Original Article

Alveolar recruitment: impact on respiratory mechanics and oxygenation of mechanically ventilated patients

Recrutamento alveolar com suspiro: impacto na mecânica respiratória e oxigenação de pacientes ventilados mecanicamente

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ABSTRACT | INTRODUCTION: The sigh is characterized by a slow and deep inhalation, followed by a slow exhalation. Studies suggest that the addition of one breath per minute in patients with acute respiratory distress syndrome, ventilated on PSV, improves oxygenation and pulmonary mechanics. **OBJECTIVE:** Analyze the impact of the alveolar recruitment maneuver through breath in pulmonary mechanics and oxygenation in mechanically ventilated patients, in addition to checking the hemodynamic impact and the incidence of complications associated with the use of the technique. **MATERIALS AND METHODS:** Experimental study with 17 patients on mechanical ventilation, showing a relationship between partial pressure of alveolar oxygen and fraction of inspired oxygen (PaO_2/FiO_2) below 300mmHg. Respiratory, pulmonary mechanics, and hemodynamic data were evaluated. Data were collected during three periods: before sigh, immediately after, and 15 minutes after the technique. Two sighs per minute were administered using airways pressure limited to 40 cmH$_2$O, during an inspiratory time of four seconds. **RESULTS:** After the sigh, there was an increase in PaO_2, resistive pressure, static compliance, and PaO_2/FiO_2 ratio, in addition to a decrease in plateau pressure and partial pressure of alveolar carbon dioxide ($PaCO_2$). After 15 minutes of sigh removal, it was observed that PaO_2, resistive pressure, static compliance, and PaO_2/FiO_2 ratio remained above the baseline, while the plateau pressure remained below. There was no significant change in hemodynamic variables. **CONCLUSION:** The sigh in mechanically ventilated patients was able to improve oxygenation and pulmonary mechanics without compromising hemodynamic stability.

KEYWORDS: Respiratory Distress Syndrome. Adult. Respiration. Artificial. Physical Therapy Modalities. Respiratory Mechanics. Oxygenation.

RESUMO | INTRODUÇÃO: O suspiro caracteriza-se pela realização de uma inspiração lenta e profunda, seguida de uma expiração lenta. Estudos sugerem que a adição de um suspiro por minuto em pacientes com síndrome do desconforto respiratório agudo, ventilados em PSV, melhora a oxigenação e a mecânica pulmonar. **OBJETIVO:** Avaliar o impacto da manobra de recrutamento alveolar através de suspiro na mecânica pulmonar e oxigenação em pacientes ventilados mecanicamente, além de verificar o impacto hemodinâmico e a incidência de intercorrências associadas à utilização da técnica. **MATERIAIS E MÉTODOS:** Estudo experimental com 17 pacientes em ventilação mecânica, apresentando relação entre pressão parcial de oxigênio alveolar e fração inspirada de oxigênio (PaO_2/FiO_2) inferior a 300mmHg. Avaliou-se dados respiratórios, de mecânica pulmonar e hemodinâmicos. Os dados foram coletados durante três períodos: antes do suspiro, imediatamente após e 15 minutos depois da técnica. Dois suspiros por minuto foram administrados utilizando pressão em vias aéreas limitada em 40cmH$_2$O, durante um tempo inspiratório de quatro segundos. **RESULTADOS:** Após o suspiro, observou-se aumento da PaO_2, pressão resistiva, complacência estática e relação PaO_2/FiO_2, além de diminuição da pressão de platô e pressão parcial de gás carbônico alveolar ($PaCO_2$). Após 15 minutos da retirada do suspiro observou-se que a PaO_2, pressão resistiva, complacência estática e relação PaO_2/FiO_2 mantiveram-se acima do valor basal, enquanto que a pressão de platô manteve-se abaixo. Não foi observada alteração significante nas variáveis hemodinâmicas. **CONCLUSÃO:** O suspiro em pacientes ventilados mecanicamente foi capaz de melhorar a oxigenação e a mecânica pulmonar sem comprometer a estabilidade hemodinâmica.

PALAVRAS-CHAVE: Síndrome do Desconforto Respiratório Agudo. Ventilação Mecânica. Modalidades de Fisioterapia. Mecânica Respiratória. Oxigenação.

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Introduction

The evolution of science is aligned with the improvement of patient survival in the Intensive Care Unit (ICU), where it is observed a progressive technological perfecting in the care provided. The understanding of the biological cost imposed by the organic life support steers to the emergence of new therapeutic strategies. In the last 50 years, within the scope of the treatment of acute respiratory discomfort syndrome (ARDS) and acute lung injury (ALI), invasive mechanical ventilation (MV) has evolved both from a technological point of view, as well as physiological and therapeutic[1].

ARDS and ALI produce a direct impact on ventilatory mechanics, reaching alveoli and interstitium, reducing surfactant production and infiltration of inflammatory cells[2]. In this context, IMV should be strategically applied, eliminating harmful parameters which might increase the damages caused not only to the lungs but also to the entire system. This way, the protective ventilation strategy is indicated in order to prevent alveolar overdistentions (barotrauma/volutrauma), shear injury with insufflation and deflation, and/or systemic inflammatory proliferation (biotrauma) in healthy areas (baby lung)[3].

The concept of protective ventilation has been constantly improving and consists of using current volume in 6ml/kg of the ideal weight estimated by height, plateau pressure (PPLAT) less than 30cmH2O with positive end-expiratory pressure (PEEP) to be adjusted based on ventilatory mechanics through respiratory System Static Compliance (Cstat) or guided by the low PEEP x Fio_2 (Oxygen Inspired Fraction) table - having as parameter a peripheral oxygen saturation greater than 92%. The respiratory rate can be adjusted up to 35ipm (as long as it does not cause auto PEEP), according to the partial pressure of alveolar carbon dioxide ($PaCO_2$) desired, with a certain tolerance to hypercapnia[4,5].

However, the application of low current volume may favor a collapse of the dependent airways and decrease of gas exhalation resulting in hypercapnia. Thus, the ventilatory strategy of sigh can be indicated[6,7].

The physiological sigh is characterized by the realization of a slow and deep inspiration, followed by a slow exhalation as well. It occurs frequently and irregularly in healthy individuals. Therefore, like any deep inspiration, it has the ability to temporarily raise the partial alveolar oxygen pressure (PaO_2), decrease $PaCO_2$, and increase venous return to the heart[8].

The maneuver of alveolar recruitment through sighing is considered by some authors as "more physiological"[9]. The role of sighing during MV in patients with ARDS has been emphasized and the automatic and periodic delivery of these sighs by a ventilator can be considered as a possible component of the ventilatory strategy in these patients[10]. It is possible that ventilatory strategies which use a prolonged time of sigh may favor the greater filling of the alveolar units through the better balance in the gas redistribution and the time constants of the respiratory system[11,12].

There is evidence that the addition of one sigh per minute in patients with ARDS, ventilated in PSV, is capable of improving oxygenation and pulmonary mechanics, associated with the reduction of the respiratory drive[10]. In this context, the maneuver of alveolar recruitment through sighing promotes benefits such as the decrease of regional distension, the improvement of oxygenation without additional hyperdistension and the redistribution of perfusion without damages to the pulmonary tissue through adverse events (barotrauma, pneumothorax and worsening of pulmonary inflammation)[6,13-17].

In view of the above, the objective of this study is to evaluate the impact of alveolar recruitment maneuver through sighing on pulmonary mechanics and oxygenation in mechanically ventilated patients, in addition to verifying the hemodynamic impact and incidence of events associated with the use of the technique.

Methods

This is an experimental study, non-controlled, of before and after type, with descriptive and analytical character, conducted in the Intensive Care Unit (ICU) of a general hospital, of large scale and high complexity, in the public network of the state of Bahia, located in the city of Salvador, Bahia, in the period from December/2009 to February/2010.

It was used a non-probabilistic sampling, for convenience, where it was included intubated patients, of both sexes, over 18 years, capable of assisting the ventilatory prosthesis, presenting PaO_2/FiO_2 ratio inferior to 300mmHg and that the legal guardians had signed the Informed Consent Form (ICF) consenting to the participation in the study.

It was excluded from the study the patients with hemodynamic instability even in the use of vasoactive amines; carrier of any previous pulmonary disease (such as pulmonary emphysema and untreated pneumothorax); and the tracheostomized. The development of hemodynamic instability during the application of the protocol (characterized by MAP < 60mmHg), depression of the respiratory drive, and exteriorization of tracheal secretion were considered as criteria for the interruption of the patient's participation in the study. However, these were not presented by any of the patients included in the study.

The sociodemographic and clinical data collected were: age (in years), sex (categorized as male and female), body mass index (BMI) in kg/m2, admission diagnosis, hypertension (SAH), diabetes mellitus (DM), smoking, alcoholism, obesity, pneumopathy, cardiovascular disease, neuropathies and neoplasms, and the factor that motivated the MV.

The pulmonary mechanic's data collected were: peak pressure (PPEAK), PPLAT, Resistive Pressure, Respiratory System Static Compliance (Cstat), partial blood oxygen pressure (PaO_2), partial blood carbon dioxide pressure ($PaCO_2$), PaO_2/FiO_2 ratio, and minute ventilation (VE). The resistive pressure was calculated by the difference between tracheal pressure and PPLAT, by means of inspiratory occlusion of six seconds, according to the equipment configuration. Cstat was calculated by the ratio between the current volume and the difference between PPLAT and total PEEP.

The hemodynamic data collected were heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP) and mean blood pressure (MAP).

Arterial blood gas values were obtained through a blood gas analyzer (Radiometer Copenhagen ABL 555). The hemodynamic variables were recorded by a pressure transducer connected to the radial artery, being obtained through a multiparameter monitor (DX 2020, Dixtal).

In the moment of the measurement of the variables of interest, the patients were in the supine position, intubated with an endotracheal tube, and mechanically ventilated through the Vela device (Viasys Healthcare Inc.). Sedated patients entered the study protocol during daily ICU awakening. The sedation level was sufficient to prevent the inhibition of the ventilatory stimulus, allowing one to be able to initiate the ventilator triggering. However, the measurement of static ventilatory mechanics was obtained in the absence of ventilatory drive.

The data were collected during three periods: before the breath (PRE), immediately after (POST), and 15 minutes after the technique (POST-15MIN). In the PRE phase, the standardization and evaluation of pulmonary mechanics were performed in a volume-limited manner (6ml/kg of body weight predicted by height), constant and sufficient flow to meet the patient's ventilatory demand and an adjusted respiratory rate to maintain $PaCO_2$ and pH levels within normality parameters. Then, the alveolar recruitment maneuver by means of sighing was applied for one hour.

The technique consisted of the adjustment of the mechanical fan in the synchronized intermittent mandatory ventilation (SIMV), with a respiratory rate programmed to two incursions per minute, during an inspiratory time of four seconds, and a airways pressure limited in 40cmH_2O. SIMV was associated with pressure support ventilation (PSV), offering a current volume of 6ml/kg of body weight. At the end of the sigh period, the pulmonary mechanics, hemogasometric, and hemodynamic values (POST measurements) were reassessed. Sequentially, the patient returned to PSV mode (6ml/kg) and, after 15 minutes, underwent a new evaluation of the variables of interest (POST-15min measurements). During the three periods, PEEP and FiO_2 were not altered.

The pulmonary mechanics and hemodynamics data were obtained by the researcher responsible for the study, except for the blood sample to measure blood gases that was collected by the physician on duty at the unit. There was no missing data in this study. All variables of interest were collected in all stages of the study, for all participants.

Statistical analysis was performed using IBM SPSS software version 22.0. The numerical variables of symmetric distribution were expressed as arithmetic mean (MA) and standard deviation (SD). Categorical data were presented in the frequency of the categories, being represented in percentage. Analysis of variance for repeated measurements (One Way ANOVA) was used to evaluate the behavior of variables in PRE and POST sigh, and POST-15MIN. To compare the groups that were statistically different, the Bonferroni post-hoc test was used. The level of statistical significance was established at 0.05 or 5%.

The research project was approved by the Research Ethics Committee of Universidade Salvador (UNIFACS), assent number 04.10.90, in accordance with the Resolutions 466/12 and 510/16 of the National Health Council.

Results

During the three-month period in which the study was conducted, 31 patients admitted in the Intensive Care Unit of the hospital were eligible. Of these, only 17 patients met the inclusion and exclusion criteria, being submitted to MV and presenting a PaO_2/FiO_2 ratio lower than 300mmHg (Figure 1). The demographic and clinical characteristics of the patients evaluated and the main ventilatory parameters used are presented in Table 1.

Figure 1. Flowchart of patients' eligibility in the Intensive Care Unit (ICU) of a general hospital-2010

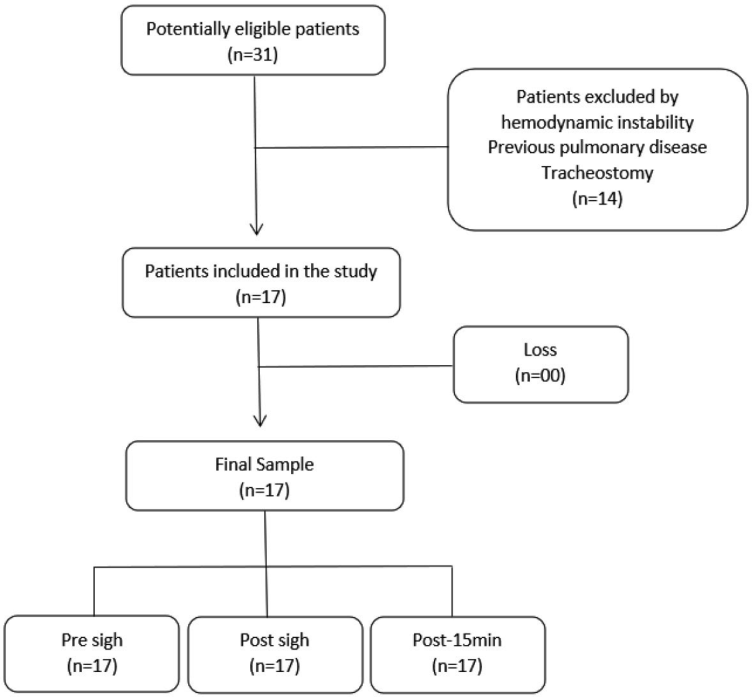

Table 1. Demographic and clinical characteristics of evaluated patients in the Intensive Care Unit (ICU) of a general hospital-2010

Variables	Sample (n=17)
Age (years)	57.7 ± 15.8
Male gender, n (%)	10 (59)
BMI (Kg/m^2)	22.1 ± 0.9
Admission diagnosis, n (%)	
Sepsis	7 (41)
Pneumonia	6 (35)
Acute pulmonary edema	2 (12)
Others	2 (12)
SAH, n (%)	8 (47)
DM, n (%)	10 (59)
Smoking, n (%)	0 (0)
Alcoholism, n (%)	1 (6)
Obesity, n (%)	0 (0)
Pneumopathy, n (%)	0 (0)
Cardiovascular disease, n (%)	9 (53)
Neuropathies, n (%)	0 (0)
Neoplasms, n (%)	2 (12)
PEEP (cmH_2O)	10.3 ± 2.5
PaO_2/FiO_2 (mmHg)	196.5 ± 55.6
PSV (cmH_2O)	14.4 ± 3.9

BMI: body mass index; SAH: systemic arteiral hypertension; DM: *diabetes mellitus*; PEEP: Positive end-expiratory pressure; PaO_2/FiO_2: ratio of arterial oxygen partial pressure to fractional inspired oxygen; PSV:.pressure support ventilation

When analyzing the data, it is observed that there was a predominance of male gender (59%) and that the age was 57.7 ± 15.8 years. There was a predominance of sepsis of respiratory focus secondary to pneumonia (35%), being that all the patients admitted in the study were ventilated under PSV mode, in which the level of established pressure was 14.4 ± 3.9cmH_2O. The PEEP level used was 10.3 ± 2.5cmH_2O and the PaO_2/FiO_2 ratio was 196.5 ± 55.6mmHg before the institution of the recruitment maneuver. The behavior of the pulmonary mechanics and oxygenation in the three periods in which the study protocol was performed are illustrated in Table 2.

Table 2. The behavior of the pulmonary mechanics and oxygenation before and after applying the sighing, in the Intensive Care Unit (ICU) of a general hospital-2010

	Sample (n=17)		
	Pre	**Post**	**Post-15 minutes**
P_{PEAK} (cmH_2O)	34.7 ± 5.6	35.5 ± 4.5	35.2 ± 4.8
P_{PLAT} (cmH_2O)	25.5 ± 5.3	23.1 ± 4.7*	23.8 ± 4.8**
P_R (cmH_2O)	9.2 ± 2.3	12.4 ± 3.3$^{\#}$	11.4 ± 3.1$^{¥}$
C_{STAT} (mL/cmH_2O)	36.3 ± 11.4	42.4 ± 11.3$^{\#}$	40.3 ± 10.8$^{¥}$
PaO_2 (mmHg)	89.6 ± 13.0	116.3 ± 1862$^{\#}$	104.8 ± 14.9$^{¥}$
$PaCO_2$ (mmHg)	35.5 ± 6.7	32.9 ± 6.8*	34.3 ± 7.3
PaO_2/FiO_2 (mmHg)	196.5 ± 55.6	256.4 ± 79.9$^{\#}$	230.3 ± 68.6$^{¥}$
VE (L)	8.1 ± 1.1	8.8 ± 0.9	8.5 ± 1.5

*Post sigh < Pre sigh (p<0.05); **After 15 minutes < Pre sigh (p<0.05); $^{\#}$Post sigh > Pre sigh (p<0.05); $^{¥}$After 15minutes > Pre sigh (p<0.05).

P_{PEAK}: pressure peak; P_{PLAT}: pressure plateau; P_R: resistive pressure; Cstat: respiratory system static compliance; PaO_2: partial pressure of arterial oxygen; $PaCO_2$: partial pressure of arterial carbon dioxide; PaO_2/FiO_2: ratio of arterial oxygen partial pressure to fractional inspired oxygen; VE: minute ventilation.

It was verified that the introduction of two sighs per minute with airways pressure limited in 40cmH_2O for four seconds led to a statistically significant improvement of PaO_2 ($P < 0.001$). The Cstat presented a statistically significant increase soon after the withdrawal of the sigh (p=0.03) and remained stable 15 minutes after the interruption of the technique. The behavior of gas exchange during the protocol presented statistically significant differences regarding the application of the therapy, evidenced by the increase of the PaO_2/FiO_2 ratio following the suppression of the sigh ($P < 0.001$) and this increment was maintained during the remaining 15 minutes ($P < 0.001$). The hemodynamic behavior during the protocol performance is illustrated in Table 3.

Table 3. Hemodynamic behavior before and after applying the sigh maneuver, in the Intensive Care Unit (ICU) of a general hospital-2010

Variiables	Samples (n=17)		
	Pre	**Post**	**Post-15 minutes**
HR (bpm)	96.0 ± 16.0	92.7 ± 14.6	96.4 ± 13.1
SBP (mmHg)	128.2 ± 17.5	130.2 ± 12.0	128.5 ± 15.1
DBP (mmHg)	68.2 ± 12.1	70.2 ± 10.7	69.5 ± 12.2
MAP (mmHg)	87.8 ± 12.5	89.6 ± 9.7	88.7 ± 11.3

HR: heart rate; SBP: systolic blood pressure; DBP: diastolic blood pressure; MAP: mean arterial pressure

The hemodynamic variables did not present statistically significant differences with the application of the sigh recruitment maneuver, withholding stability after 15 minutes from the application of the maneuver.

No intercurrence was registered associated with the use of the sigh technique to what concerns the development of hemodynamic instability during the application of the protocol, characterized by MAP < 60mmHg; depression of respiratory drive or exteriorization of tracheal secretion.

Discussion

The addition of two intermittent sighs per minute in association with the PSV mode improved arterial oxygenation and Cstat and possibly promoted alveolar recruitment of patients with a PaO_2/FiO_2 ratio lower than 300 submitted to MV.

The positive effects of the alveolar recruitment maneuver on gas exchanges may be associated with the increment in the current volume, suggesting that the application of the sigh may prevent alveolar collapse in patients who present a deficit in gas exchange. It is worth noting that alveolar recruitment maneuvers should be used in the context of pulmonary protection and not only as a means to improve oxygenation[7].

Another parameter is the time of sustenance or maintenance of the average pressure in airways what can favor the alveolar filling, balancing the constants of time of the respiratory system and, consequently, improving the gas distribution.

In consonance, Güldner et al.[6], in their experimental study with swine receiving 60% of the current volume in sighs, observed an improvement in pulmonary oxygenation with perfusion redistribution, which implied in the reduction of the ventilation/perfusion gradient, without alterations in pulmonary weight (by the formation of edema or inflammatory load). These results were confirmed by Mauri et al.[13],reporting improvement in PaO_2 and decreasing in the current regional volume, that is, the sigh provided a better regional distribution of such volume favoring a decrease of pulmonary heterogeneity with the reduction of its distention.

In terms of pulmonary viscoelasticity, Antonaglia et al.[12] evidenced a strong relation of the improvement of PaO_2 with these properties, indicating that the greater the viscoelastic variation, the greater the potential for gain in terms of recruitment of collapsed areas by reduction of the heterogeneous pulmonary gradient. However, due to the variation of patients with different viscoelastic properties and the reduced sample amount, there was no evidence of significant alteration in terms of PaO_2 and Cstat[12].

In this aspect, in a randomized clinical trial carried out by Mauri et al.[17] that compared the Pressure Support Ventilation (PSV) and PSV mode associated with a sigh, no expressive differences were found in terms of PaO_2/FiO_2 ratio and important clinical outcomes such as length of hospital stay, days of mechanical ventilation and mortality. Nonetheless, it has been shown to be a safe maneuver without adverse events and tissue damage.

Steimback et al.[18] identified positive results, especially in terms of tissue damage. However, the addition of 3 sighs per minute seemed to be prejudicial when compared to 1 sigh every 6 minutes. As such, these authors suggest that, in ratification to the previous study of Vaporidi et al.[19], the frequency of exposure to sighs might be related to the intrinsic repairing capacity of the pulmonary epithelium.

Analyzing the sustenance of the effects achieved by the alveolar recruitment maneuver through sighing, Pelosi et al.[16] have shown that, after its interruption, all variables of mechanics in the respiratory system returned to baseline values. Rival et al.[20], when they submitted patients with ARDS to prolonged breaths of $45cmH_2O$ associated with the prone position, demonstrated an accentuated improvement of oxygenation, maintaining the acquired increase in the PaO_2/FiO_2 ratio for up to 13 hours after the end of the study.

Immediately after the suspension of the sigh technique and 15 minutes from suspension had elapsed, the values of Cstat, PaO_2, and gas exchanges presented statistically significant differences, indicating that the viscoelastic properties or the heterogeneity of the respiratory system, alongside the oxygenation, can be improved with the sigh. Nonetheless, it is important to emphasize that these values are dependent on pulmonary elastance, with an evidenced tendency in the reduction of its values, suggesting that the persistence of the sighs for a longer time might be beneficial in the maintenance of these values.

Another variable that also presented elevation during the application of the technique and remained as such after 15 minutes of sighing was the resistive pressure. This elevation can be explained by the interaction of high current volumes and the flow, having as the final product the high resistance due to turbulent air passage. The maintenance of these values after the procedure can be explained by the reactivity of the bronchial wall to elevated flows[7]. Considering the behavior of resistive pressure, the literature review has demonstrated that this was, until the present moment, the only study to evaluate this variable, and it can therefore be considered as a pioneer.

The recruitment maneuvers are not exempt from risks[5]. Studies suggest that pulmonary lesions such as barotrauma, pneumothorax appearance, arrhythmias, arterial hypotension, and desaturation are the adverse events that can occur, the latter two being the most common during the recruiting maneuvers[5,21]. The hemodynamic variables analyzed in this study did not show statistically significant differences, remaining stable, during and after the recruitment maneuver, that is, none of the patients in question presented hemodynamic instability. Also, there were no registered episodes of desaturation during the application of the protocol. Similar results were found by Patroniti et al.[11], when demonstrating that, during the administration of the recruitment maneuver with intermittent sighs, the hemodynamic parameters did not undergo any significant changes throughout the study. In this regard, Mauri et al.[17] also did not identify hemodynamic changes, presence of barotrauma, or significant arrhythmias in the PSV group with Sigh versus PSV group, demonstrating to be a safe maneuver and possible to be performed without clinical damage.

Even though the results presented have been considered substantial and with clinical significance, it is still necessary to carry out clinical trials, randomized, controlled, in the attempt to clarify which is the alveolar recruitment strategy most appropriate to the increment of pulmonary mechanics and oxygenation in patients submitted to mechanical ventilation.

Among the limitations of this study, there is the use of a non-probabilistic sampling, by convenience, reducing the ability to generalize the results with statistical precision. Besides that, it is not possible to ensure the safety of the technique, given that the patients were followed for only 15 minutes after the sigh maneuver was done. What can be stated is that during the period in which the maneuver was performed, and after 15 minutes of its execution, there were no hemodynamic impact and intercurrences associated with the use of the technique.

Conclusion

In this study, the utilization of sighs in patients submitted to invasive mechanics was able to improve the oxygenation and the pulmonary mechanics, without compromising the hemodynamic stability. Therefore, the technique may be considered as an efficient strategy for the maintenance of alveolar recruitment and prevention of possible atelectasis.

Contributions of the authors

Batista Neto AF, Avena KM, and Mendes KMB contributed to the conception, development, and writing of the scientific article, having the approved final version been sent to publication. Duarte HB contributed to the writing of the scientific article, having the approved final version been sent to publication. Olivieri FM and Feijó LF contributed to the development and the writing of the scientific article, having the approved final version been sent to publication.

Competing interests

No financial, legal or political conflict involving third parties (government, companies and private foundations, etc) was declared for any aspect of the submitted work (including, but not limited to the grants and financing, participation in advisory boards, study design, manuscript preparation, statistical analysis, etc.).

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