Air stacking and chest compression increase peak cough flow in patients with Duchenne muscular dystrophy*

Empilhamento de ar e compressão torácica aumentam o pico de fluxo da tosse em pacientes com distrofia muscular de Duchenne

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Abstract

Objective: To evaluate cough efficiency using two manually-assisted cough techniques. **Methods:** We selected 28 patients with Duchenne muscular dystrophy. The patients were receiving noninvasive nocturnal ventilatory support and presented FVC values < 60% of predicted. Peak cough flow (PCF) was measured, with the patient seated, at four time points: at baseline, during a spontaneous maximal expiratory effort (MEE); during an MEE while receiving chest compression; during an MEE after air stacking with a manual resuscitation bag; and during an MEE with air stacking and compression (combined technique). The last three measurements were conducted in random order. The results were compared using Pearson's correlation test and ANOVA with repeated measures, followed by Tukey's post-hoc test ($p < 0.05$). **Results:** The mean age of the patients was 20 ± 4 years, and the mean FVC was 29 ± 12%. Mean PCF at baseline, with chest compression, after air stacking and with the use of the combined technique was 171 ± 67, 231 ± 81, 225 ± 80, and 292 ± 86 L/min, respectively. The results obtained with the use of the combined technique were significantly better than were those obtained with the use of either technique alone ($F[3.69] = 67.07$; $p < 0.001$). **Conclusions:** Both chest compression and air stacking techniques were efficient in increasing PCF. However, the combination of these two techniques had a significant additional effect ($p < 0.0001$).

Keywords: Muscular dystrophy, Duchenne; Intermittent positive-pressure ventilation; Cough; Insufflation; Peak expiratory flow rate.

Resumo

Objetivo: Avaliar a eficiência da tosse através do uso de duas manobras manuais de auxílio à tosse. **Métodos:** Foram selecionados 28 pacientes portadores de distrofia muscular de Duchenne em uso de ventilação mecânica não-invasiva noturna e CVF < 60% do previsto. O pico de fluxo da tosse (PFT) foi medido, com o paciente sentado, em quatro momentos: com esforço expiratório máximo (EEM) de forma espontânea (basal), EEM associado à compressão torácica, EEM após empilhamento de ar com bolsa de ventilação e EEM com o uso dessas duas técnicas (técnica combinada). As três últimas medições foram realizadas em ordem aleatória. Os resultados foram comparados usando o teste de correlação de Pearson e ANOVA para medidas repetidas, seguido do teste post hoc de Tukey ($p < 0,05$). **Resultados:** A idade média dos pacientes foi de 20 ± 4 anos, e a CVF média foi de 29 ± 12%. A média de PFT basal, com compressão torácica, com empilhamento de ar e com o uso da técnica combinada foi 171± 67, 231 ± 81, 225 ± 80, e 292 ±86 L/min, respectivamente. Os resultados com o uso da técnica combinada foram maiores que aqueles com o uso das duas técnicas separadamente [$F(3,69) = 67,07$; $p < 0,001$]. **Conclusões:** As técnicas de compressão torácica e de empilhamento de ar foram eficientes para aumentar o PFT. No entanto, a combinação dessas manobras teve um efeito aditivo significativo ($p < 0,0001$).

Descritores: Distrofia muscular de Duchenne; Ventilação com pressão positiva intermitente; Tosse; Insuflação; Pico do fluxo expiratório.

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Introduction

Muscular dystrophies, peripheral neuropathies and motor neuron diseases are the most common neuromuscular diseases.[1] The muscular dystrophies are genetic alterations that are characterized by the progressive deterioration of muscle strength. Duchenne muscular dystrophy (DMD) is the most common of the muscular dystrophies, affecting 1 in 3,500 live male births. In general, the diagnosis is made in early childhood. The progressive deterioration of muscle strength leads to the loss of ambulation at the end of the first decade of life and to respiratory failure at the end of the second decade.[1,2]

In patients with muscular dystrophy, the progressive loss of respiratory muscle strength leads to restrictive lung disease, and, over time, those patients develop hypoxemia and nocturnal hypercapnia. However, the loss of the expiratory muscle strength results in inefficient spontaneous cough and the accumulation of secretion in common viral respiratory infections.[1] Patients with marked pulmonary restriction and without adequate clearance of tracheobronchial secretions frequently develop respiratory failure, requiring hospitalization, tracheal intubation (for the removal of secretions), and invasive mechanical ventilation. If tracheobronchial secretions are not removed from the bronchi, the patient can rapidly develop tracheobronchitis or bacterial pneumonia.[3]

In approximately 90% of cases of respiratory failure in patients with muscular dystrophy, there are accompanying episodes of flu due to ineffective cough. Without the appropriate clinical approach, patients with neuromuscular disease develop respiratory failure and are at risk of premature death.[4] It was recently shown that the improved survival observed in patients with DMD is attributable not only to treatment involving noninvasive mechanical ventilation but also to measures for the clearance of tracheobronchial secretions.[3] Such measures include assisted cough, through chest compression or through pulmonary insufflation, performed with the aid of a manual resuscitation bag.[3-5] Another efficient assisted cough technique involves the use of devices for mechanical cough assistance, such as the *In-exsufflator* (J. H. Emerson Co; Cambridge, MA, USA) and *Cough Assist* (Philips Respironics, Murrysville, PA, USA), which provide insufflations and exhalations at pressures of ± 40 cmH_2O.[6] However, the devices are costly, which precludes their acquisition by individual health care facilities within the context of the economic reality in Brazil.

The objective of the present study was to determine whether specific assisted cough maneuvers, alone or in combination, result in a significant increase in the peak cough flow (PCF).

Methods

We selected 30 patients with DMD, > 10 years of age, on noninvasive mechanical ventilation (bilevel positive airway pressure), presenting an FVC < 60% of predicted and an intellectual level sufficient to perform the maneuvers.[7] Patients with current acute infection were excluded, as were those with any neuromuscular disease other than DMD and those in whom a nasogastric tube was being used. Of the patients selected, 17 presented pronounced kyphoscoliosis.

All of the patients selected were under treatment in the Pediatric Sector of the Noninvasive Mechanical Ventilation Outpatient Clinic of the Psychobiology Department of the Sleep Institute at the *Universidade Federal de São Paulo* (UNIFESP, Federal University of São Paulo). All patients or their legal guardians gave written informed consent. The study protocol was approved by the UNIFESP Research Ethics Committee (CEP 0775/06).

After the clinical evaluation, we measured percutaneous oxygen saturation and expired carbon dioxide, as well as performing pulmonary function testing. The spirometry was performed with a KoKo Digidoser Spirometer (PDS Instrumentation, Louisville, CO, USA), while the patient was seated, and standard procedures were followed.[8,9] In all of the patients, the PCF was measured at four time points: at baseline; during chest compression; after air stacking with a manual resuscitation bag had been used; and when the two techniques were used together (combined technique). At each time point, we made three measurements, the highest of which was registered. To avoid the influence of the order of the maneuvers and minimize patient fatigue, the sequence of the time points (other than, obviously, baseline) was random. The PCF measurements following the use of air stacking were taken after three insufflations with a manual resuscitation bag (Moriya, São Paulo, Brazil). The

unidirectional valve of the manual resuscitation bag remained closed. All measurements were made with the patient seated and were taken by the same examiner. The PCF measurements were made using a disposable cardboard mouthpiece attached to a peak flow meter (Mini-Wright AFS; Clement Clarke International, Essex, England).

For the baseline measurement, spontaneous maximal expiratory effort (MEE) was elicited after a deep inhalation. For the chest compression-only time point, the PCF measurements were taken during a spontaneous MEE accompanied by chest compression, which consisted of the application of external pressure over the rib cage. The respiratory therapist positioned one hand over the posterosuperior region of the chest of the patient, and the other hand supported the anterior region of the chest, at the inferior third of the sternum. Patients were asked to inhale deeply and hold their breath (glottal closure), after which, in conjunction with the forced exhalation of the patient, the respiratory therapist applied the chest compression in the direction of the abdomen (downward and inward). For the air stacking-only time point, the PCF measurements were made after air stacking with a manual resuscitation bag. This technique was applied with the patient seated. The head was supported in order to avoid hyperextension of the neck. The mask of the manual resuscitation bag was fitted to the face of the patient and pressed downward in order to avoid air leaks. With each compression of the manual resuscitation bag, the patient took a deep breath and held it. With each subsequent compression of the manual resuscitation bag, the patient inhaled again, without releasing the air inhaled previously. One complete air stacking maneuver consisted of three insufflations without exhalation. After the third insufflation, the patient made a forced exhalation, and the PCF with MEE was measured. For the combined technique time point, the PCF was measured after the use of air stacking with a manual resuscitation bag followed by chest compression with MEE.

The data were compared using Pearson's correlation test and ANOVA with repeated measures, followed by Tukey's post hoc test ($p < 0.05$).[10] Statistical analysis was performed using the STATISTICA program, version 5.1 (StatSoft Inc., Tulsa, OK, USA).

Results

The final sample consisted of 28 patients, with a mean age of 20 ± 4 years, mean FVC of 29 ± 12% of predicted and mean body weight of 56 ± 17 kg. We excluded 2 patients for not having the intellectual capacity to understand and perform the maneuvers involved in the spirometry and PCF measurements. The mean PCF at baseline, during chest compression, after air stacking and after the use of the combined technique was of 171 ± 67, 231 ± 81, 225 ± 80, and 292 ± 86 L/min, respectively. The ANOVA showed a statistically significant difference among the conditions studied [$F(3.69) = 67.07$; $p < 0.001$]. The PCF values obtained during chest compression, after air stacking, and after the use of the combined technique were significantly higher than that obtained at baseline ($p < 0.001$; Figure 1). The comparison between chest compression alone and air stacking alone

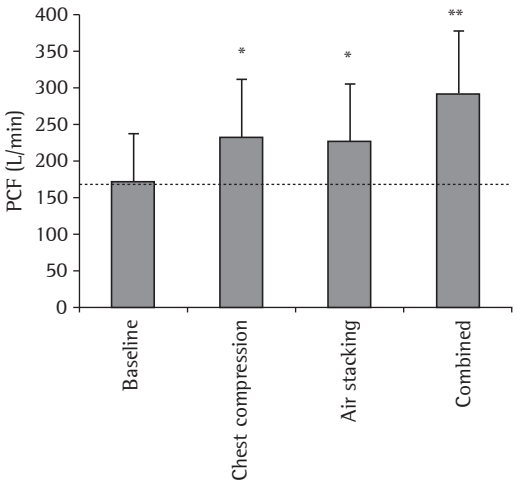

Figure 1 - The vertical bars represent the means, and the vertical lines represent the standard deviation of the peak cough flow (PCF) values in the four conditions. The horizontal dotted line represents the critical PCF threshold associated with a greater risk of pulmonary infection (160 L/min). The PCF values obtained during chest compression were comparable to those obtained after air stacking, both being higher than the baseline PCF values. The PCF values obtained after the use of the combined technique were significantly higher than those obtained at baseline, during chest compression alone, and after air stacking alone. *$p < 0.001$ *vs.* baseline; **$p < 0.001$ *vs.* baseline; and $p < 0.05$ *vs.* chest compression and air stacking.

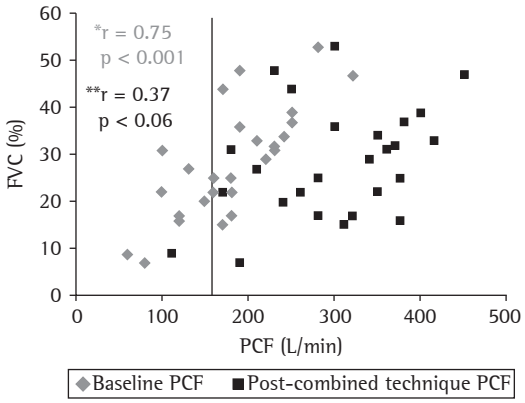

Figure 2 - Direct correlation between FVC and peak cough flow (PCF), at baseline and after the use of the combined technique. The vertical dotted line represents the critical PCF threshold associated with a greater risk of pulmonary infection (160 L/min).

revealed no statistically significant differences. When PCF was measured after air stacking together with chest compression (combined technique), the values were significantly higher than when either of the two techniques were applied in isolation (Figure 1).

The patients who presented pronounced kyphoscoliosis also presented baseline PCF values lower than those obtained for the patients without kyphoscoliosis, as was also true for the three other conditions. However, there were no differences in the PCF between the patients with and without kyphoscoliosis in terms of the magnitude of the increase in the PCF in the three conditions of assisted cough in relation to the baseline value ($p > 0.05$).

We observed a direct, moderate correlation between FVC and PCF ($r = 0.75$; $p < 0.0001$; Figure 2). However, that correlation was weak when the combined technique was used.

Discussion

In the present study, we have shown that, in adolescents with DMD and severe restrictive lung disease, the assisted cough techniques of air stacking and chest compression both increased cough efficiency. In the second decade of life, when such patients develop kyphoscoliosis or pulmonary restriction, they are likely to present episodes of respiratory failure potentiated by the accumulation of tracheobronchial secretion. During the episodes of pulmonary infection, however, it is fundamental to establish an appropriate therapeutic strategy designed to strengthen the expiratory muscles. The initial treatment of acute respiratory failure in normal individuals includes oxygen supplementation; however, in patients with neuromuscular disease, there is greater risk of carbon dioxide retention and oxygen therapy provides no benefit.[11] In addition, oxygen therapy precludes using oxygen saturation as a warning sign that the accumulation of secretion has occurred, a point at which caregivers or health care professionals should take measures aimed at the clearance of the pulmonary secretion. In the present study, we found the use of the combined technique to be more efficacious than was either of the two techniques in isolation. In all but one of the patients, an increase in the PCF was achieved, including 7 of the 8 patients who presented a baseline PCF < 160 L/min. This is an important finding, since 160 L/min is the threshold recognized as the major risk factor for pulmonary infection.[3] Therefore, it is important to instruct family members in the chest compression and air stacking techniques, as well as to advise them to acquire a manual resuscitation bag.

The cough is an essential protective reflex that removes foreign bodies and excess secretions from the airways during viral infections, preventing lung diseases such as pneumonia, atelectasis and respiratory failure.[4,12] The normal cough is a process that occurs in three phases: the inspiratory phase; the compression phase; and the expulsive phase. In patients with neuromuscular disease, not only are the inspiratory muscles quite weak, making it difficult to draw a deep breath, but the expiratory muscles cannot generate the closed-glottis force needed in order to create a functional air flow velocity. Therefore, to assist coughing, it is necessary to employ methods that increase the capacity of the expiratory muscles to generate high intrathoracic pressures, such as muscle training, electrical stimulation of the abdominal muscles, and thoracoabdominal compression.[12]

The volume prior to coughing has considerable influence on the effectiveness of the cough in patients with neuromuscular disease. Loss of the capacity to produce strong exhalations reduces lung elasticity, increasing respiratory effort and predisposing patients to atelectasis. In the advanced stages of the disease, patients with neuromuscular disease present VC values

near the closing volume of the alveoli. The objective of air stacking is to achieve the maximum insufflation capacity, or rather, the maximum volume of air that can be actively introduced into in the lungs.[5] The maximum insufflation capacity is an indirect indicator of lung compliance. An increase in lung volume can be achieved through air stacking,[2,12] through glossopharyngeal breathing[13] or simply through the use of the inspiratory phase of a mechanical cough assistance device.[3,6] The techniques to achieve maximum insufflation capacity lead to an increase in lung volume, a reduction in microatelectasis, an increase in lung compliance, and an improvement in cough effectiveness.[5] During the cough of normal individuals, 2.3 ± 0.5 L of air are expelled at a flow rate of 360-1,200 L/min.[5] These values are well above the values obtained for the patients with DMD in the present study, for whom the mean baseline PCF was 171 L/min. In addition, to improve cough efficacy, high intra-abdominal pressures are necessary in order to generate an effective cough flow during glottal opening; therefore, effective coughing requires high lung volumes and the capacity to sustain respiration.[14]

Patients with neuromuscular disease and pulmonary restriction are at a high risk of respiratory complications when the PCF is below 160 L/min.[3] In the present study, the assisted cough technique of air stacking accompanied by chest compression increased the PCF significantly in all of the patients, values remaining below 160 L/min in only one case (Figure 1). It should be borne in mind that manually assisted cough techniques are subject to diverse problems, such as a lack of coordination between the patient and the respiratory therapist and air leaks from the mask, as well as inadequate force or inappropriate application of chest compression. Therefore, it is important that patients and caregivers receive simple and detailed training, so that they will be able to perform the appropriate maneuvers without the assistance of health care professionals.

The data obtained in the present study are similar to those reported by another group of authors, who demonstrated that, in patients who are tetraplegic due to spinal trauma, assisted cough techniques result in an increase in the PCF of 216-390 L/min.[15] Other authors demonstrated the effectiveness of manually-assisted cough in patients with high-level spinal injury,[16] post-polio syndrome,[5,17] muscular dystrophy,[5,6] amyotrophic lateral sclerosis,[5,18] and progressive spinal muscular atrophy.[5,19] Determining PCF is important for evaluating bulbar muscle function, allowing patients with preserved pharyngeal muscles, such as those with DMD, to be distinguished from those with bulbar amyotrophic lateral sclerosis.[2] The function of the bulbar muscles also can be evaluated by determining the difference between the maximum insufflation capacity and the VC.[12] However, we found that PCF values behaved differently than did those obtained for the "dart" flow, which is defined as the intraoral air pressure generated by lip and tongue propulsion when the mouth is closed. As the mouth opens, the tongue releases the air in a maneuver similar to that employed in propelling a dart from a blowpipe. The dart flow is primarily a reflection of the function of the orofacial muscles and is associated with the inadequate saliva control.[20] In general, the dart flow is greater than the PEF and the PCF.

As was expected, PCF fell in proportion to the age-dependent drop in FVC, as has been reported by other authors.[21] The correlation between FVC and the PCF after the use of the combined technique was weak, suggesting that there are other factors that influence maximum insufflation capacity and chest compression. Respiratory system compliance differed among the subjects studied; In addition, kyphoscoliosis can impede the performance of assisted cough maneuvers.[22] In the present study, there were no differences between the patients with and without kyphoscoliosis in terms of the increase in PCF. However, since the patient sample was small, there is a chance that this was a type II error.

The present study has certain limitations. The findings might have been influenced by the spirometry technique, by the sequence in which PCF was measured, and by the respiratory therapist. In patients with neuromuscular disease, spirometry is subject to various problems. In such patients, common problems include air leaks around the mouthpiece, fatigue during the maneuvers, and short expiratory time. Therefore, we used standard spirometry criteria.[6] In addition, since the patients we unable to exhale for the requisite 6 s, we accepted curves with

expiratory plateaus of ≥ 2 s.[8] In the cases in which there were air leaks around the mouthpiece, we used an oronasal mask.[23] To prevent the sequence of the assisted cough maneuvers from influencing the results, we randomly alternated that sequence. Air stacking was always performed by the same respiratory therapist, and the majority of the patients had already been using air stacking at least three times per day at home. Therefore, we do not believe that the data were adversely affected by any inappropriate application of the technique. Although similar studies have been conducted by other authors,[4,12] the data obtained in the present study have internal validity for application in Brazil, where the level of education and socioeconomic status of the patients are lower than in developed countries.

In conclusion, we found that using the techniques of chest compression and air stacking with a manual resuscitation bag in conjunction has a greater positive effect on PCF than do either of the maneuvers used in isolation. Therefore, we recommend the use of these assisted-cough techniques in the respiratory management of patients with DMD, as well as of those with other neuromuscular diseases that cause the pulmonary restriction.

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