Analysis of mechanical power during pressure-controlled ventilation in patients with severe burns

Arthur Simonete, [1] Natalia Alberti da Silva, [1] Claudio Luciano Franck [2]

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ABSTRACT

Introduction: The clinical evolution of severe burns can lead to Acute Respiratory Distress Syndrome (ARDS) with increased requirements for mechanical ventilation, which may lead to the development of Ventilator-Induced Lung Injury (VILI). Together, ARDS and VILI may cause irreversible lung damage. Mechanical power measures the amount of energy transferred from the ventilator to the respiratory system and is considered to be a unifying concept of the etiology VILI. However, doubts are still to be clarified. The goals of this study were to analyze pressure-controlled ventilation (PCV) in severe burn injury patients, to associate the mechanical power values over time with the outcome of burn patients (death or survival) and to associate the components of ventilation with the outcome of burn patients.

Methods: A longitudinal, observational, and analytical study of 172 measurements of parameters collected daily from the ventilators of 26 severe burn patients undergoing mechanical ventilation with PCV. Statistical analysis was performed on the obtained values and the components of mechanical ventilation in relation to the outcome of the patients.

Results: The mechanical power calculated daily in burn patients was 22.83 ± SD joule per minute (J/min). Higher values of mechanical power were significantly related to the mortality (P 0.029) regardless of ventilation time, as well as higher values of PEEP, peak pressure, plateau pressure and driving pressure, (P <0.001), respiratory rate (P 0.01), variation of inspiratory pressure (P 0.03) and lower values of tidal volume (P 0.005).

Conclusion: In this analysis of mechanical ventilation, mean values of mechanical power in burn patients were elevated and that, regardless of mechanical ventilation time, these values are related to mortality, as well as higher values of pressures, driving pressure, respiratory rate and lower values of tidal volume, indicating the importance of stress frequency and propulsion force to overcome lung elastance.

Keywords: Ventilator-Induced Lung Injury; Burns; Acute Respiratory Distress Syndrome; Intensive Care Units

Authors
1. Academic of Evangélica Mackenzie of Paraná College, Brazil
2. MD, PhD. Mackenzie Evangelical College of Paraná, Brazil

Corresponding author: claudiolfranck@hotmail.com

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Introduction

Burn injuries are amongst the four most frequent types of traumas worldwide and, they affect 1.2 million people per year in the United States of America alone, of which 40,000 require hospitalization with approximately 5,000 deaths. [1,2] Respiratory failure may occur shortly after the burns, presenting an indication for mechanical ventilation, which is determined by the loss of consciousness, facial edema and inhalation injuries, and hypoxia. [3]

Through the clinical evolution of a severe burn injury patient, the incidence of Acute Respiratory Distress Syndrome (ARDS) varies between 20% to 56% and occurs due to direct lung injury caused by inhaled smoke and steam or mediated by the associated systemic inflammatory response, determined by diffuse inflammatory pulmonary edema with heterogeneous distribution, atelectasis, reduced lung volume and compliance. [4-6] In these circumstances, mechanical ventilation is a life supporter, but consequently, it can lead to Ventilator-Induced Lung Injury (VILI), causing damage to the pulmonary structure through the implementation of mechanical forces. [7-9]

Protective ventilation is defined as the maintenance of tidal volume (V_T) values ≤ 6-8 ml/Kg of predicted weight, plateau pressure (Pplat) < 30 cmH_2O, driving pressure (ΔP) ≤ 15 cmH_2O [10] and positive end-expiratory pressure (PEEP) between 8 cmH_2O and 14 cmH_2O. [10,11]. Although measuring the output for prediction of VILI is still questionable, the mechanical power (MP) provides a consistent evaluation of the interaction between the lung and the ventilator and it has been indicated that values above 17 joule per minute (J/min) is associated with increased mortality, however, for patients who suffer from severe ARDS, these values vary between 19 and 24 J/min. [12-15]

In pressure-controlled ventilation (PCV), a decelerating flow pattern is delivered while airway pressure remains constant as set by clinicians, generating a variation of variation of the VT dependent on the respiratory system mechanics and patients' efforts. [6,16] Becher [17] and Van der Meijden [16] have both described a formula for measuring MP in PCV. Becher's simplified formula [17] a less complicated version to be utilized bedside, which still provides satisfactory accuracy. During data collection from the ventilator, patients were sedated from 5 to 6 according to the Ramsay scale and those with respiratory drive must be excluded. [18,19]

The objectives of this research were to analyze PCV mode in severe burn injury patients, to associate the MP values over time with the outcome of burn patients (death or survival) and to associate the components of ventilation with the outcome of burn patients.

Methods

We analyzed the parameters collected daily from the ventilators of patients admitted to the ICU of the Evangélico Mackenzie University Hospital through a longitudinal, observational and analytical study. Data collection began after approval by the Research Ethics Committee of Evangélica Mackenzie of Paraná College (CEP/FEMPAR): 4.762.382 from June 2021 to January 2022. Informed consent was waived.

Data available on the ventilator screen of 26 patients was collected once a day. We included patients that had severe burn injuries that affected face, hands, genitalia or joints, burn injuries that extended through more than 25% of body surface in adult patients or more than 20% in patients that were over 65 years old, circumferential burns in limbs or thorax in any age group and were suffering from mild or moderate ARDS. [3,4] All patients were undergoing mechanical ventilation in PCV mode (FlexMagPlus, Magnamed, Cotia, SP Brazil), receiving deep sedation and analgesia, with a total of 172 measurements. Patients that were under 18 years old, presented with inhalation burn injuries, or were hospitalized for other reasons that were not primarily a severe burn were excluded.

The collected parameters were peak pressure (Ppeak, cmH_2O), plateau pressure after a brief inspiratory pause (Pplat cmH_2O), PEEP (cmH_2O), V_T (l), inspiratory pressure rise time (s) and respiratory rate (RR, breaths/min). The MP was calculated using a simplified formula developed by Becher [17]

$$0.098 \times RR \times V_T \times (PEEP + \Delta P_{insp})$$

where RR is the respiratory rate (1/min), V_T is the tidal volume (l), PEEP is the positive end-expiratory pressure (cmH_2O), ΔP_{insp} is the change in airway pressure during inspiration (cmH_2O) and 0.098 is the correction factor to obtain the results in J/min.

After calculating the MP values, we analyzed the results in the following situation: the association of mean values of mechanical power and ventilation components with the outcome of burn patients (death or survival), and for a deeper analysis, the importance of the interference of time or the intensity of the energy, we divided the patients into three different groups based on time undergoing mechanical ventilation (1-5, 6-9, ≥ 10 days) to associate the mean values of MP according to the outcome.

In the statistical analysis, for the quantitative response variables, the normality distribution was verified through the Shapiro-Wilk test and the results were reported utilizing mean (± standard deviation) or median (interquartile range). As for the qualitative variables, the values were expressed through absolute numbers (percentage of the total).

To verify the statistical significance of the conclusions, different tests were applied depending on the nature of the analyzed variable. For the analysis of the difference for means between outcomes we utilized the parametric T-test or the Mann-Whitney U test, depending on data distribution. On the condition of a comparison involving more than two groups, the ANOVA was used, and then, the suitable post-hoc test was applied. For all the analysis, values of $P < 0.05$ were considered sufficient to reject the null hypothesis and consider the result statistically significant. All statistical analyses, construction of graphs and tables were performed using the 1.6.7 version of the statistical software JAMOVI, which is based on the R language.

Results

Between June 2021 and January 2022, 26 severe burn patients undergoing mechanical ventilation in PCV mode were analyzed. 172 measurements of mechanical ventilation parameters were collected from the ventilator of these subjects and MP was calculated. In the analysis, we found a mean value of MP of 22.83 ± SD J/min. The MP analysis was carried out by separating the groups according to the ventilation time (Table 2).

In the association of the ventilation components with the outcomes (death or survival), the analysis showed that higher mean values of PEEP, Ppeak , Pplat and ΔP affected the mortality with a P <0.001, RR with a P 0.015 and variation of inspiratory pressure with a P 0.033, on the other hand, the relation with the outcome death occurred with lower values of V_T with a P 0.005 (Table 1).

Indirectly, by calculating the ratio of the mean V_T and ΔP, we observed that the mean compliance value in the non-survivor group was 27 ± 8.05 and for the surviving group was 60 ± 18.02 ml/cmH_2O respectively, with the respective elastance values of 37.03 ± 0.12 and 16.58 ± 0.05 cmH_2O/ml respectively. Regarding the importance of the interference of time or the intensity of the energy in the outcome (death or survival), we divided the patients into three groups taking into account the quantity of days they remained under mechanical ventilation in the PCV mode and deep sedation and analgesia. This analysis indicated that ventilation time did not interfere in the outcome, but higher values of energy were significantly related to death with a P 0.029 (Table 2).

Table **1** – Mechanical ventilation components and outcome

	Outcome	N	Mean	Median	SD ±	Min	Max	P value
RR (Breath/min)	Survival Death	10 16	20.7 26.43	22.0 26.5	4.57 5.92	15 17	30 37	0.015*
T_{insp} (s)	Survival Death	10 16	0.94 0.87	0.95 0.8	0.15 0.14	0.65 0.7	1.2 1.3	0.233**
PEEP (cmH_2O)	Survival Death	10 16	7.6 12.0	7.5 11.0	1.5 3.1	5 8	11 19	<0.001*†
P_{peak} (cmH_2O)	Survival Death	10 16	23.1 31.87	23.0 32.0	4.81 5.41	21	42	<0.001*
P_{plat} (cmH_2O)	Survival Death	10 16	18.3 29.46	19.0 29.0	3.3 5.19	12.0 19.0	23.0 38.0	<0.001*
ΔP_{insp} (cmH_2O)	Survival Death	10 16	15.5 19.875	15.5 20.5	4.64 4.88	7 7	22 27	0.033*
ΔP (cmH_2O)	Survival Death	10 16	9.57 15.25	9.4 15.4	2.93 3.03	6 9.5	13.2 19.4	<0.001*
V_T (l)	Survival Death	10 16	0.57 0.41	0.56 0.39	0.18 0.08	0.33 0.27	0.97 0.57	0.005*

Min: Minimum value; Max: Maximum value; * t test; ** Mann-Whitney test: †: Levene's variance violated test; RR: Respiratory rate; T_{insp}: inspiratory pressure rise time, P_{peak}: peak pressure, PEEP: positive end-expiratory pressure, P_{plat}: plateau pressure, ΔP_{insp}: change in airway pressure during inspiration, ΔP: driving pressure, V_T: tidal volume.

Table 2: Mechanical power and outcome

	Number of days	Outcome	N	Mean	SD ±	P value
Mechanical power (J/min)	1-5	Survival Death	5 9	17.60 24.42	5.54 7.76	0.029*†
	6-9	Survival Death	3 4	17.42 30.01	2.92 10.81	
	10+	Survival Death	2 3	22.31 25.20	0.82 5.86	

N: number of patients, 2-way ANOVA test *, Significant interaction for death outcome, †: Significant Tukey post-hoc test

Discussion

The main finds of our study are that higher values of mechanical power were significantly related to the mortality regardless of ventilation time, as well as the individual components of MP (PEEP, peak pressure, plateau pressure, driving pressure, respiratory rate, variation of inspiratory pressure and lower values of tidal volume).

According to Chi and colleagues, [20] safety thresholds for mechanical power vary for different lung conditions. For lungs affected by ARDS, lower values of MP can generate VILI, when compared to a healthy lung. The problem lies in establishing an expected value of MP for each triggering factor capable of causing lung injury. As expected, our study detected high values of MP in severe burn patients.

Mechanical power is a well confirmed concept in literature; however, its practical use still faces few challenges, one of which is the standardization for each clinical situation. As stated by Lam and colleagues, [4] ARDS rates in burn patients vary between 20% and 56%. Arnal and colleagues [21] demonstrated a higher prevalence of ARDS when MP values were above 12 J/min during the first days of mechanical ventilation. On the other hand, Van der Meijden and colleagues [16] found higher mean values of MP (24.31 J/min) in ARDS, while Maiolo and colleague [15] observed similarly high levels (21±10 J/min). A multivariate analysis of MP for PCV mode [22] has indicated that mean values of 30.7 J/min affected the outcome of COVID-19 patients with moderate ARDS. In this present study, the mean values obtained for the burn group (22.83 J/min) corresponding to those found by Maiolo and colleagues. [15]

As Franck & Franck have pointed out, [23] the correlations between components and MP have an influence on their high momentary values and correlations of components amongst each other influenced their behavior throughout the study period. In this research, we demonstrated that the mortality was related to higher values of MP, both in short and extended periods of ventilation.

As mechanical ventilation time goes by in an injured lung, ARDS, and VILI merge in such a unique and complex way that their individual contributions for lung injury become indistinguishable. [13] Thus, there is no way to quantify the contribution of each one to an unfavorable outcome. [24] It is necessary to resolve the injury that determines the change in lung mechanics, as well as to allow enough tissue restoration, otherwise, it is inexorably heading towards the irrecoverable vortex of VILI. [25] Isolated MP values cannot provide definitive information on the prognosis of pulmonary recovery capacity from VILI in burn patients, as they seem to represent the severity of ARDS, which is most likely the predominant cause of death related to the severity of burns.

When we analyzed the mean compliance values, considering the interference of the severity of ARDS on pulmonary conditions, we found lower values for the non-survivors (27 ± 8.05) and a higher value of in the surviving group (60 ± 18.02) ml/cmH_2O. A similar result was found by Franck and colleagues [22] in their SARS-CoV-2 patient analysis, with statistical significance related to the outcome, in which the elastance of the non-survivor group (42.41 cmH_2O/l) was also higher than the surviving group (26.72 cmH_2O/l).

Such data can be determined by two hypotheses: the first being that lower V_T values were imposed in the ventilator settings by the operator in order to prioritize protection of the lung, affected by severe ARDS. The second is that higher V_T values are due to a mild ARDS, which presents itself with high compliance and low elastance values. That is, in both hypotheses, the severity of ARDS has suppressed the benefits of protective ventilation in relation to the outcome.

In order to avoid alveolar collapse and overdistension, protective ventilation strategies are utilized, in which plateau pressure values are maintained under 30 cmH_2O and ΔP values under 15 cmH_2O, since lower values of driving pressure have been associated with increased survival rate on patients with ARDS. [10, 26,27] It was observed in this present study that the mean values of Pplat were kept within the acceptable limits of protective ventilation, and yet, death was still related to higher mean values of this component with statistical significance. Mean values of ΔP were slightly above the acceptable limits for protective ventilation and this component was also related to death with statistical significance.

In a randomized study by Wiedemann and colleagues, [28] no significant statistical difference was observed in mortality when comparing high PEEP versus low PEEP values in patients with ARDS. However, in this current study, we found that higher PEEP values were related to the death of burn patients, with statistical significance. In addition, low V_T values were also related to the outcome of death in burn patients, as found by our group in a SARS-CoV-2 induced moderate ARDS study [22] on patients undergoing PCV mode, in which patients who died, presented elevated ΔP and elastance values, compensated by an increased respiratory rate, denoting the importance of the frequency of stress and propulsion force to overcome the lung elastance.

Similar to our previous finding in the above study in SARS-CoV-2 patients, [22] the values of MP showed no influence on the outcomes (P 0.864) when analyzed through a univariate analysis, but the multivariate analysis presented evidence that higher values of MP increased the risk of death (P 0.023). In our univariate analysis of severe burn patients through time, MP values for survivors remained close to baseline for the first 9 days, while those for non-survivors increased, and the majority of deaths occurred in the first 5 days. This could mean that these deaths may have occurred due to other reasons such as massive fluid resuscitation, pneumonia or sepsis. For survivors of 10 days or more, MP values were elevated but still lower than those who died, with a smaller difference between the outcomes when compared to the other groups. This could suggest that these deaths most likely occurred due to ARDS and not due to other causes relating to the acute effects of burns. The use of a multivariate analysis could enlighten this scenario, but unfortunately, the number of patients in the sample was too small and did not allow this kind of analysis.

This study is an observational study with no specific protocol for ventilation or an intervention group. Additionally, the small numbers of enrolled patients might have affected the results. Furthermore, the groups were not separated by lung severity, but only those with severe burns under controlled mechanical ventilation were considered.

Conclusion

In the analysis of mechanical ventilation it was found with statistical significance that mean values of MP in burn patients were elevated and that, regardless of mechanical ventilation time, these values interfere in the death outcome, as well as higher values of inspiratory pressures, ΔP, PEEP, RR and lower values of V_T, indicating the importance of stress frequency and propulsion force to overcome lung elastance.

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