Original Article

Effects of manually assisted coughing on respiratory mechanics in patients requiring full ventilatory support*

Efeitos da tosse manualmente assistida sobre a mecânica do sistema respiratório de pacientes em suporte ventilatório total

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Abstract

Objective: Manually assisted coughing (MAC) consists of a vigorous thrust applied to the chest at the beginning of a spontaneous expiration or of the expiratory phase of mechanical ventilation. Due to routine use of MAC in intensive care units, the objective of this study was to assess the effects of MAC on respiratory system mechanics in patients requiring full ventilatory support. **Methods:** We assessed 16 sedated patients on full ventilatory support (no active participation in ventilation). Respiratory system mechanics and oxyhemoglobin saturation were measured before and after MAC, as well as after endotracheal aspiration. Bilateral MAC was performed ten times on each patient, with three respiratory cycle intervals between each application. **Results:** Data analysis demonstrated a decrease in resistive pressure and respiratory system resistance, together with an increase in oxyhemoglobin saturation, after MAC combined with endotracheal aspiration. No evidence of alterations in peak pressures, plateau pressures or respiratory system compliance change was observed after MAC. **Conclusions:** The use of MAC alters respiratory system mechanics, increasing resistive forces by removing secretions. The technique is considered safe and efficacious for postoperative patients. Using MAC in conjunction with endotracheal aspiration provided benefits, achieving the proposed objective: the displacement and removal of airway secretions.

Keywords: Cough; Sputum; Respiratory mechanics; Respiration, artificial.

Resumo

Objetivo: A tosse manualmente assistida (TMA) consiste na compressão vigorosa do tórax no início da expiração espontânea ou da fase expiratória da ventilação mecânica. Tendo em vista a utilização rotineira da TMA na unidade de terapia intensiva, a proposta deste estudo foi analisar os efeitos dessa técnica no comportamento da mecânica do sistema respiratório de pacientes submetidos a suporte ventilatório total. **Métodos:** Foram estudados 16 pacientes intubados, sedados e submetidos à ventilação mecânica controlada, sem participação interativa com o ventilador. A mecânica do sistema respiratório e a saturação periférica de oxigênio foram mensuradas antes e após a aplicação de TMA e após a aspiração traqueal. Foram realizadas 10 aplicações bilaterais da técnica por paciente, com intervalos de 3 ciclos respiratórios entre cada aplicação. **Resultados:** Os dados evidenciaram a diminuição da pressão resistiva e da resistência do sistema respiratório e aumento da saturação periférica de oxigênio após a aplicação da TMA associada à aspiração traqueal. Não foram evidenciadas alterações das pressões de pico, platô e complacência do sistema respiratório após a aplicação da TMA. **Conclusões:** A TMA foi capaz de alterar a mecânica do sistema respiratório, mais especificamente aumentando as forças resistivas através do deslocamento de secreção. A técnica pode ser considerada eficaz e segura para pacientes em pós-operatório imediato. A associação entre TMA e aspiração traqueal mostrou-se benéfica, alcançando os objetivos propostos: deslocamento e remoção de secreção das vias aéreas.

Descritores: Tosse; Secreção; Mecânica respiratória, Respiração artificial.

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Introduction

Patients in intensive care units (ICUs) tend to retain secretion, due to impaired mucociliary clearance.[1] The accumulation of mucus is commonly observed in these patients, principally in those who use mechanical ventilation for long periods, generating complete or partial obstruction of the airway, which contributes to the formation of atelectasis, air trapping, and pulmonary hyperdistension.[2] As a consequence, there is loss of ventilation homogeneity, affecting gas exchange and the respiratory mechanics.[2,3]

Improvement in the respiratory mechanics and in gas exchange have been observed after the secretion has been dislodged through the use of various bronchial hygiene techniques.[4] Chief among these techniques is manually assisted coughing (MAC).

The MAC technique[5,6] is also known as quad cough,[4,7] manual chest compression,[8] expiratory rib cage compression and squeezing.[9,10] The technique consists of vigorous compression of the chest at the beginning of spontaneous expiration or of the expiratory phase of mechanical ventilation.[4,6,11-15] As the name suggests, MAC is aimed at simulating one of the most efficacious mechanisms of airway clearance: coughing.[16] This maneuver promotes greater compression during expiration,[11] increasing the velocity of expired air, and is useful for the displacement of the secretions toward the trachea, from where they can be removed through coughing or tracheal aspiration.[12] The MAC technique is applied exclusively to the chest, placing the hands bilaterally on the lower third of the thorax[5], or unilaterally, with the hands placed on the middle third of the thorax;[11] or simultaneously on the chest and abdomen, placing one of the hands ventrally on the chest (above the sternum) and the other on the abdominal region.[5,11,14,17]

Studies have shown that MAC is capable of dislodging secretions from the airways, thereby influencing oxygenation and respiratory mechanics.[18] In addition, some authors suggest that the frequent use of MAC can reduce the incidence of pulmonary complications caused by retention of secretion.[2,14] Most studies have been limited to analyzing the effects of the clearance of secretion through the determination of peak expiratory flow, volume of expectorated secretion and the repercussions for oxygenation.[2,4,6,12,14,16] There have been few studies addressing MAC, and those that have done so have not reported the MAC-related behavior of the respiratory mechanics variables. The objective of the present study was to evaluate the effects of MAC on the behavior of respiratory mechanics in intubated, mechanically ventilated patients.

Methods

We selected consecutive patients submitted to surgical procedures and admitted to the ICU. The study was carried out from January to April of 2003.

Written informed consent was obtained from the person directly responsible for each patient. The study was approved by the Ethics in Research Committees of the Triangle University Center in Uberlândia, Brazil and the *Hospital Português*, Salvador, Brazil.

The patients included in the study were intubated, sedated and submitted to controlled mechanical ventilation, without interactive participation with the ventilator. The patients were ventilated using Evita 2-Dura and Evita 4 devices (Drager Medical, Lubeck, Germany), in the controlled volume mode, at a tidal volume of 8 mL/kg of body weight, with a constant flow (square wave), using a positive end-expiratory pressure (PEEP) of 10 cmH_2O or lower, with the respiratory rate set to maintain normocapnia (according to volume per minute) and with the ratio of inspiratory time to total time set to 0.4. We excluded patients who presented any of the following: a history of pulmonary disease; hemodynamic instability; tracheostomy; abnormalities in the thoracic wall or abdominal wall; obesity; severe scoliosis; pregnancy; use of a cardiac pacemaker; pneumothorax; unstable chest; presence of vascular fragility; and PEEP higher than 10 cmH_2O.[19,20]

Variables measured

For peak inspiratory pressure (PIP), we considered the measurement, in cmH_2O, displayed on the screen of the mechanical ventilator.[18] End-inspiratory plateau pressure (Pplat), in cmH_2O, was determined using the technique of rapid airway occlusion during insufflation with constant flow.[18] Pulmonary resistance (Rpul), in cmH_2O, was calculated by determining the difference between PIP and Pplat.[3] Respiratory resistance (Rsr), in $cmH_2O/L/s$, was calculated based on the ratio between Rpul and inspiratory flow.[18] Dynamic compliance (Cdyn), in mL/cmH_2O, was determined by dividing the tidal volume by PIP subtracted from PEEP.[18] Static compliance (Cstat), in mL/cmH_2O, was calculated by dividing the tidal volume by Pplat subtracted from PEEP.[18] Peripheral oxygen saturation (SpO_2) was measured using an HP Viridia 24C vital sign monitor (Hewlett Packard, Boeblingen, Germany) with a finger sensor.[21,22] Secretion was removed through tracheal aspiration[13] and was collected in sterile graduates (Broncozamm Tr; Zammi Instrumental Ltda, Duque de Caxias, Brazil).

Protocol

Patients were placed in the supine position, with the head of the bed at zero degrees of inclination. Respiratory mechanics was monitored by a physiotherapist, while MAC was applied by other physiotherapist, who was blinded to the initial conditions of the respiratory mechanics of each patient. Both physiotherapists were previously trained to carry out the study. The MAC technique employed consisted of vigorous compression of the chest, carried out bilaterally, both hands being placed on the lower third of the chest of the patient.[11] The technique was applied at the beginning of the expiratory phase of the mechanical ventilation, 10 times in each patient, with intervals of three respiratory cycles between each application. For approximately 1 min after MAC was performed, no intervention was conducted, thereby allowing the stabilization of the ventilation, and additional monitoring was subsequently carried out (post-MAC measurements). After the second monitoring period, patients were submitted to tracheal aspiration through an orotracheal tube. Patients were submitted to hyperoxygenation (fraction of inspired oxygen [FiO_2] of 1.0) at 1 min before the procedure, in order to avoid hypoxemia. Additional monitoring of the respiratory mechanics was carried out (post-aspiration measurements) at 1 min after tracheal aspiration. The development of arterial hypotension, hypoxemia, bradycardia or bronchospasm[23,24] was registered in the evaluation chart of the patients.

Statistical analysis

One-way analysis of variance for repeated measurements was used to evaluate the pre-MAC, post-MAC and post-aspiration behavior of the respiratory mechanics variables, as well as that of the pre-MAC, post-MAC and post-aspiration SpO_2. In order to isolate statistically different groups, the Student-Newman-Keuls method was used. The level of statistical significance was set at 0.05, or 5%.

Results

We studied 16 consecutive patients submitted to surgical procedures and later admitted to the ICU. All 16 were intubated, sedated and submitted to controlled mechanical ventilation, without interactive participation with the ventilator. The mean age was 56.6 ± 15.2 years, and 12 (75%) of the patients were male. The characteristics of the patients are detailed in Table 1.

Table 2 presents the analysis of the pre-MAC, post-MAC and post-aspiration values for the respiratory mechanics variables (PIP, Pplat, Rpul, Rsr, Cdyn and Cstat) and for SpO_2.

We observed no statistically significant differences among the pre-MAC, post-MAC and post-aspiration time points in terms of PIP, Pplat, Cdyn or Cstat. However, when comparing the post-MAC and post-aspiration time points in terms of Rpul and Rsr, we observed statistically significant decreases. In addition, we observed a statistically significant increase in the post-MAC SpO_2 when compared with the post-aspiration SpO_2, as well as in the pre-MAC SpO_2 when compared with the post-aspiration SpO_2.

None of the patients presented arterial hypotension, hypoxemia, bradycardia or bronchospasm[23,24] during or after the procedures (MAC and tracheal aspiration). In addition, no factor that might interfere with the measurement of the SpO_2, such as shock or peripheral perfusion, was identified. Auto-PEEP was not detected in any of the patients evaluated.

Discussion

Many studies have shown, through the analysis of the volume of expectorated secretion, oxygenation and peak expiratory flow, the efficacy of bronchial hygiene techniques in displacing airway secretion. A review of the literature revealed that no specific analysis of the respiratory mechanics after the use of MAC in humans has been described to date. Therefore, ours can be considered a groundbreaking study.

Table 1 - Characteristics of the patients evaluated (n = 16).

Pat.	Age (years)	Gender	Surgical Procedure	Surgical time (min)	Total (mm)	Total time (days)
1	75	M	EVD for H-CVA - PO	60	8.0	3
2	48	M	EL for acute inflammatory abdomen - PO	130	8.0	2
3	26	F	MR - IPO	200	8.0	1
4	74	F	EL for acute obstructive abdomen - IPO	130	7.5	1
5	64	M	Total esophagectomy - IPO	480	8.5	2
6	58	M	MR - IPO	210	8.5	1
7	70	M	MR - PO	240	8.5	1
8	49	F	Cerebral aneurysm clipping - IPO	150	8.0	2
9	60	M	MR - IPO	200	8.5	1
10	36	M	Mitral valve replacement - IPO	110	8.5	1
11	68	F	Debridement of diabetic foot - PO (CRA in the OR)	195	8.5	5
12	64	M	EL for fecal peritonitis + colostomy - PO	120	8.5	3
13	63	M	MR - IPO	300	8.5	1
14	28	M	Mitral and aortic valve replacement - IPO	310	8.0	1
15	51	M	Aortic valve replacement - IPO	225	9.5	1
16	55	M	MR - IPO	270	8.5	1
AM	56.6			208		1.7
SD	15.2			101		1.1

Pat.: patient; PO: postoperative; EVD: external ventricular drainage; H-CVA: hemorrhagic cerebrovascular accident; EL: exploratory laparotomy; IPO immediate postoperative; MR: myocardial revascularization; CRA: cardiorespiratory arrest; OR: operating room; AM: arithmetic mean; and SD: standard deviation.

In the present study, the analysis of the behavior of the respiratory mechanics variables (PIP, Pplat, Rpul, Rsr, Cdyn and Cstat) and of SpO_2, evaluated in 16 patients in the postoperative period, demonstrated that, after the performance of MAC followed by tracheal aspiration, there was a decrease in Rpul and Rsr, together with an increase in SpO_2. A comparison between the initial condition of the variables and the post-aspiration time point showed that the patients, after being submitted to MAC accompanied by tracheal aspiration, returned to a condition similar to the baseline status, except for SpO_2, which presented a statistically significant increase.

The observed behavior of Rpul and Rsr can be explained by the fact that the Rsr is determined by calculating the ratio between Rpul and inspiratory flow. Since the patients were ventilated in a mode that uses constant inspiratory flow, it was expected that alterations in Rpul would directly modify the Rsr. Therefore, after the performance of the tracheal aspiration, a decrease in Rpul and Rsr was observed. Bearing in mind that the alterations in the resistance component of the respiratory system (caused by secretion, airway obstruction, bronchospasm, etc.)[24] are responsible for the increase in Rpul and Rsr, we can affirm that MAC was capable of dislodging the secretion, since, after the secretion had been removed through tracheal aspiration, these variables returned to baseline levels. These results are in accordance with the findings reported by Guglielminotti et al.[25,26]

The behavior of these variables after the performance of MAC might have been more dramatic if there had been greater volumes of secretion in the airways of the patients evaluated.

Avena et al.[27] observed no decrease in inspiratory resistance after the performance of tracheal aspiration without the addition of clearance maneuvers in sedated children receiving a neuromuscular blocking agent and submitted to mechanical ventilation. However, the present study showed that it is possible to reduce the resistance by combining tracheal aspiration and MAC, suggesting that the combination of the two techniques has beneficial effects.

We found that, after MAC and after tracheal aspiration, SpO_2 was higher than the baseline value. Two mechanisms can explain this behavior: the association between dislodgment and the removal

Table 2 - Behavior of the respiratory mechanics variables and peripheral oxygen saturation at the three time points evalauated: pre-manually assisted coughing; post-manually assisted coughing; and post-aspiration.

	Pre-MAC	Post-MAC	Post-Aspir
PIP (cmH_2O)	32.0 ± 5.8	32.8 ± 6.3	31.3 ± 4.9
Pplat (cmH_2O)	18.3 ± 3.9	17.9 ± 3.5	18.7 ± 3.9
Rpul (cmH_2O)	13.7 ± 4.7	14.9 ± 5.1	12.6 ± 3.9*
Rsr (cmH_2O/L/s)	0.2 ± 0.08	0.3 ± 0.1	0.2 ± 0.07*
Cdyn (mL/cmH_2O)	20.4 ± 4.0	20.9 ± 6.4	21.7 ± 5.5
Cstat (mL/cmH_2O)	42.6 ± 11.0	43.6 ± 10.4	41.5 ± 10.7
SpO_2 (%)	98.8 ± 1.7	99.0 ± 1.6	99.8 ± 0.8**

MAC: manually assisted coughing; Aspir: aspiration; PIP: peak inspiratory pressure; Pplat: respiratory system plateau pressure; Rpul: pulmonary resistance; Rsr: total respiratory resistance; Cdyn dynamic compliance; Cstat: static compliance; SpO_2: Peripheral oxygen saturation. *Post-aspir < Post-MAC ($p < 0.05$); and **Pré-MAC < Post-aspir > Post-MAC ($p < 0.05$).

of the secretions, promoting better distribution of pulmonary ventilation; and the hyperoxygenation of the patients, initiated at 1 min after the performance of the tracheal aspiration. In the present study, the latter is considered the most likely hypothesis. However, clinically, the increase in SpO_2 does not represent any improvement in the clinical profile of the patients, since the variation achieved was quite small (1-2%).

In the Avena et al. study,[27] sedated children receiving a neuromuscular blocking agent and submitted to mechanical ventilation presented a significant decrease in SpO_2 immediately after tracheal aspiration, and SpO_2 returned to baseline values 10-20 min later. However, in the present study, there was an increase in SpO_2 after the performance of MAC followed by tracheal aspiration, which confirms the idea that there is a beneficial effect of using the two techniques in conjunction.

Alterations in respiratory system impedance, due to factors which increase resistance (presence of secretion in the airways, bronchospasm, etc.) or decrease compliance (pleural effusion, pulmonary edema, etc.),[21,24] can alter the behavior of the PIP and Cdyn. Therefore, we expected that the application of MAC (and consequent dislodgment of the secretion) would result in an increase in PIP and a decrease in Cdyn, neither of which was observed.

It is known that the clearance of secretion can influence certain respiratory mechanics variables. Since the PIP corresponds to the strength necessary to overcome the total respiratory system impedance[9] (resistance and parenchymatous components), we can presume that a significant increase in the airway resistance component occurs after dislodgment of the secretion, significantly increasing PIP after the application of MAC. This increase in the resistance component of airway would occur due to the dislodgment of the secretion from the most distal pulmonary areas (peripheral) to the most proximal (central) airways, as was expected in the present study. It is important to emphasize that the lack of an improvement in PIP might have been due to the small volume of secretion (ranging from 0 to 5 mL) present in the airways of the patients evaluated, which is attributable to the short period of mechanical ventilation (63% of the patients were in the immediate postoperative period) and to the fact that none of the patients presented previous pulmonary alterations that would increase the production of secretion or the accumulation of mucus in the airways.

We also expected that Pplat, inversely to Cstat, would decrease after the application of MAC and increase after the performance of the tracheal aspiration. However, again, this was not observed. Although there is no confirmation of the behavior described above with the data presented in this study alone, it is impossible to rule out the hypothesis that the pulmonary ventilation is redistributed after MAC-induced displacement of secretion, which allows the ventilation of formerly obstructed airways, thus decreasing Pplat, improving Cstat and improving gas exchange. In addition, the current literature suggests that MAC-induced stretching of the rib cage muscles can increase the elastic recoil of the respiratory system. The stretching of these muscles would allow better thoracic mobility and, therefore, better pulmonary ventilation. Kakizaki et al.,[28] after analyzing the effects that stretching the respiratory musculature has on rib cage mobility in patients with chronic obstructive pulmonary disease, suggested that it is possible that such stretching promotes an increase in vital capacity and endurance capacity after the reduction of rib cage elastance, leading to an increase in thoracic mobility.

It is believed that the dislodgment of secretion can promote a decrease in Pplat by allowing better distribution of the pulmonary ventilation. In order to clear bronchial secretions in the patients evaluated in the present study, it was necessary to disconnect the mechanical ventilator, thereby depressurizing the respiratory system, which can decrease pulmonary volume, cause peripheral airway collapse and increase Pplat, as shown by Maggiore et al.[29] Since the measurements in this study were taken at 1 min after the end of tracheal aspiration, it is possible that a decrease in Pplat, after secretion removal, would have been observed after the reestablishment of adequate ventilation through subsequent monitoring of the respiratory mechanics.

The results of this study are in accordance with those of Unoki et al.[9], who evaluated the effect of MAC, performed with or without placing the subject in the prone position, on the ventilation and oxygenation of 41 paralyzed, mechanically ventilated rabbits presenting atelectasis induced by the accumulation of artificial mucus in the trachea. The authors did not observe significant alterations in gas exchangein the ratio of arterial oxygen tension to the fraction of inspired oxygen (PaO_2/FiO_2) or in arterial carbon dioxide tension ($PaCO_2$) or in respiratory system compliance. However, those effects might have been masked by not removing the dislodged secretion, since the authors did no perform tracheal aspiration after applying the MAC technique. Secretion dislodgment and removal might improve oxygenation and ventilation.

In another study, Unoki et al.[30] evaluated the effect of MAC on the clearance of secretion, oxygenation and ventilation of 31 patients on ventilatory support submitted to tracheal aspiration with or without MAC. No differences were observed between the two groups (with and without MAC) in terms of PaO_2/FiO_2, $PaCO_2$, Cdyn or pre-aspiration/post-aspiration secretion clearance, which suggests that MAC should not be used routinely. However, unlike the patients evaluated in our study, those patients presented many different types of pulmonary impairment and were either on pressure support ventilation or on ventilation in the controlled volume mode, which might have influenced the results obtained by those authors.

In the present study, the small size of the sample evaluated might have made it more difficult to characterize the behavior of certain variables. The repetition of this study in a larger patient sample might produce a better definition of the influence of MAC on the respiratory mechanics. In addition, it would be interesting to observe the behavior of the variables some time after the performance of the tracheal aspiration in order to analyze the evolution and duration of the alterations produced. Subsequent monitoring might clarify the behavior of some variables, principally Pplat and Cstat. Therefore, further studies addressing this theme are needed in order to expand the sample and follow the evolution of the alterations in the respiratory system mechanics after tracheal aspiration. In addition, the data presented show the necessity of reproducing this study in patients on prolonged mechanical ventilation or who present previous pulmonary alterations that promote increased production of secretion or accumulation of mucus in the airways, justifying the use of bronchial hygiene techniques. We chose to pre-oxygenate the patients to an FIO_2 of 100% prior to tracheal aspiration in order to avoid hypoxemia. This practice can be considered a limitation to the interpretation of the post-MAC and post-aspiration SpO_2, due to a small variation in the oxygen-hemoglobin dissociation curve.

In conclusion, the results of the present study suggest that MAC alters the respiratory mechanics, more specifically increasing the resistance forces through the dislodgment of secretions. In addition, this technique can be considered safe and efficacious, allowing it to be used during the immediate postoperative period. We also showed that the combination of MAC and tracheal aspiration was beneficial, achieving the predicted goal: dislodgment and removal of the secretion in the airways.

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