	20.64	
Δ End-Start	10	28.70	-26.00	15.25	27.50	45.25	71.00	27.01	0.008
PaO_2/FiO_2 Start	10	108.93	83.00	97.00	103.17	116.00	146.00	19.90	
PaO_2/FiO_2 End	10	231.31	184.00	227.88	231.50	244.50	248.57	18.71	
Δ End-Start	10	122.37	92.00	104.25	128.50	137.50	150.24	21.45	<0.001
SpO_2 (%) Start	10	91.30	86.00	89.50	91.50	93.50	96.00	3.27	
SpO_2(%) End	10	96.70	90.00	95.50	97.00	98.75	100.00	2.87	
Δ End-Start	10	5.40	-4.00	3,00	6,50	8.00	12.00	4.53	0.004
$EtCO_2$ (mmHg) Start	10	39.88	31.70	34.80	37.30	45.90	50.50	7.04	
$EtCO_2$ (mmHg) End	10	40.08	32.40	33.00	36.95	44.95	55.20	8.58	
Δ End-Start	10	0.20	-17.50	-2.80	3.15	6.03	7.50	8.01	0.939
$PaCO_2$ Start	10	50.90	41.00	46.25	50.00	55.00	64.00	7.26	
$PaCO_2$ End	10	48.80	40.00	42.25	46.00	53.75	62.00	8.47	
Δ End-Start	10	- 2.10	- 18.00	- 3.50	- 1.00	1.00	7.00	7.37	0.391
Gradient $PaCO_2$ - $EtCO_2$ Start	10	11.02	7.30	8.35	11.15	13.40	14.80	2.86	
Gradient $PaCO_2$ - $EtCO_2$ End	10	8.72	6.30	7.15	8.55	9.88	12.60	1.94	
Δ End-Start	10	- 2.30	- 6.50	- 4.08	- 1.30	- 0.53	- 2.20	2.29	0.011

(*) Student's t test for dependent samples; $P<0.05$

Table 2: Initial values and at the end of prone positioning of ventilatory mechanics variables.

Prone	N	Mean	Min.	1º quartile	Median	3º quartile	Max.	Standard Deviation	P value
RR (1/minute) Start	10	27.90	24.00	25.25	27.00	30.00	34.00	3.48	
RR (1/minute) End	10	26.80	22.00	24.00	27.50	29.50	32.00	3.39	
Δ End-Start	10	-1.10	-4.00	-2.00	-2.00	-0.25	4.00	2.13	0.142^{+}
VT (L) Start	10	0.41	0.37	0.39	0.41	0.43	0.45	0.03	
VT (L) End	10	0.40	0.37	0.38	0.40	0.42	0.44	0.02	
Δ End-Start	10	-0.01	-0.08	-0.01	0.00	0.01	0.03	0.03	0.385
Ppeak (cmH$_2$0) Start	10	30.90	26.00	29.25	30.50	33.50	36.00	3.18	
Ppeak (cmH$_2$0) End	10	28.90	26.00	27.00	28.50	30.75	34.00	2.60	
Δ End-Start	10	-2.00	-7.00	-4.50	-1.50	0.00	2.00	3.27	0.085
Pplateau (cmH$_2$0) Start	10	27.60	25.00	25.00	27.50	28.75	32.00	2.76	
Pplateau (cmH$_2$0) End	10	25.20	23.00	24.00	25.00	26.00	28.00	1.55	
Δ End-Start	10	-2.40	-6.00	-4.00	-2.00	-1.00	1.00	2.27	0.009
Pres (cmH$_2$0) Start	10	3.30	1.00	2.25	3.50	4.00	5.00	1.34	
Pres (cmH$_2$0) End	10	3.70	2.00	3.00	3.00	4.00	7.00	1.64	
Δ End-Start	10	0.40	-1.00	-1.00	0.00	1.75	3.00	1.58	0.443
PEEP (cmH$_2$0) Start	10	12.90	10.00	11.25	13.00	14.00	18.00	2.42	
PEEP (cmH$_2$0) End	10	11.80	10.00	10.00	12,00	13,50	14,00	1.75	
Δ End-Start	10	-1.10	-4.00	-2.00	-0.50	0.00	0.00	1.37	0.032
ΔP (cmH$_2$O) Start	10	14.70	11.00	13.00	14.50	16.50	20.00	2.95	
ΔP (cmH$_2$O) End	10	13.40	12.00	12.25	13.00	14.00	16.00	1.35	
Δ End-Start	10	-1.30	-5.00	-2.75	-0.50	0.00	1.00	2.11	0.083
Elast (cmH2O/L) Start	10	36.29	24.44	31.09	34.94	40.41	54.35	8.41	
Elast (cmH2O/L) End	10	33.68	27.46	31.16	34.73	35.09	40.51	3.66	
Δ End-Start	10	-2.60	-13.84	-5.32	-2.13	1.02	5.94	5.67	0.180
Cstat (L/cmH2O) Start	10	0.029	0.018	0.025	0.029	0.032	0.041	0.006	
Cstat (L/cmH2O) End	10	0.030	0.025	0.029	0,029	0.032	0.036	0.003	
Δ End-Start	10	0.001	-0.008	-0.001	0.002	0.004	0.006	0.004	0.414
MPW(J/minute) Start	10	26.21	22.04	22.77	24.94	27.87	33.87	4.24	
MPW (J/minute) End	10	23.26	17.34	19.82	23.81	24.97	31.91	4.32	
Δ End-Start	10	-2.95	-6 70	-4.15	-2.93	-1.63	0.21	2.06	0.001

(*) Student's t test for dependent samples (+) Wilcoxon non-parametric test; $P<0.05$

Table 3: Correlations of mechanical ventilation components with mechanical power.

Components	Correlation	*P* value
RR (1/minuto)	-0.22	0.538
VT(L)	0.33	0.345
Ppeak (cmH2O)	0.60	0.065
Pplateau (cmH2O)	0.65	0.037
Pres (cmH2O)	0.29	0.407
PEEP (cmH2O)	0.69	0.023
ΔP (cmH2O)	0.25	0.479
Elast (cmH_2O/L)	0.06	0.875
Cstat (L/cmH_2O)	-0.03	0.926

Discussion

The medical literature indicates that prone positioning for periods longer than 16 hours without delay can increase survival [21] and reduce mortality. [22] In this study, the duration of prone positioning was 24 hours and the sample's mortality was 50%, although the average mortality predicted by the ABSI score of 11-12 (severe) was up to 65% with an average stay in the intensive care unit of 34 days. The results are below than those reported in burns with ABSI with predicted mortality between 55 and 82%, which suggest prolonged mechanical ventilation for more than 21 days, difficult weaning, in addition to pneumonia and ventilator-induced lung injury. [5] The increase in mechanical power values during prone positioning is related to death, [23] in this research we found a significant reduction in mechanical power with mortality below that predicted by the specific ABSI index for burns.

Prone position is not well described in the burn population and remains controversial due to the risk of wound complications, a recent small retrospective study by Nemec and colleagues [24] found that prone position didn't affect mortality in burn patients with ARDS, and similar to our findings, didn't affect wound complications.

Prone positioning is suggested to provide lung recruitment and improve the V/Q ratio with optimization of the P_aO_2/F_IO_2, SpO_2, and P_aCO_2. [24] However, in this research, there were no significant differences at the beginning and end of prone positioning in, $PaCO_2$ and $EtCO_2$, however the $PaCO_2 – EtCO_2$ gradient was significantly lower this can be explained by the improvement in the V/Q mismatch and improved in the alveolar dead space per the Bohr - Enghoff's modification equation: [25]

$$\frac{V_d}{V_t} = \frac{P_aCO_2 - P_eCO_2}{P_aCO_2}$$

In a study by Yousuf and colleagues [26] they found that the partial pressure of arterial carbon dioxide and end tidal carbon dioxide gradient correlated with the severity of ARDS.

This finding could also be explained by improved the right ventricular cardiac output, and reduction of pulmonary vascular resistance induced by the prone position. [27] We did not use volumetric capnometry to measure the change in alveolar tidal volume, dead space fraction or measurement of cardiac output in this study.

On the other hand, oxygenation and ventilatory mechanics improved with statistical significance, as was observed in patients with severe ARDS due to COVID-19, where the prone positioning improved ventilatory mechanics and oxygenation, with the effects on respiratory mechanics remained after supine repositioning. [28]

Prone positioning can improve oxygenation by improving ventilation in the posterior lung regions that receive a large part of the blood flow, homogenizing aeration and ventilation-perfusion distribution, and the consequent reduction of shunt, as well as derecruitment, lung stress and strain, driving transpulmonary pressure with improved compliance. [17] It was found that there can be a significant increase in the P_aO_2/F_iO_2 ratio of up to 35% and in compliance by up to 23% with a reduction in driving pressure by up to 20% and in mechanical power by up to 18%. [28] Results partially coincide with this research, in which a significant increase in the P_aO_2/F_iO_2 ratio was found with a reduction in mechanical power, however driving pressure and compliance did not demonstrate statistically significant differences. This could be explained by the reduction of the driving pressure and PEEP from the beginning to the end of the prone position in our study.

In patients with ARDS due to COVID-19 on the volume-controlled ventilation, there was a moderate positive correlation between mechanical power, PEEP and plateau pressure, however with driving pressure the positive correlation was weak, similarly with a weak negative correlation with elastance. [29] Those findings corroborate with this research, in which the correlation of mechanical power with plateau pressure and PEEP was statistically significant, however the driving pressure, and compliance did not demonstrate a correlation. Facts that lead to the reasoning that prone positioning improves ventilatory mechanics by reducing stress related to plateau pressure and PEEP with a consequent reduction in the delivered energy demonstrated by the significant reduction in mechanical power.

In a study by Laghlam and colleagues in COVID-19 patients, [28] prone positioning induced changes in driving pressure (r -0.37) and mechanical power (r -0.38) were significantly correlated with the induced changes in PaO_2/FiO_2 ratio, but not with compliance (r 0.15).

Driving pressure is considered a predictor of mortality that may not change with prone positioning, [30] however, reductions in transpulmonary driving pressure have been demonstrated to be more reliable due to its greater precision of the exclusion of the chest wall component and present the stress applied to the lung parenchyma. [31]

Prone positioning is considered a good strategy to reduce VILI, as titrating PEEP to lower values during prone positioning correlates with a reduction in transpulmonary driving pressure and mechanical power. [32] Conflicting with mechanical power, which was shown to be increased after prone positioning, but in agreement that there may be a reduction in transpulmonary driving pressure and increase in the lung compliance, but not in respiratory system compliance and driving pressure, [33] denoting the importance of the esophageal pressure catheter. Our research verified the correlation of the reduction in mechanical power with the reduction in PEEP and plateau pressure, however the reduction in driving pressure did not have statistical significance, as did the negligible improvement in compliance.

It was demonstrated by computed tomography analysis that prone positioning can increase pulmonary recruitment and reduce pulmonary overdistension. [34] From an analysis using electrical impedance tomography and computed tomography, a more considerable dorsal recruitment of the lungs was observed with prone positioning than derecruitment in the ventral regions, which provides an overall increase in recruitment of up to 12.7%, however the compliance of the respiratory system did not change with the prone position, suggesting a reduction in atelectrauma. [35] During prone positioning, the sum of the pressure of the anterior chest wall in bed and the abdominal pressure, several studies point to an increase in the elastance of the chest wall, however, changes in lung elastance would not be noticed if the resulting changes were of the same magnitude. In a paper by Su and colleagues, the total respiratory and lung compliance but not the chest wall compliance improved in the reverse trendelenburg during the prone position. [36] Compliance reflects the pulmonary tension of driving pressure in relation to the aerated lung surface, that is, the momentary tidal volume, however changes in compliance in prone positioning remain inconclusive, as studies demonstrate reduction, increase and unchanged. [18] Possibly, the lungs of these burned patients were recruitable and with the gradual increase in the ventilated lungs, the new titrated PEEP value reduced significantly, as well as the plateau pressure, however there would need to be an even greater reduction in the plateau pressure to indicate an improvement in the respiratory system compliance with a reduction in driving pressure. This fact denotes a reduction in stress, but not in the propulsion force necessary to inflate the lungs.

Our study has some limitations that need to be considered. The study was conducted in a single center with small number of burn induced ARDS subjects and with no control group for comparison. We did not measure the alveolar tidal volume or dead space fraction and did not use an esophageal balloon to measure the transpulmonary driving pressures and lung compliance.

Conclusion

The prone position in burn induced ARDS improved oxygenation and reduced arterial partial pressure to end tidal CO_2 gradient, furthermore, reducing plateau pressures and PEEP, which in turn reduced mechanical power.

References

1. Porter C, Tompkins RG, Finnerty CC et al. The metabolic stress response to burn trauma: current understanding and therapies. Lancet 2016; 388(10052):1417-1426.

2. Jeschke MG, van Baar ME, Choudhry MA, et al. Burn injury. Nat Rev Dis Primers. 2020; 6(1):11.

3. Rotta AT, Kunrath CLB, Wiryawan B. O manejo da síndrome do desconforto respiratório agudo. J Pediatr 2003; 79(suppl 2):149-160.

4. Shirani KZ, Pruitt BA Jr, Mason AD Jr. The influence of inhalation injury and pneumonia on burn mortality. Ann Surg 1987; 205(1):82-87.

5. Xiao K, Chen WX, Li XJ. Analysis of risk factors of prolonged mechanical ventilation in patients with severe burn injury. Clin Respir J 2023; 17(8):791-798.

6. Foncerrada G, Culnan DM, Capek KD et al. Inhalation injury in the burned patient. Ann Plast Surg 2018; 80(3 Suppl 2):S98-S105.

7. Vasques F, Duscio E, Pasticci I, et al. Is the mechanical power the final word on ventilator-induced lung injury? we are not sure. Annals of translational medicine 2018; 6(19)395.

8. Coppola S, Caccioppola A, Froio S, et al. Effect of mechanical power on intensive care mortality in ARDS patients. Critical Care 2020; 24(246):2-10.

9. Chi Y, He HW, Long Y. Progress of mechanical power in the intensive care unit. Chinese Medical Journal 2020; 133(18):2197-2204.

10. Van der Meijden S, Molenaar M, Somhorst P et al. Calculation mechanical power for pressure-controlled ventilation. Intensive Care Med 2019; 45(20):1495-1497.

11. Maiolo G, Collino F, Vasques F et al. Reclassifying acute respiratory distress syndrome. Am J Respir Crit Care Med 2018; 197(12):1586-1595.

12. Marini JJ, Gattinoni L, Rocco PRM. Estimating the damaging power of high stress ventilation Respir Care 2020; 65(7):1046-1052.

13. Messerole E, Peine P, Wittkopp S et al. The pragmatics of prone positioning. Am J Respir Crit Care Med 2002; 165(10):1359-1363.

14. Johnson NJ, Luks AM, Glenny RW. Gas exchange in the prone posture. Respir Care 2017; 62(8):1097-1110.

15. Hale DF, Cannon JW, Batchinsky AI et al. Prone positioning improves oxygenation in adult burn patients with severe acute respiratory distress syndrome. J Trauma Acute Care Surg 2012; 72(6):1634-1639.

16. Franck CL. Prone position in pregnant woman with major burns with severe ARDS on mechanical ventilation. J Mech Vent 2023; 4(2):93-96.

17. Papazian L, Munshi L, Guérin C. Prone position in mechanically ventilated patients. Intensive Care Med 2022; 48(8):1062–1065.

18. Mezidi M, Guérin C. Effects of patient positioning on respiratory mechanics in mechanically ventilated ICU patients. Ann Transl Med 2018; 6(19):384.

19. Usmani A, Pipal DK, Bagla H, et al. Prediction of mortality in acute thermal burn patients using the abbreviated burn severity index score: A single-center experience. Cureus 2022; 14(6):e26161.

20. Gattinoni L, Tonetti T, Cressoni M, et al. Ventilator-related causes of lung injury: the mechanical power. Intensive Care Med 2016; 42(10):1567-1575.

21. La Vita CJ, De Santis Santiago RR. Prone position: A strategy in expansion? Respir Care 2021; 66(5):884-885.

22. Guérin C, Albert RK, Beitler J et al. Prone position in ARDS patients: why, when, how and for whom. Intensive Care Med 2020; 46(12):2385-2396.

23. Fonseca RSA, Boniatti VMC, Carneiro Teixeira MC et al. Mechanical power in prone position intubated patients with COVID-19-related ARDS: A cohort study. Crit Care Res Pract 2023; 6604313.

24. Nemec H, Cheng A, Chestovich P, et al. Assessing the impact of prone positioning among adult burn patients with Acute Respiratory Distress Syndrome. Journal of Burn Care & Research 2023; 44:S132–S133.

25. Aeen FB, Pakzad R, Rad MG, et al. Effect of prone position on respiratory parameters, intubation and death rate in COVID-19 patients:

systematic review and meta-analysis. Sci Rep 2021; 11(1)14407.

26. Respiratory Physiology: The Essentials, John B. West, 7th edition . Philadelphia : Wolters Kluwer Health/Lippincott Williams & Wilkins; 2005:169.

27. Yousuf T, Brinton T, Murtaza G, et al. Establishing a gradient between partial pressure of arterial carbon dioxide and end-tidal carbon dioxide in patients with acute respiratory distress syndrome. J Investig Med 2017; 65(2):338-341.

28. Lai C, Monnet X, Teboul JL. Hemodynamic implications of prone positioning in patients with ARDS. Crit Care 2023; 27(1):98.

29. Laghlam D, Charpentier J, Hamou ZA, et al. Effects of prone positioning on respiratory mechanics and oxygenation in critically ill patients with COVID-19 requiring venovenous extracorporeal membrane oxygenation. Front Med 2022; 8:810393.

30. Franck CL, Franck GM. Influence of mechanical power and its components on mechanical ventilation in SARS-CoV-2. Rev Bras Ter Intensiva 2022; 34:212-219.

31. Riad Z, Mezidi M, Subtil F, et al. Short-term effects of the prone positioning maneuver on lung and chest wall mechanics in patients with acute respiratory distress syndrome. Am J Respir Crit Care Med 2018; 197(10):1355-1358.

32. Mentzelopoulos SD, Roussos C, Zakynthinos SG. Prone position reduces lung stress and strain in severe acute respiratory distress syndrome. Eur Respir J 2005; 25(3):534-544.

33. Boesing C, Graf PT, Schmitt F, et al. Effects of different positive end-expiratory pressure titration strategies during prone positioning in patients with acute respiratory distress syndrome: a prospective interventional study. Critical Care 2022; 26(1):82.

34. Redaelli S, von Wedel D, Suleiman A, et al. Mechanical power during prone positioning in critically ill patients. Am J Respir Crit Care Med 2023;207:A4564.

35. Cornejo RA, Diaz JC, Tobar EA, et al. Effects of prone positioning on lung protection in patients with acute respiratory distress syndrome. Am J Respir Crit Care Med 2013; 188:440-448.

36. Fossali T, Pavlovsky B, Ottolina D et al. Effects of prone position on lung recruitment and ventilation-perfusion matching in patients with COVID-19 acute respiratory distress syndrome: A combined CT Scan/Electrical Impedance Tomography study. Crit Care Med 2022; 50(5):723-732.

37. Su M, Yamasaki K, Daoud EG. Effect of trendelenburg position during prone ventilation in fifteen COVID-19 patients. J Mech Vent 2021; 2(4):125-130.