J. Phys. Ther. Sci.
27: 2509–2513, 2015

Original Article

Upper extremity muscle tone and response of tidal volume during manually assisted breathing for patients requiring prolonged mechanical ventilation

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Abstract. [Purpose] The aim of the present study was to examine, in patients requiring prolonged mechanical ventilation, if the response of tidal volume during manually assisted breathing is dependent upon both upper extremity muscle tone and the pressure intensity of manually assisted breathing. [Subjects] We recruited 13 patients on prolonged mechanical ventilation, and assessed their upper extremity muscle tone using the modified Ashworth scale (MAS). The subjects were assigned to either the low MAS group ($MAS \leq 2$, n=7) or the high MAS group ($MAS \geq 3$, n=6). [Methods] The manually assisted breathing technique was applied at a pressure of 2 kgf and 4 kgf. A split-plot ANOVA was performed to compare the tidal volume of each pressure during manually assisted breathing between the low and the high MAS groups. [Results] Statistical analysis showed there were main effects of the upper extremity muscle tone and the pressure intensity of the manually assisted breathing technique. There was no interaction between these factors. [Conclusion] Our findings reveal that the tidal volume during the manually assisted breathing technique for patients with prolonged mechanical ventilation depends upon the patient's upper extremity muscle tone and the pressure intensity.

Key words: Manually assisted breathing, Muscle tone, Prolonged mechanical ventilation

(This article was submitted Mar. 23, 2015, and was accepted May 5, 2015)

INTRODUCTION

The number of patients requiring prolonged mechanical ventilation (PMV) has recently increased due to advances in medical technology and the development of medical equipment[1)]. Physical therapy for patients on PMV commonly includes range of motion exercises that aim to prevent joint contracture in the extremities and trunk, activities of daily living (ADL) training that aims to maintain and improve ADL, and pulmonary physical therapy that aims to improve airway clearance using postural drainage, mobilization and manually assisted breathing techniques (MBAT)[2)].

MBAT is primarily performed to improve of ventilation and airway clearance through using manual compression of the rib cage in accordance with the physiological chest movement[3)]. It is one of the most used techniques in clinical situations, and it can be performed for a broad range of patients with pulmonary disease, such as pneumonia, chronic obstructive lung disease and postoperative conditions. It has been recognized that gravity, improvement of air entry into the peripheral airway, and increase of expiratory flow volume are important for the effective clearance of sputum from the peripheral airways to the central airway[3)]. The cough action is also necessary for sputum expectoration to the central airway.

For tracheostomy patients using mechanical ventilation, it is difficult to increase expiratory flow during the cough action because they have difficulty in closing the glottis and increasing the intrapleural pressure. Therefore, the tidal volume (VT) becomes an important factor of airway clearance for them. When the mechanical ventilation is prolonged, respiratory muscle weakness is induced which in turn will results in patients having greater difficulty in increasing VT by themselves. In addition, when PMV patients have disturbance of consciousness, they are unable to increase VT unless the settings of the mechanical ventilator are changed. In contrast, MBAT can be performed to temporarily increase VT without the use of special tools or changes in the ventilator settings. Thus MBAT is an effective and practical pulmonary physical therapy maneuver which can be used

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*Corresponding author. Akira Morino (E-mail: a-morino@chitose-reha.ac.jp) in various clinical situations, such as in the hospital and at home-based.

However, MBAT has been criticized for not being an evidence-based technique. Although it is widely and commonly used in Japan, it is hardly mentioned in the published guidelines for pulmonary rehabilitation[4–6]. Also few studies have examined the technique, and those studies investigated the effects of MBAT on airway-secretion removal in the acute phase[7], effects of MBAT with shaking on VT in patients with central nervous system disease[8], and its efficacy in respiratory conditioning in chronic obstructive pulmonary disease[9]. Moreover, the majority of studies of MBAT did not define the pressure of the compression; therefore, the results of the MBAT may have been affected by the subjective pressure intensity of the therapists.

Some patients with respiratory failure due to hypoxic-ischemic encephalopathy, cerebrovascular disease, or neurodegenerative disease require mechanical ventilation. These diseases often result in changes in muscle tone. Sadamori et al. reported that abnormality of muscle tone affects the response of VT during MBAT in patients with severe motor and intellectual disabilities[10]. Nevertheless, no study has examined whether MBAT improves VT, and whether VT is influenced by the muscle tone of PMV patients.

Therefore, we aimed to evaluate the influence of muscle tone in the upper extremity on the response of VT during MBAT for PMV patients. The muscle tone of the upper extremity is easily assessed in clinical situations. In the present study, MBAT was defined as a maneuver that compresses the rib cage during expiration and releases it just before the initiation of inspiration, and the magnitude of MBAT pressure was quantified.

SUBJECTS AND METHODS

This prospective observational study was approved by the Institutional Review Board of Heiseikai Hospital (approval number: 11H23), and written informed consent was obtained from all of the participants or their legal guardians.

The study was carried out at the Heiseikai Hospital. The subjects were recruited from among those who required tracheostomy for prolonged mechanical ventilation and were receiving rehabilitation. Patients who had hypoxic-ischemic encephalopathy, cerebrovascular disease or neurodegenerative disease, and had been on a mechanical ventilator (Servo s, Fukuda Denshi, Tokyo, Japan) for more than a month were considered eligible for this study. The ventilator was set for synchronized intermittent mandatory ventilation. Exclusion criteria were patient difficulty in synchronizing with the ventilator, rib fracture, presence of a chest tube, hemodynamic instability, or a history of pneumonia in the two weeks prior to the initiation of the study.

To measure the muscle tone in the upper extremity, elbow flexor muscles on the side of greater hypertonicity were assessed using the modified Ashworth scale (MAS)[11]. The patients were assigned to either a low MAS group ($MAS\leq2$) or a high MAS group ($MAS\geq3$).

The position for the MBAT was a 30 degree laterally inclined position which is often used for the prevention of pressure ulcers[12]. The patients were then randomly assigned to either right or left side-lying with a 1:1 allocation. The upper and lower extremities were positioned comfortably in order to avoid increasing the muscle tone during periods of rest. MBAT was applied at pressures of 2 kgf and 4 kgf which were set as light and normal pressures, based upon a previous study[13]. In order to measure pressure intensity, a hand-held dynamometer (HHD; μTas F-1, Anima Corporation, Tokyo, Japan) with a fixing-belt was used; the dimensions of the pressure sensor were 56 millimeters (length) by 56 millimeters (width). MBAT was applied through the HHD. With the subjects lying on their sides, the center of the HHD pressure sensor was placed on the intersection of the seventh intercostal space, halfway between the middle axillary line and the mid-clavicular line on the upmost side. All of the MBAT applications were administered by a single physical therapist, who had 11 years' clinical experience, and was well trained in respiratory rehabilitation. During MBAT, the PT directed the manual pressure in accordance with the respiratory chest movement of the patients, while paying attention to the HHD monitor so as to achieve and maintain the target pressure intensity. The pressure was applied throughout the expiration, and the pressure was released just before the initiation of inspiration. No other maneuvers, such as vibration and/or springing were performed. The reproducibility of the intervention by the PT was confirmed in advance by calculating the intraclass correlation coefficients ($ICC_{(1,1)}$) of VT, which were 0.964 and 0.971 for 2 kgf and 4 kgf manual assistance, respectively.

Each MBAT was initially applied at 2 kgf pressure, allowed for each followed by 4 kgf pressure. Before and after each application, a sufficient stabilization period was set for the patient. After application the patient was allowed to restabilize and then once stabilized a further two minutes of rest was observed before MBAT was applied again.

Upon commencing the measurement, the PT visually confirmed that there was no water in the corrugated tube of the mechanical ventilator, and confirmed that no retention of sputum was present on auscultation. Throughout the maneuver, the PT concentrated on performing the MBAT and did not watch the instantaneous changes shown on the ventilator monitor. Those changes were filmed by a video camera, and reviewed after the application had been completed.

The following information regarding subjects' characteristics and medical conditions was collected from their medical records: age, gender, body weight, the primary disease leading to the use of mechanical ventilator, the duration of mechanical ventilator use, and the presence of pleural effusion. The level of consciousness was assessed using the Glasgow Coma Scale (GCS)[14]. Additionally, the resting chest expansion difference (CED) under the mechanical ventilator was measured at three levels (axially, and at the xiphoid and the tenth rib levels) using a tape measure. The measurement was repeated three times, and the highest value was recorded as the CED.

Ten respiration events were recorded for each condition (at rest, and with 2 kgf and 4 kgf manual assistance), once the pressure maneuver was sufficiently synchronized with the mechanical ventilator. The VT and respiratory rate (RR) were obtained from the average of eight respiration events, after excluding the highest and lowest valued respiration

Table 1. Characteristics of the patients

	Low MAS group (n=7)	High MAS group (n=6)
Age (years)	72.3 ± 16.7	63.3 ± 19.6
Gender (M/F)	2/5	5/1
Body weight (kg)	41.5 ± 7.4	53.9 ± 11.5
Disease (number of patients)	7	6
Hypoxic-ischemic encephalopathy	3	3
Cerebrovascular disease	4	1
Neurodegenerative disease	0	2
Glasgow coma scale §	3.0 (3.0–6.0)	4.0 (3.0–7.0)
MAS in the upper extremity		
0/1/1+/2/3/4 (number of each grade) ***	2/3/0/2/0/0	0/0/0/0/6/0
Duration of ventilator support (days)	585.4 ± 476.5	1216.8 ± 716.5
RR at rest (breath per minute) *	17.3 ± 5.0	10.4 ± 2.1
Settings of ventilator		
PIP (cmH_2O)	13.4 ± 2.5	13.7 ± 2.3
PC (cmH_2O)	8.7 ± 1.9	8.2 ± 1.8
PS (cmH_2O)	7.4 ± 2.5	6.5 ± 3.3
PEEP (cmH_2O)	5.3 ± 0.8	5.5 ± 1.0

§ median (interquartile range), All data show means ± SD, except §.
* $p < 0.05$; *** $p < 0.001$
MAS: modified Ashworth scale; RR: respiratory rate; PIP: peak inspiratory pressure; PC: pressure control; PS: pressure support; PEEP: positive end-expiratory pressure

events.

As associated indicators of mechanical ventilation, the following settings and values were recorded from the ventilator monitor: peak inspiratory pressure (PIP), pressure control (PC), pressure support (PS), positive end-expiratory pressure (PEEP).

Statistical analysis was conducted of the patients' characteristics between the low and high MAS groups using Fisher's exact test, the unpaired t-test, and the Mann-Whitney U test. A split-plot analysis of variance (ANOVA) was used to analyze the data for VT at the different MBAT pressures between the low and high MAS groups. When a main effect was detected by ANOVA, Dunnett's post-hoc test was additionally performed. R2.8.1 was used for the statistical work, and statistical significance was accepted for values of $p < 0.05$ in all analyses.

RESULTS

Table 1 shows the patients' characteristics and medical conditions. Of the 20 subjects, three patients were excluded because they had problems in synchronizing with the mechanical ventilator, two patients were excluded because of hemodynamic instability, one patient was excluded because of the presence of pneumothorax and an inserted thoracostomy tube, and another patient was excluded because of a history of pneumonia in the two weeks prior to the initiation of the study. Therefore, 13 patients were studied. Of those 13 participants, 7 and 6 patients were assigned to the low and the high MAS group, respectively. The primary diseases leading to the patients receiving mechanical ventilation were hypoxic-ischemic encephalopathy for 6 patients, cerebrovascular disease for 5 patients (of those, two had subarachnoid hemorrhage, two had brain-stem hemorrhage, and one had cerebral infarction), and 2 patients had neurodegenerative disease. All patients presented disturbance of consciousness and quadriplegia. In terms of patients characteristics, CED, the duration of mechanical ventilation use, the settings and values of the mechanical ventilator, there were no significant differences between the low and the high MAS groups. The mean value of RR at rest was significantly lower in the high MAS group than that of the low MAS group.

All values of VT with MBAT were measured under pressure support ventilation. The mean values of VT were 286.7 ± 87.4 mL at rest, 338.9 ± 98.7 mL with 2 kgf MBAT, and 383.9 ± 93.9 mL with 4 kgf MBAT in the low MAS group. In the high MAS group, the mean VTs were 417.6 ± 67.6 mL at rest, 468.9 ± 89.7 mL with 2 kgf MBAT, and 540.7 ± 118.7 mL with 4 kgf MBAT.

In the results of the split-plot ANOVA, a main effect was observed between the low and the high MAS groups ($F = 7.43, p = 0.020$) as well as between the applied pressures ($F = 68.86, p < 0.001$). However, no significant interaction was detected between the low and the high MAS groups ($F = 1.32, p = 0.280$). Within both groups, Dunnett's post-hoc test following multiple comparison indicated there was no significant difference between the applied pressure intensities (low MAS group: $p = 0.179$, high MAS group: $p = 0.109$).

DISCUSSION

The present study showed that VT is influenced by muscle tone in the upper extremity. Patients who had higher muscle tone in the elbow flexor muscles had higher values of VT than those with lower muscle tone.

To observe how chest movement influences VT, an assessment of muscle tone in and around the chest wall, e.g. upper trapezius and pectoralis major muscles, should be considered. However, the elbow flexor muscles were assessed in this study, and the reasons were as follows: it is difficult to objectively assess muscle tone in the upper trapezius and pectoralis major muscles in patients with disturbances of consciousness and prolonged mechanical ventilation; it is easier to assess the elbow flexors rather than the aforementioned muscles in daily clinical situations; and there was no objective way to assess chest flexibility and expansibility[15]. In patients with hypoxic-ischemic encephalopathy, cerebrovascular disease or neurodegenerative disease, elbow flexor muscle tone is likely to increase when the muscular tonicity of the pectoralis major is increased. This is because the innervation zone of the shoulder and elbow joints in the cerebral motor cortex are physically adjacent, and the innervated segmental levels of the elbow flexor and pectoralis major muscles partially overlap. The pectoralis major muscle is one of the major inspiratory muscles, and the rib cage is induced at a high inspiratory level when this muscle's tone is increased. Mechanical ventilation was set as pressure-limited in this study, therefore a more greatly expanded rib cage resulted in higher values of VT when the same inspiratory pressure was applied to patients. Given this, increased muscle tone in the elbow flexors i.e. pectoralis major was considered to have induced significantly higher VTs in the high MAS group.

Another main finding of this study was that an increase of MBAT pressure intensity tended to increase in VT. With pressure-limited ventilation, the expiratory volume is controlled by balancing the intrapleural pressure with the alveolar pressure made by the mechanical ventilator. MBAT is a maneuver which encourages the expiration of the air within the alveoli by increasing intrapleural pressure, thus pressuring the alveoli through compression of the rib cage while maintaining PEEP. The finding of increased VT with increased MBAT pressure in the present study was in agreement with the findings of previous studies. Kurita et al. studied central nervous system disease sufferers who were at level V according to the Gross Motor Function Classification System, and reported that MBAT significantly increased VT compared to its value at rest, while MBAT with vibration had no beneficial effect on VT[8]. McCarren et al. reported that administration of MBAT caused an increase in intrapleural pressure, as measured by an oesophageal balloon catheter, and an increase in the expiratory flow rate[16]. Stronger compression of the rib cage induces a higher volume of expiration.

This study had some limitations. First, the sample size was small. With a larger number of subjects, it would be possible carry out subgroup analysis according to the diagnosis or ventilator dependence, therby allowing the elucidation of the interactions between the effects of MBAT and diagnosis or ventilator dependence. Second, the mechanical ventilator should be configured with consideration of the individual's body type, thus predicted body weight calculated using patient's height and gender is generally used for the settings. However, we were unable to calculate the predicted body weight as we were unable to measure the patient's height because the subjects in this study were patients who presented disturbance of consciousness and quadriplegia, and required PMV. While there was no significant difference of the average measured body weights between the groups, more careful consideration of the influences of an individual's body type is needed. Third, this study did not refer to the range of motion of the elbow, because the modified Ashworth scale was performed within the maximum range of joint motion. However, the range of motion might affect the tidal volume. Lastly, we did not consider the pressure-volume curve. Under mechanical ventilation, the VT increase becomes significant when inspiratory pressure exceeds the lower inflection point, and it becomes difficult to increase when inspiratory pressure is over the upper inflection point[17]. This requires further study as it would influence the changes in VT.

In conclusion, our present research examined the changes in VT resulting from changes in MBAT pressure applied to PMV patients. We found that the effects of these changes were governed by differences in muscle tonicity in the upper extremity, and confirmed this by quantifying the MBAT pressure intensity. VT had higher values in the high MAS group at rest, and these higher values of VT continued to be observed during the MBAT application. This study was more objective than previous research because it succeeded in quantifying the magnitude of pressure intensity using an HHD. The HHD is a device which has recently become popular in clinical situations due to the simplicity of its use and its relative cheapness. The results of this study have important clinical implications. In order to administer effective MBAT to patients on PMV, there should not only be a focus on the ventilator settings and the MBAT pressure intensity, but also on the condition of muscle tone in the upper extremity.

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