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Changes in respiratory mechanics during respiratory physiotherapy in mechanically ventilated patients

Alterações da mecânica ventilatória durante a fisioterapia respiratória em pacientes ventilados mecanicamente

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ABSTRACT

Objective: To evaluate the changes in ventilatory mechanics and hemodynamics that occur in patients dependent on mechanical ventilation who are subjected to a standard respiratory therapy protocol.

Methods: This experimental and prospective study was performed in two intensive care units, in which patients dependent on mechanical ventilation for more than 48 hours were consecutively enrolled and subjected to an established respiratory physiotherapy protocol. Ventilatory variables (dynamic lung compliance, respiratory system resistance, tidal volume, peak inspiratory pressure, respiratory rate, and oxygen saturation) and hemodynamic variables (heart rate) were measured one hour before (T_{-1}), immediately after (T_0) and one hour after (T_{+1}) applying the respiratory physiotherapy protocol.

Results: During the period of data collection, 104 patients were included in the study. Regarding the ventilatory variables, an increase in dynamic lung compliance (T_{-1} = 52.3 ± 16.1mL/cmH_2O versus T_0 = 65.1 ± 19.1mL/cmH_2O; $p < 0.001$), tidal volume (T_{-1} = 550 ± 134mL versus T_0 = 698 ± 155mL; $p < 0.001$), and peripheral oxygen saturation (T_{-1} = 96.5 ± 2.29% versus T_0 = 98.2 ± 1.62%; $p < 0.001$) were observed, in addition to a reduction of respiratory system resistance (T_{-1} = 14.2 ± 4.63cmH_2O/L/s versus T_0 = 11.0 ± 3.43cmH2O/L/s; $p < 0.001$), after applying the respiratory physiotherapy protocol. All changes were present in the assessment performed one hour (T_{+1}) after the application of the respiratory physiotherapy protocol. Regarding the hemodynamic variables, an immediate increase in the heart rate after application of the protocol was observed, but that increase was not maintained (T_{-1} = 88.9 ± 18.7 bpm versus T_0 = 93.7 ± 19.2bpm versus T_{+1} = 88.5 ± 17.1bpm; $p < 0.001$).

Conclusion: Respiratory therapy leads to immediate changes in the lung mechanics and hemodynamics of mechanical ventilation-dependent patients, and ventilatory changes are likely to remain for at least one hour.

Keywords: Respiratory therapy; Respiration, artificial; Respiratory mechanics

INTRODUCTION

Ventilatory support is provided to patients with acute respiratory failure to provide rest for the respiratory muscles and reduce the work of breathing until the acute condition is resolved. The mobilization and removal of respiratory secretions plays a key role in improving bronchial hygiene and gas exchange and in reducing the work of breathing, thus changing the mechanics of critically ill patients subjected to invasive ventilatory support.[1]

In most intensive care units (ICUs), respiratory physiotherapy is an integral part of the management of critically ill patients who require invasive ventilatory support. Respiratory physiotherapy techniques include postural drainage (PD), mobilization, vibration, percussion, manual hyperinflation (MH), and aspiration of the airways.(2) The routine combination of these techniques primarily aims to prevent complications such as tracheal prosthesis obstruction, ventilator-associated pneumonia (VAP), and patient-ventilator asynchrony.(3-14)

Numerous respiratory therapy protocols have been described for the care of mechanical ventilation (MV)-dependent patients, but with conflicting results.(10-12,15,16) The aim of this study was to evaluate the changes in ventilatory mechanics and hemodynamics that occur in MV-dependent patients undergoing a standard respiratory physiotherapy protocol.

METHODS

This was an experimental and prospective study conducted at two mixed ICUs: the Intensive Care Center of the *Hospital Moinhos de Vento* in Porto Alegre and the ICU of the *Hospital de Pronto-Socorro de Canoas* in Canoas, both in the state of Rio Grande do Sul. The study was approved by the Research Ethics Committees of both hospitals (Project no. 2004/18 and 05-407, respectively), and patients and close family members participated in the study after signing an informed consent form.

All patients dependent on MV for ≥ 48 hours and who were prescribed respiratory physiotherapy during the period from February to September 2014 were consecutively included in the study after signing the informed consent form. The exclusion criteria consisted of patients with hemodynamic instability (change in vasopressor dose in the last two hours, mean blood pressure ≥ 120mmHg or ≤ 60mmHg, heart rate (HR) ≥ 130bpm or ≤ 50bpm, and the presence of serious ventricular arrhythmias); patients with ventilatory instability, i.e., the need for a fraction of inspired oxygen (FiO_2) ≥ 0.8 or the need for positive end-expiratory pressure (PEEP) ≥ 15cmH_2O; dying patients (as defined by the medical staff); patients with radiological evidence of fracture of two or more ribs; and patients with severe bronchospasms.

Respiratory physiotherapy protocol

The following protocol was applied to all patients. First, the use of inhaled or intravenous bronchodilators, as well as changes in the MV parameters 120 minutes before and after respiratory physiotherapy care, were not allowed. Then, chest compression-vibrations were performed for five minutes in right lateral decubitus and five minutes in the left lateral decubitus. This technique consists of manually compressing the chest during expiration and releasing the compression at the end of expiration, facilitating active inspiration to mobilize pulmonary secretions and improve alveolar ventilation. Next, manual hyperinflation (MH) was performed by the instillation of 10ml of saline solution (0.9% saline) in the endotracheal tube and the use of a manual resuscitation bag for one minute, followed by aspiration of bronchial secretions for a maximum of 15 seconds. Finally, the patient was placed in a 30º-decubitus position.

Data collected

All patients were mechanically ventilated using Savina®, Evita-2®, or Evita-4® ventilators (Drager, Lübek, Germany) with the capacity to analyze the pressure, flow, and volume curves. The ventilatory variables collected consisted of the ventilation mode, dynamic lung compliance (C_{dyn}), respiratory system resistance (R_{sr}) in patients receiving constant-flow, volume-controlled ventilation, tidal volume (V_T), peak inspiratory pressure (PIP), and PEEP. The hemodynamic and oxygenation variables continuously recorded by the multiparameter monitors (Siemens SC 7000® and SC 9000® (Siemens, Sweden)) consisted of the heart rate, respiratory rate (RR), and peripheral oxygen saturation (SpO_2). All data were collected at three timepoints relative to the application of the respiratory physiotherapy protocol: (a) pre-protocol - the variables were analyzed one hour before applying the respiratory physiotherapy protocol (T_{-1}); immediate post-protocol - immediately after applying the respiratory physiotherapy protocol (T_0); and (c) late post-protocol - one hour after applying the respiratory therapy protocol (T_{+1}). Pulmonary radiological data from the ICU admission day (radiologist report), the causes of acute respiratory failure, preexisting conditions, and MV parameters, as well as demographic data, were also acquired.

Statistical analysis

A descriptive analysis of the data was conducted using the means and standard deviations for quantitative variables (or medians and interquartile ranges), while categorical variables were expressed as frequencies and percentages. The Kolmogorov-Smirnov test was used to verify the normal distribution of the data. In the inferential analysis, to assess the variation among the three measurements performed on the same patient, the ANOVA test for repeated measures was used with Bonferroni multiple comparisons to identify potential differences between the assessment timepoints. Statistical Package for the Social Sciences (SPSS) 12.0 was used for data analysis, and the significance level was set at 5%.

RESULTS

During data collection, 104 patients were included in the study. Each patient was included only once in the analysis. The mean age of patients was 53 ± 22 years, and the main causes of respiratory failure were multiple trauma (26.9%) and traumatic brain injury (22.1%), as shown in table 1.

Table 1 - Sample characterization

Variables	N = 104
Sex (male)	77 (74.0)
Age	53.8 ± 22.1
Hospital	
HMV	38 (36.5)
EHC	66 (63.5)
Cause of respiratory failure	
Severe multiple trauma	28 (26.9)
TBI	23 (22.1)
Sepsis	12 (11.5)
Stroke	15 (14.4)
COPD Exacerbation	14 (13.5)
Major surgeries PO	20 (19.0)
Preexistent conditions	
Hypertension	18 (17.3)
COPD	14 (13.5)
Coronary artery disease	9 (8.7)
Diabetes mellitus	5 (4.8)
Radiological changes	
Pulmonary infiltrate	31 (30.8)
Pleural effusion	32 (30.7)
Atelectasis	15 (21.2)
Normal	26 (17.3)
Ventilation mode on the assessment day	
Volume-controlled ventilation	46 (44.3)
Pressure support	33 (31.7)
Pressure-controlled ventilation	25 (24.0)
Death in ICU	36 (34.6)

HMV - *Hospital Moinhos de Vento*; HPSC - *Hospital de Pronto-Socorro de Canoas*; TBI - traumatic brain injury; COPD - chronic obstructive pulmonary disease; PO - postoperative; ICU - intensive care unit. The results are expressed as N (%) and means ± SD.

Table 2 shows an increase in the C_{dyn}, V_T, RR, and SpO_2, and a decrease in the R_{sr} immediately after applying the respiratory physiotherapy protocol. The changes observed remained during the assessment performed one hour after the end of the respiratory therapy protocol. An immediate increase in the heart rate, which was not sustained, is shown in table 2.

Table 2 - Behavior of ventilatory and hemodynamic variables at the three assessment timepoints, i.e., one hour before (T_{-1}) and immediately (T_0) and one hour after (T_{+1}) application of the respiratory therapy protocol

Variables	T_{-1}	T_0	T_{+1}
C_{dyn} (ml/cmH_2O)	52.3 ± 16.1[a]	65.1 ± 19.1[b]	64.7 ± 20.2[b]
V_T (ml)[#]	550 ± 134[a]	698 ± 155[c]	672 ± 146[b]
PIP (cmH_2O)[##]	22.2 ± 5.54[b]	21.6 ± 5.71[ab]	21.5 ± 5.24[a]
R_{SR} (cmH_2O/l/s)[##]	14.2 ± 4.63[b]	11.0 ± 3.43[a]	11.2 ± 3.68[a]
RR (bpm)	20.8 ± 5.40[b]	21.9 ± 5.89[c]	19.4 ± 4.97[a]
SpO_2 (%)	96.5 ± 2.29[a]	98.2 ± 1.62[c]	97.8 ± 1.79[b]
Heart rate (bpm)	88.9 ± 18.7[a]	93.7 ± 19.2[b]	88.5 ± 17.1[a]

C_{dyn} - dynamic lung compliance; V_T - tidal volume; PIP - peak inspiratory pressure; R_{sr} - respiratory system resistance; RR - respiratory rate; SpO_2 - peripheral oxygen saturation. The results are expressed as means ± standard deviations. * ANOVA for repeated measures. [a,b,c] The same letter indicates no difference according to the Bonferroni test ($p < 0.001$). [#] Values for the 58 patients who received pressure-controlled ventilation; [##] Values for the 46 patients who received constant-flow, volume-controlled ventilation.

DISCUSSION

The findings of this study suggest that, in MV-dependent patients, significant hemodynamic and ventilatory changes occur immediately after respiratory therapy; however, only the ventilatory changes persisted for at least one hour.

Respiratory therapy is part of the multidisciplinary care of critically ill patients dependent on MV because pulmonary complications resulting from the depression of the cough reflex, reduction in mucociliary clearance, and increase in bronchial mucus production can lead to the retention of bronchial secretions, atelectasis formation, and the development of nosocomial pneumonia.[2-5,17] Particularly in intubated, sedated, and MV-dependent patients, respiratory therapy techniques facilitate the mobilization and elimination of bronchial secretions.[1-3,18]

Respiratory physiotherapy techniques consist of manual, postural, and kinetic techniques.[1,2] Conventional techniques include PD, chest compression-vibrations, manual chest compression, MH, tracheal aspiration (TA), and cough stimulation.[2] As for the PD, the positioning in bed helps to improve the V/Q ratio, increase lung volume, reduce the work of breathing, minimize myocardial work, and mobilize and remove secretions from the airway with the help of gravity.[7] Manual chest compression provides an expansion of collapsed lung areas, thus improving the V/Q ratio, in addition to acting as a facilitating stimulus of thoracic mobility, which can be decreased.[12] The chest compression-vibrations applied to the expiratory phase of the respiratory cycle allow better lung emptying, thus facilitating bronchial hygiene.[2,6] MH favors the displacement of accumulated secretions in the airways and reduces pulmonary shunting.[6,8-19] This technique, performed on patients with spontaneous ventilation, aims to prevent alveolar collapse, expand collapsed alveoli, improve oxygenation and lung compliance, and minimize the risk of hypoxemia, as well as stimulate coughing in MV-dependent patients.[9,11,12] Our study protocol utilized the application of two physiotherapy techniques (manual chest compression and MH).

Although most authors compare those techniques alone, protocols combining different techniques are part of the physiotherapy practice in the ICU and have a primary goal of the removal of respiratory secretions. Fink[14] studied the alternate application of the techniques TA, PD, and chest percussion and observed improved SpO_2 and airway resistance (R_{aw}) in all sessions performed in the four days of the study. Mackenzie et al.[16] applied manual chest techniques in 19 patients and found increased C_{dyn} up to two hours after finishing the application of the maneuver. In our study, the increase in SpO_2 and C_{dyn} and decrease in R_{aw} started immediately after applying the protocol and were sustained for the next hour. However, the changes in the pulmonary mechanics did not exceed 30 minutes.[8,10]

Regarding the changes in the oxygenation indices, Barker and Adams[5] showed no differences in oxygenation (PaO_2) or alveolar ventilation ($PaCO_2$) in 17 patients with acute respiratory distress syndrome when comparing three treatment protocols: TA, TA + PD, and TA + PD + MH. In our patients, SpO_2 measurements showed improved oxygenation immediately after applying the respiratory physiotherapy protocol, which lasted at least one hour. Other authors[20,21] have found similar results of improved oxygenation, however, with shorter duration.

Few studies[20] have evaluated the changes in PIP during and after physiotherapy treatment. Our data showed a persistent reduction of PIP after completion of the protocol.

In a study of difficult-to-wean patients, Hodgson et al.[9] and Maa et al.,[19], in 18 and 23 patients, respectively, showed improvement of static lung compliance (C_{stat}) in the group that underwent MH. Choi and Jones[15] confirmed that a physiotherapy protocol (MH + TA) could increase C_{stat} and decrease R_{sr} for at least 30 minutes. In our study, which included the evaluation of patients who were receiving pressure support ventilation (PSV), the chest compliance changes were demonstrated by measuring the C_{dyn}.

Regarding techniques for tracheal secretion removal, a protocol consisting of MH + PD + TA increased the amount (weight) of mucus removed.[9,23] Mackenzie et al.[16] showed that after completion of a bronchial hygiene protocol, a reduction of 20% in the intrapulmonary shunt, an increase of C_{dyn} by 14%, and an improvement of gas exchange within two hours after physiotherapy were observed. Hodgson et al.[9] showed an increased removal of respiratory secretions and an increase of 30% of C_{dyn} after the use of MH, compared to TA alone, in 18 mechanically ventilated patients. Unoki et al.[12] found no differences when comparing those two techniques in 31 mechanically ventilated patients. Stiller et al.[22] found greater efficacy in the resolution of atelectasis and improvement in oxygenation when using a protocol that combined PD, chest compression-vibrations, MH, and TA compared with a protocol consisting of MH and TA.

Regarding the changes in hemodynamics, Hodgson et al.[9] and Paratz et al.[11] showed a 10% decrease in the mean blood pressure when MH techniques were applied, but no changes in the heart rate were observed, which contradicts our findings.

Ntoumenopulos et al.[23] evaluated the clinical effectiveness of respiratory physiotherapy in the prevention of pneumonia in 60 MV-dependent patients. Patients undergoing the physiotherapy protocol had a lower incidence of pneumonia (39% versus 8%; $p = 0.02$), but this study did not evaluate the physiological effects of the techniques. Therefore, it is unclear whether the improvement of respiratory mechanics provided by the respiratory physiotherapy, as demonstrated in our study and in previous reports, is the cause of clinical improvement or is only associated with improvement (e.g., VAP). Our study was not designed with that purpose in mind and does not have a sufficient sample power to evaluate relevant clinical outcomes (e.g., complications or death), but it was able to demonstrate the ventilatory and hemodynamic changes triggered by a physiotherapy session and how long such changes last. We also emphasize other limitations of this study, including (a) measurement of the variables only in the first 60 minutes, which did not allow determination of the duration of the changes in ventilatory mechanics; (b) the use of one physiotherapy treatment protocol, which did not allow individualized assessment of each protocol technique; and (c) the heterogeneity of the sample studied (e.g., evaluation of patients under different ventilation conditions), which did not allow evaluation according to the ventilation mode used or the cause of respiratory failure (hypoxemic versus hypercapnic patients), among others.

CONCLUSION

The physiotherapy protocol applied was effective in improving the respiratory mechanics of patients dependent on mechanical ventilation. It is worth noting that these effects were measured after 60 minutes and remained present in most patients.

RESUMO

Objetivo: Avaliar as alterações da mecânica ventilatória e da hemodinâmica que ocorrem em pacientes dependentes de ventilação mecânica submetidos a um protocolo padrão de fisioterapia respiratória.

Métodos: Estudo experimental e prospectivo realizado em duas unidades de tratamento intensivo, nas quais pacientes dependentes de ventilação mecânica por mais de 48 horas foram alocados, de forma consecutiva, e submetidos a um protocolo estabelecido de manobras de fisioterapia respiratória. Variáveis ventilatórias (complacência pulmonar dinâmica, resistência do sistema respiratório, volume corrente, pressão de pico inspiratório, frequência respiratória e saturação periférica de oxigênio) e hemodinâmicas (frequência cardíaca) foram mensuradas 1 hora antes (T_{-1}), imediatamente (T_0) e após 1 hora (T_{+1}) da realização do protocolo de manobras de fisioterapia respiratória.

Resultados: Durante o período de coleta dos dados, 104 pacientes foram incluídos no estudo. Quanto às variáveis ventilatórias, houve aumento da complacência pulmonar dinâmica (T_{-1} = 52,3 ± 16,1mL/cmH_2O *versus* T_0 = 65,1 ± 19,1mL/cmH_2O; p < 0,001), do volume corrente (T_{-1} = 550 ± 134mL *versus* T_0 = 698 ± 155mL; p < 0,001) e da saturação periférica de oxigênio (T_{-1} = 96,5 ± 2,29% *versus* T_0 = 98,2 ± 1,62%; p < 0,001), além de redução da resistência do sistema respiratório (T_{-1} = 14,2 ± 4,63cmH_2O/L/s *versus* T_0 = 11,0 ± 3,43cmH_2O/L/s; p < 0,001) logo após a realização das manobras de fisioterapia respiratória. Todas as alterações se mantiveram na avaliação realizada 1 hora (T_{+1}) após as manobras de fisioterapia respiratória. Já com relação às variáveis hemodinâmicas, houve elevação imediata, porém não sustentada da frequência cardíaca (T_{-1} = 88,9 ± 18,7bpm *versus* T_0 = 93,7 ± 19,2bpm *versus* T_{+1} = 88,5 ± 17,1bpm; p < 0,001).

Conclusão: Manobras de fisioterapia respiratória geram mudanças imediatas na mecânica pulmonar e na hemodinâmica dos pacientes dependentes da ventilação mecânica, e as alterações ventilatórias provavelmente permanecem por pelo menos 1 hora.

Descritores: Terapia respiratória; Respiração artificial; Mecânica respiratória

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