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Original Article

Changes in ventilation mechanics during expiratory rib cage compression in healthy males

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Abstract. [Purpose] The purpose of this study was to clarify the differences in ventilation mechanics between quiet breathing and expiratory rib cage compression, and between expiratory rib cage compression on the upper rib cage and on the lower rib cage. [Subjects and Methods] Subjects comprised 6 healthy males. Expiratory rib cage compression was performed manually by compressing the upper and lower rib cages. Changes in the lung volume, flow rate, and esophageal and gastric pressure were examined. [Results] The end expiratory lung volume was significantly lower during expiratory rib cage compression than at rest, but the end inspiratory lung volume was not significantly different. When compared with the esophageal and gastric pressures on the upper and lower rib cages at rest, the gastric pressures were significantly higher at end expiration. Lung resistance was significantly higher during expiratory rib cage compression than at rest. [Conclusion] Although expiratory rib cage compression promoted expiration and increased tidal volume, the lung volume did not increase beyond end inspiratory levels at rest. Lung resistance may increase during expiratory rib cage compression due to a decrease in lung volume. The mechanism by which expiration is promoted differed between the upper and lower rib cages.

Key words: Expiratory rib cage compression, Lung resistance, Lung volume

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INTRODUCTION

Chest physiotherapy is an essential component of the multidisciplinary approach in critical care. In addition to early mobilization[1, 2)] and positioning[3)], some manual techniques, such as expiratory rib cage compression (ERCC) and manual hyperinflation, have been used to help increase the clearance of secretions and re-expansion of atelectatic areas[4)]. However, the available evidence on the efficacy of some of these techniques remains unclear[5–7)]. A systematic review reported limited evidence on the ineffectiveness of ERCC and the possible short-term beneficial effects of manual hyperinflation on respiratory mechanics[8)].

To demonstrate the value of these techniques, standard performance of maneuvers and simultaneous measurement of respiratory system parameters are needed. However, manual chest compression during expiration do not have uniform methods and are called by terminologies, such as ERCC[5, 6)] or vibration[9)]. Moreover, little is known about the changes in ventilation mechanics during performance of these techniques. These are considered to be the reasons for the unclear effects of chest physiotherapy techniques.

ERCC entails manual compression of the rib cage during expiration and releasing the compression at the end of expiration,

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with the objective of mobilizing and removing secretions, facilitating active inspiration, and improving alveolar ventilation5). The rationale of applying compression to the rib cage is to increase intrapleural pressure, which increases expiratory flow rate and leads to mechanical loosening of secretions9). On the other hand, the increase in intrapleural pressure accompanying rib cage compression can induce collapse of the alveoli and airways, which can decrease lung compliance6). The purpose of this study was to clarify that the difference in ventilation mechanics between quiet breathing and ERCC, and between ERCC on the upper rib cage and on the lower rib cage.

SUBJECTS AND METHODS

The study population comprised 6 healthy males without any history of pulmonary or cardiovascular disease. The study subjects had a mean age of 35.6 ± 6.7 years, mean height of 175.8 ± 4.4 cm, and mean body weight of 65.6 ± 6.2 kg. In order to minimize inter-therapist variability, ERCC was performed by the same physiotherapist who was 31 years old (height 180.0 cm, body weight 91.0 kg) and had 9 years of chest physical therapy experience. Prior to participation in the study, written informed consent was obtained from all subjects. The study was approved by the ethics committee of Hyogo College of Medicine (approval number: 2691).

ERCC was performed with the subjects kept in supine position and the operator standing on the left side of the subject. After quiet breathing for 1 minute (rest), ERCC was performed in random order to the upper rib cage (U-ERCC) and to the lower rib cage (L-ERCC) for 2 minutes each (Fig. 1). During the performance of ERCC, both hands of the operator were positioned on the upper rib cage (U-ERCC) and on the lower rib cage (L-ERCC) of the subject. The compression forces to the rib cage were applied during every breath, but only during expiration. The maneuver rate was synchronized with the respiratory rate of the subject3).

Lung volume (V) and flow rate ($\dot{V}$) was measured using a hot wire flow meter (Minato Medical Science Co., Ltd., Osaka, Japan) that was connected to a mouthpiece. Esophageal pressure (Pes), which reflects intrapleural pressure, and gastric pressure (Pga), which reflects abdominal pressure, were measured using the esophageal and gastric balloon catheter methods, respectively10). A 2-mm polyethylene tube catheter was fitted into a balloon that measured 100 mm long and 12 mm in diameter (Fig. 2) before connecting to a pressure transducer (Chest MI Inc., Tokyo, Japan). The balloon was filled with air, 0.2 ml for Pes and 2 ml for Pga, in order to minimize the effects of balloon volume. Correct positioning of the esophageal balloon was confirmed by observing constant fluctuation of the Pes at negative pressure during inspiration in the sitting position and no change in the transpulmonary pressure (Ptp) during airway occlusion. Further, the balloon position was adjusted to maintain Pes at approximately −5 cmH_2O at end expiratory lung volume (EELV) in the sitting position. Correct positioning of the gastric balloon was confirmed by observing constant fluctuation of the Pga at positive pressure during breathing. The pressure in the mouthpiece, which reflected airway opening pressure (Pao), was measured and Ptp was calculated from the following equation:

$$\text{Ptp}=\text{Pao}-\text{Pes}$$

Lung volume, $\dot{V}$, and pressure signal were converted from analog to digital at a sampling frequency of 100 Hz with the use of the ML880PowerLab16/30 (AD Instruments, Dunedin, New Zealand) and were analyzed using Labchart8 (AD Instruments). All subjects performed the inspiratory capacity maneuver at the start and end of each measurement to correct for possible drift caused by mechanical error11). The last 5 breaths were analyzed breath-by-breath in each subject in order to calculate the following parameters: mean tidal volume (VT), respiratory rate (RR), end inspiratory lung volume (EILV), EELV, end inspiratory Ptp (EI-Ptp), end expiratory Ptp (EE-Ptp), end inspiratory Pes (EI-Pes), end expiratory Pes (EE-Pes), end inspiratory Pga (EI-Pga), and end expiratory Pga (EE-Pga). EILV and EELV were normalized according to the vital capacity of each subject. Dynamic lung compliance (Cdyn) was obtained from the following the equation:

$$\text{Cdyn}=\text{VT}/(\text{EI-Ptp}-\text{EE-Ptp})$$

Lung resistance (RL) was calculated during rest and ERCC by measuring the changes in Ptp (ΔPtp), $\dot{V}$ and lung volume. RL was determined by multivariate regression using a simple linear equation of motion12), as follows:

$$\Delta\text{Ptp}=\text{RL}\bullet\dot{V}+\text{V}/\text{Cdyn}$$

The quality of fit of the measured data with the equation of motion was assessed by examining the statistical variable r^2. Expiratory resistance was much greater than the inspiratory resistance, and the quality of fit of the data to the linear model was low; therefore, only resistance during inspiration was considered12). The goodness of fit among subjects was defined as having an r^2 value of >0.8.

For statistical analysis, the differences in each value between rest and both types of ERCC were tested using repeated-measures analysis of variance using the IBM SPSS Statistics 20 software package. A risk function value of <5% was set as the level of significance.

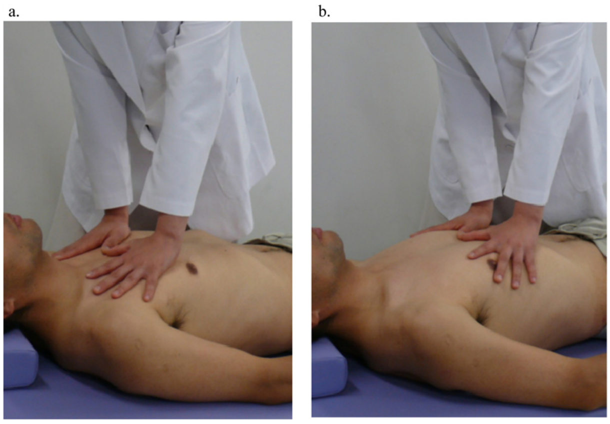

Fig. 1. Application of manual expiratory rib cage compression to the upper rib cage (U-ERCC) (a) and lower rib cage (L-ERCC) (b).
During the performance of ERCC, both hands of the operator were positioned on the upper rib cage (U-ERCC) and on the lower rib cage (L-ERCC) of the subject.

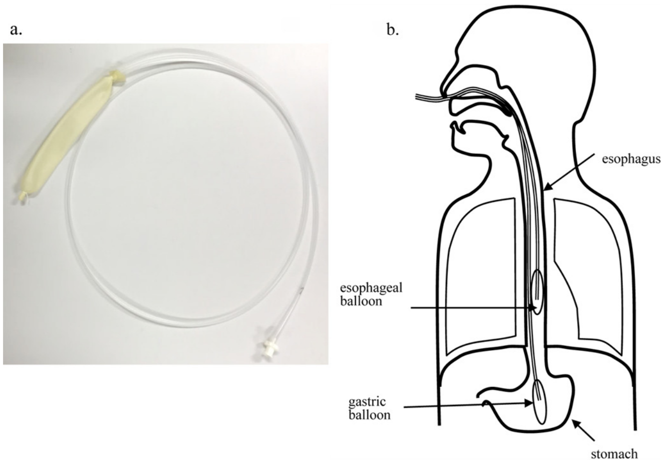

Fig. 2. The esophageal gastric balloon catheter method.
a: balloon catheter, b: esophageal gastric balloon catheter method.

RESULTS

As shown in Table 1, compared with the rest period, the U-ERCC and L-ERCC had significantly higher VT ($p<0.01$), significantly lower RR and EELV ($p<0.01$), similar EILV, significantly lower EE-Ptp ($p<0.01$), and significantly higher EE-Pes and EE-Pga ($p<0.01$). The EE-Pga was significantly higher during L-ERCC than during U-ERCC ($p<0.01$). The EI-Ptp, EI-Pes, and EI-Pga were not significantly different between ERCC and rest. As shown in Table 2, RL was significantly higher during U-ERCC and L-ERCC than at rest ($p<0.01$), but there was no significant difference in Cdyn between ERCC and rest.

DISCUSSION

This study demonstrated that compared with breathing at rest, breathing during ERCC changed to a deep and slower pattern, with doubling of the VT. However, EILV and EI-Ptp did not increase during ERCC, and the increase in VT was caused by a decrease in EELV. These results implied that although ERCC promoted expiration and increased VT, it did not increase the lung volume beyond end inspiratory levels at rest in healthy subjects.

RL is the sum of airway resistance and lung tissue viscous resistance. In healthy subjects, Airway resistance accounts for 80% of RL13). Airway resistance is affected by several factors, such as length and diameter of the airways and the nature of gas; among them, airway diameter has the strongest effect, based on Poiseu’s law. Therefore, RL is mainly affected by

Table 1. Changes in breathing pattern, lung volumes, and pressure parameters during expiratory rib cage compression (N=6).

	Rest	U-ERCC	L-ERCC
VT (l)	0.49 ± 0.10	0.96 ± 0.12**	1.03 ± 0.20**
RR (beats/min)	16.3 ± 3.1	7.8 ± 1.8**	8.1 ± 2.7**
EILV (%)	35.7 ± 7.3	28.9 ± 6.9	33.8 ± 5.1
EELV (%)	28.0 ± 7.0	6.5 ± 5.0**	9.9 ± 4.5**
EI-Ptp (cmH_2O)	1.28 ± 1.54	0.53 ± 2.69	1.00 ± 2.74
EE-Ptp (cmH_2O)	−1.02 ± 2.25	−5.48 ± 4.48**	−5.44 ± 4.12**
EI-Pes (cmH_2O)	−1.25 ± 1.61	−0.44 ± 2.78	−0.91 ± 2.83
EE-Pes (cmH_2O)	1.04 ± 2.30	5.55 ± 4.57**	5.54 ± 4.15**
EI-Pga (cmH_2O)	6.71 ± 0.98	5.53 ± 2.00	6.12 ± 1.73
EE-Pga (cmH_2O)	3.09 ± 1.63	9.47 ± 3.48**	19.5 ± 3.53**##

Values are presented as mean ± SE. **$p<0.01$ vs. rest; $^{\#\#}p<0.01$ vs. U-ERCC.
U-ERCC: expiratory rib cage compression to the upper rib cage; L-ERCC: expiratory rib cage compression to the lower rib cage; VT: tidal volume; RR: respiratory rate; EILV: end inspiratory lung volume; EELV: end expiratory lung volume; EI-Ptp: end inspiratory transpulmonary pressure; EE-Ptp: end expiratory transpulmonary pressure; EI-Pes: end inspiratory esophageal pressure; EE-Pes: end expiratory esophageal pressure; EI-Pga: end inspiratory gastric pressure; EE-Pga: end expiratory gastric pressure.

Table 2. Changes in lung mechanics during expiratory rib cage compression (N=6)

	Rest	U-ERCC	L-ERCC
Cdyn (ml/cmH_2O)	242 ± 78	205 ± 71	221 ± 77
RL ($cmH_2O/l/S$)	1.43 ± 0.29	3.01 ± 1.01**	2.57 ± 0.86**

Values are presented as mean ± SE. **$p<0.01$ vs. rest.
U-ERCC: expiratory rib cage compression to the upper rib cage; L-ERCC: expiratory rib cage compression to the lower rib cage; Cdyn: dynamic lung compliance; RL: lung resistance.

changes in the airway diameter. An increase in lung volume expands the diameter of the airways, which results to a decrease in airway resistance[14] that is brought about by the radial traction on the airways during elastic recoil of the lung. In this study, EELV was lower and RL was higher at L-ERCC and U-ERCC than at rest. These results suggested that the increase in RL was secondary to the reduction in airway diameter caused by a decrease in lung volume during ERCC.

It has been suggested that although ERCC increased intrapleural pressure during expiration and increased expiratory flow, the rise in intrapleural pressure during ERCC may induce collapse of the alveoli and airways[6, 15]. Guimarães[6] observed limitation in expiratory flow during ERCC in mechanically ventilated patients. Collapse of the alveoli and airways will decrease pulmonary compliance and increase airway resistance. Our data showed that EE-Pes and RL significantly increased during ERCC compared with the values at rest, suggesting the possibility of alveoli and airway collapse during ERCC. On the other hand, studies have shown that clearance of secretions and lung compliance were better when lung hyperinflation was combined with ERCC[7, 16] than when ERCC was performed alone in patients on mechanical ventilation[5, 6]. Hyperinflation of the lung is a method of expanding the lung by applying high positive pressure for a short time. This may be achieved through modification of the ventilator settings or ventilator disconnection and use of a manual resuscitation bag. Therefore, lung hyperinflation may prevent lung volume decrease, which is a disadvantage of ERCC. It is necessary to combine ERCC with methods of lung expansion, such as positioning and hyperinflation.

In this study, EE-Pga was higher in L-ERCC than in U-ERCC, but no differences were found in the other parameters between L-ERCC and U-ERCC. Since the upper rib cage covers the pleural cavity, the compressive force during U-ERCC directly increased intrapleural pressure and decreased EELV. On the other hand, since the lower rib cage covers the abdominal cavity, the compressive force increased abdominal pressure during L-ERCC; therefore, upward movement of the diaphragm due to elevation of the abdominal pressure indirectly increased intrapleural pressure and decreased EELV during L-ERCC. These results indicated that the mechanism by which expiration is promoted was different between U-ERCC and L-ERCC.

A limitation of the present study was that measurements were only performed in the supine position, which has a lower functional residual capacity than other positions, such as the side-lying and sitting position. Therefore, compared with other positions, there is a possibility that RL tends to increase during ERCC in the supine position. In a future study, it will be necessary to clarify the changes in ventilation mechanics when ERCC is performed in other positions with different lung volumes, and when lung hyperinflation was combined with ERCC.

In conclusion, this study clarified the changes in ventilation mechanics during expiratory rib cage compression. Although ERCC promoted expiration, it did not increase the lung volume beyond EILV levels at rest in healthy subjects. The increase in RL was secondary to the reduction in airway diameter caused by a decrease in EELV during ERCC. The compressive force during U-ERCC directly increased intrapleural pressure and decreased EELV. The compressive force increased abdominal pressure during L-ERCC; therefore, indirectly increased intrapleural pressure and decreased EELV during L-ERCC.

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Conflict of interest

The authors have no conflicts of interest to declare.

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