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Original Article

Comparison of changes in tidal volume associated with expiratory rib cage compression and expiratory abdominal compression in patients on prolonged mechanical ventilation

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Abstract. [Purpose] This study was designed to compare and clarify the relationship between expiratory rib cage compression and expiratory abdominal compression in patients on prolonged mechanical ventilation, with a focus on tidal volume. [Subjects and Methods] The subjects were 18 patients on prolonged mechanical ventilation, who had undergone tracheostomy. Each patient received expiratory rib cage compression and expiratory abdominal compression; the order of implementation was randomized. Subjects were positioned in a 30° lateral recumbent position, and a 2-kgf compression was applied. For expiratory rib cage compression, the rib cage was compressed unilaterally; for expiratory abdominal compression, the area directly above the navel was compressed. Tidal volume values were the actual measured values divided by body weight. [Results] Tidal volume values were as follows: at rest, 7.2 ± 1.7 mL/kg; during expiratory rib cage compression, 8.3 ± 2.1 mL/kg; during expiratory abdominal compression, 9.1 ± 2.2 mL/kg. There was a significant difference between the tidal volume during expiratory abdominal compression and that at rest. The tidal volume in expiratory rib cage compression was strongly correlated with that in expiratory abdominal compression. [Conclusion] These results indicate that expiratory abdominal compression may be an effective alternative to the manual breathing assist procedure.

Key words: Expiratory abdominal compression, Expiratory rib cage compression, Prolonged mechanical ventilation

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INTRODUCTION

Manual breathing assist technique is aimed at increasing tidal volume (VT), decreasing the workload of breathing, and improving airway clearance. In Japan, expiratory rib cage compression (ERCC) is commonly performed[1)]; ERCC involves providing manual rib cage compression during physiological expiration[2)]. ERCC is suitable for use in a range of patient groups, including patients receiving prolonged mechanical ventilation (PMV), and those with acute pneumonia, with postoperative respiratory complications, or chronic obstructive pulmonary disease[3)].

With advances in medical treatments, the number of patients that receive mechanical ventilation is gradually increasing over time. Depending on the medical treatment administered in the acute stage, patients can be removed from mechanical ventilation; however, there are patients who require mechanical ventilation over a month. Such patients frequently experience respiratory muscle weakening and decreased rib cage mobility. Consequently, it can become difficult for patients on PMV to increase their expiratory flow rate and VT, which are important factors in phlegm expulsion. The use of ERCC can increase VT; as such, ERCC is an effective therapeutic technique for patients who cannot have their mechanical ventilator settings changed. However, it is necessary to be mindful of secondary osteoporosis, due to prolonged immobility[4)]. Compression of the rib cage in ERCC can also lead to rib fracture.

Expiratory abdominal compression (EAC) stimulates expiration by the application of abdominal pressure[5)], and is aimed at increasing VT and aiding coughing for mucus clearance[6–8)]. Suitable candidates include patients with muscular dystrophy or amyotrophic lateral sclerosis, as well as postoperative patients. In terms of assisted coughing, the abdomen is pressed forcefully, in synchronization with coughing, as in the Heimlich maneuver[9)]. EAC, which aims at clearing mucus, is performed by gently pressing the abdomen in synchronization with expiration. We consider EAC

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effective in facilitating sputum expectoration in patients at a high risk of rib fracture due to secondary osteoporosis, or in patients who have undergone surgery or sustained trauma, where the application of pressure to the chest wall is difficult. While previous research clearly indicates that EAC increases VT in healthy subjects[5], the strength of manual expiratory compression has never been quantified. To the best of our knowledge, there have been no reports on the use of EAC in patients on PMV.

The present study was conducted to compare EAC with ERCC in patients on PMV, using VT as the primary outcome measure.

SUBJECTS AND METHODS

Subjects were patients at Heiseikai Hospital that had undergone tracheostomy and were receiving artificial ventilation, due to a central nervous system disorder or neurodegenerative disease. All subjects were managed for a minimum of 1 month, using a Servo s ventilator (Fukuda Denshi, Ltd., Tokyo) in synchronized intermittent mandatory ventilation mode. Eighteen subjects participated in the study. Subjects were excluded if synchronizing the mechanical ventilator was problematic; a thoracotomy tube was inserted; pneumothorax or a rib fracture was sustained; pneumonia developed within 2 weeks of the study period; the circulatory dynamics were unstable.

This prospective observational study was conducted according to the principles of the Declaration of Helsinki (1975, revised 1983) and Japanese clinical study ethics guidelines. Informed consent was obtained from the subject, or their legally acceptable representative. This study was approved by the ethics committee of Heiseikai Hospital (No. 11H23).

During the administration of ERCC and EAC, the subject was placed in a 30° lateral recumbent position, a position generally used for preventing bedsores[10]. The order in which ERCC and EAC were implemented was decided using random number tables, and 1:1 randomization. Before the measurements, the absence of water retention in the ventilator breathing tubes, and the absence of sputum retention, was confirmed by visual observation and auscultation.

The compression site chosen for ERCC was the level of the 7th rib, between the midaxillary line and the midclavicular line unilaterally at the anterior aspect; the compression site for EAC was the navel. Compression was applied using a hand-held dynamometer (HHD) (μTasF-1, Anima Corp., Tokyo, Japan). Compression strength was set at 2-kgf, based on the previous literature in which 2-kgf compression was shown to have left no soreness or discomfort in healthy subjects[11]. We applied compression in synchronization with expiration, and released compression immediately before inspiration, while monitoring the HHD monitor screen to ensure that a 2-kgf compression administered. Neither vibration nor springing was employed. According to the HHD, the intraclass correlation coefficients for expiratory compression of the rib cage and the abdomen were 0.964 and 0.987, respectively. Reproducibility was confirmed prior to conducting the experiments.

Data including subject age, gender, and weight, disease leading to the need of mechanical ventilation, and duration of ventilator use, were collected from the subjects' medical records. The level of consciousness of each subject was evaluated using the Glasgow coma scale[12].

The rib cage expansion difference was measured, using a tape measure, at 3 sites: the level of the axilla, the level of the xiphisternum, and the level of the 10th rib. Abdominal expansion difference was measured at the point of maximal abdominal protrusion. Each site was measured 3 times, and the maximum score was used.

VT was measured over 10 breaths in which there were no synchronization issues with the mechanical ventilator at rest. From the 10 breaths, the maximum and minimum values were excluded, and the mean of the 8 remaining breaths was divided by body weight; the resultant value was used as VT. The process was repeated for each of ERCC and EAC. For respiration rate (RR), the mean value displayed on the ventilator monitor screen at the time of the 8 breaths was used. The values for pressure control (PC), pressure support (PS), positive end-expiratory pressure (PEEP), and inspiratory pressure range (PIP − PEEP: ΔP) were taken directly from the mechanical ventilator display screen. We also calculated dynamic pulmonary compliance (Cdyn = VT at rest/ΔP).

One-way analysis of variance was used to assess for differences in VT (at rest, during ERCC, and during EAC). If a significant statistical difference was observed, a multiple comparison with Tukey's post hoc test was performed. VT-related factors during ERCC and EAC were analyzed using the Pearson's product-moment correlation coefficient. Further, we also calculated the regression equation for VT during ERCC and EAC.

Statistical processing was performed using SPSS software version 19 (SPSS Japan Inc., Tokyo, Japan), and the significance level for each analysis was set at 5%.

RESULTS

Table 1 shows the characteristics of the 18 patients. Mean patient age was 69.7 ± 15.9 years, and the mean number of days of ventilator support was 830.4 ± 45.3 days. VT during ERCC and EAC were measured with PS. Table 2 shows the VT and RR at rest, during ERCC and EAC. There was a significant difference in VT at rest and VT during EAC. Table 3 shows the factors related to VT during ERCC and EAC. We also derived the following equation for the difference between VT during ERCC and VT during EAC: VT during EAC = 0.957 × VT during ERCC + 1.106 ($R^2 = 0.843$, $p < 0.001$).

DISCUSSION

In this study, we compared VT in ERCC with VT in EAC, in patients on PMV. We identified a strong relationship between VT during ERCC and VT during EAC. Further, VT increased significantly during EAC, compared with that at rest. This demonstrates that when increasing VT by manual expiratory compression, EAC is useful, and is more effective than ERCC.

McCarren et al. observed an increase in intrathoracic pressure as well as in the amount of ventilation achieved during manual expiratory compression using an esophageal

Table 1. Characteristics of the study subjects

Variable	Values
Age, yrs	69.7 ± 15.9
Gender M/F, N	9/9
Weight, kg	47.6 ± 9.4
BMI, kg/m^2	19.5 ± 3.6
Disease, N (%)	
Hypoxic-ischemic encephalopathy	7 (38.9)
Chronic respiratory failure	4 (22.2)
Cerebrovascular disease	3 (16.7)
Spinal cord injury	2 (11.1)
Neurodegenerative disease	2 (11.1)
Glasgow coma scale score†	4.0 (3.0–6.0)
Rib cage expansion difference, mm	
Axilla	2.4 ± 2.3
Xiphisternum	2.4 ± 1.6
10th rib	3.2 ± 1.7
Abdomen expansion difference, mm	3.0 ± 1.4
Ventilator settings	
PS (cmH_2O)	7.1 ± 2.9
PEEP (cmH_2O)	5.7 ± 1.6
Cdyn	40.7 ± 10.5

Values are expressed as mean ± SD unless otherwise indicated.
†Median (interquartile range)
BMI: body mass index; PS: pressure support; PEEP: positive end-expiratory pressure; Cdyn: dynamic compliance

Table 2. Tidal volume and respiratory rate results according to treatment

Variable	Rest	ERCC	EAC
VT (mL/kg)	7.3 ± 1.7	8.3 ± 2.1	9.1 ± 2.2*
RR (breath per minute)	15.0 ± 6.2	15.4 ± 5.3	15.6 ± 5.6

*$p = 0.027$, compared with VT at rest
VT: tidal volume; RR: respiratory rate; ERCC: expiratory rib cage compression; EAC: expiratory abdominal compression

Table 3. Correlation between variables and tidal volume during expiratory rib cage compression and expiratory abdominal compression

Variables	VT during ERCC	VT during EAC
Age	−0.025	0.003
Rib cage expansion difference (10th rib)	0.384	0.298
Abdomen expansion difference	0.499 *	0.597 **
Days of ventilator support	−0.012	0.082
PS	0.387	0.310
PEEP	0.094	0.188
Cdyn	0.434	0.591 **
VT at rest	0.973 ***	0.949 ***

*$p < 0.05$, **$p < 0.001$, ***$p < 0.0001$
VT: tidal volume; ERCC: expiratory rib cage compression; EAC: expiratory abdominal compression; PS: pressure support; PEEP: peak end-expiratory pressure; Cdyn: dynamic compliance

balloon[13]. ERCC raises the intrathoracic pressure through compression of the rib cage, increasing the expiration level and resulting in a relative increase in inspiration level. Our study included patients on PMV; therefore, most patients had a low level of consciousness, and autonomous movement was difficult. Although the artificial ventilation, known as positive pressure ventilation, spreads to the rib cage in the inspiration level, it does not lead to contraction of the rib cage in the expiration level. Therefore, rib cage mobility probably decreases due to disuse. Moreover, it has been reported that the mobility of the rib cage is reduced by 36.9% in elderly subjects, compared with young subjects[14]. In view of this decreased mobility of the rib cage, we do not consider VT during ERCC to have sufficiently increased. In contrast, with EAC, the rise in intraabdominal pressure from abdominal compression, which is minimally affected by decreased mobility of the rib cage, mobilizes the diaphragm upward[5]. As a result, intrathoracic pressure rises, the expiration level is increased, and there is a relative increase in inspiration volume. This explains the significant increase in VT during EAC.

In the present study, VT during EAC was 9.1 ± 2.2 mL/kg, which is lower than that reported in a previous study by Kaneko et al[5]. Previous reports on ERCC have indicated compression strengths ranging between 1.7-kgf and 5.4-kgf[11]. While the 2-kgf compression strength used during EAC in this study falls within the range used in previous studies. The study by Kaneko et al. did not quantify the compression strength used during EAC; however, between-study differences in compression strengths may influence VT.

Further, the results of the present study clarify the relationship between VT during EAC, and abdominal expansion difference, Cdyn, and VT at rest. In our study, we quantified the compression strength. Allowing the abdomen to move easily may increase the strength of abdominal compression, thus increasing intra-abdominal pressure more efficiently. We therefore believe that we have identified a relationship between differences in abdominal expansion and VT during EAC. It is considered that Cdyn is affected by RR; in our study, we did not observe significant differences between RR at rest, during ERCC, and during EAC. As a result, we consider that Cdyn indicates the ease with which the lungs and rib cage expand. Given that the mechanical ventilator was set to pressure control ventilation, we believe that Cdyn and VT are related.

It is important to note the practical differences between EAC and ERCC. Caution is required while performing EAC, because compressing the abdomen stimulates the vagal reflex, causing reflux of the stomach contents. Although no adverse events were observed in this study, it is necessary to pay attention to vital signs such as blood pressure. Further, the advantages and disadvantages of performing EAC must be reviewed when the subject has a sense of abdominal fullness, for example, immediately after a meal.

The present study has 2 main limitations. First, we did not examine the influence of the indication for PMV. The number of cases requiring PMV is likely to increase in future, and a review according to each illness will be necessary. Second, manual expiratory compression techniques are affected not only by compression strength, but also by body position and the site, direction, and duration of compression. In the present study, patients were examined in only one position. It is necessary to be careful with generalizing our conclusions to all manual expiratory compression techniques. Future studies evaluating patients in different positions are warranted.

The results of the present study demonstrated that EAC is more effective, in terms of VT, than ERCC, in patients on PMV. EAC can be safely used as a method of rehabilitation for patients who are at risk for rib fracture due to osteoporosis, associated with chronic artificial respiration and prolonged immobility.

The present study examined the use of EAC in patients on PMV, with regard to changes in VT. The results clearly demonstrate that the increase in VT during EAC is higher than that during ERCC. This indicates that EAC may be a new manual expiratory compression procedure that can be used as an alternative to ERCC in patients on PMV.

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