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Original Article

Effects of postural differences on intrapleural pressure during chest wall compression in healthy males

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Abstract. [Purpose] This study aimed to investigate the difference in intrapleural pressure between the supine and lateral decubitus positions during manual chest wall compression. [Participants and Methods] Eight healthy males participated in this study. The same physiotherapist performed chest wall compression on participants lying supine, and on their right and left sides. We noted changes in intrapleural pressure and lung volume in each participant during quiet breathing and chest wall compression. [Results] During chest wall compression, intrapleural pressure at the end-expiratory lung volume and the end-inspiratory lung volume were lower in the right and left decubitus positions than in the supine position. We observed the following low inflection points in the pressure-volume loops during chest wall compression: all participants in the supine position, no participants in the right decubitus position, and two participants in the left decubitus position. [Conclusion] Chest wall compression in the bilateral decubitus positions may not cause excessive intrapleural pressure on the airway and alveoli as compared to chest wall compression in the supine position.
Key words: Chest wall compression, Pressure-volume loops, Low inflection points

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INTRODUCTION

Manual chest wall compression (CWC) is a form of pulmonary rehabilitation that promotes deep expiration by compressing the chest wall manually, and it can increase the inspiratory volume. Several studies have shown that CWC increased expiratory flow rates, improved removal of airway secretions, and improved gas exchange and pulmonary mechanics[1–5]. However, there is a remarkable increase in the intrapleural pressure during CWC[6], as a result, this may increase the risk of airway and alveolar collapse[3]. Furthermore, CWC could threaten the protective strategy of the lung for acute respiratory distress (ARDS)/acute lung injury (ALI). It would be desirable to have possibilities to repeat the airway and alveolar collapse during expiration, and airway opening during inspiration, because CWC decreases end-expiratory lung volume to approximately residual volume; this induces atelectrauma, and this may have adverse effects on pulmonary protection of ARDS/ALI.

Furthermore, the increase in sudden inspiratory flow rate by CWC may result in barotrauma of the lung due to the exces-

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sive increase in transpulmonary pressure (Ptp). Several studies have reported that Ptp, indicating the stress caused to the lung and the change of the lung shape caused by the strain are important[5, 7]. Therefore, it is necessary to confirm the character of ventilator mechanics by the CWC to verify adaptation and important aspects of CWC. Also, CWC is carried out with various postures in response to a site of ventilator impairment of the lung. There have been no reports on the effects of differences in posture during CWC on intrapleural pressure (Ppl).

This study aimed to investigate the difference in intrapleural pressure between the supine and bilateral decubitus positions during CWC. We hypothesized that Ppl at the end expiration during CWC in the supine position is higher than Ppl in the decubitus positions.

PARTICIPANTS AND METHODS

The study population comprised 7 healthy males (mean age, 27.3 ± 2.0 years; height, 176.6 ± 6.5 cm; and body weight, 62.7 ± 6.4 kg) without any history of pulmonary or cardiovascular disease. To minimize inter-therapist variability, CWC was performed by the same physiotherapist with 8 years of experience in chest physical therapy. Prior to participating in the study, all participants submitted written informed consents. The study was approved by the ethics committee of Konan Women's University (approval number: 2011210). CWC was performed on participants lying in in supine position and in the right and left decubitus positions. After quiet breathing (QB) for 1 minute, CWC was performed randomly on participants in the supine position, on their right decubitus position, and their left decubitus position for 2 minutes each. During CWC, the physical therapist placed both hands on the upper rib cage of the patient when they were in the supine position and on the lower rib cage of the patients when they were in the right and left decubitus positions (Fig. 1). CWC was started from the initiation to the end of expiration. The highest tolerable level of force was applied to the participants' chest wall and then released as soon as the participants began inspiration. The maneuver rate was synchronized with the respiratory rate of the participants.

Inspiratory capacity maneuver was performed on all participants at the beginning and end during QB and CWC to correct the volume measuring errors ("drift")[8].

Airflow rates and lung volume changes during QB and CWC were measured using hot wire spirometer attached to a face mask (AE300-s, Minato Medical Science, Tokyo, Japan); flow signal was integrated to determine volume. Esophageal pressure was measured as a representative of intrapleural pressure using an esophageal balloon catheter (latex balloon; 12 cm-long, polypropylene tube; 1.5 mm-internal diameter, 100 cm-long) and differential pressure transducer (Chest Inc., Tokyo, Japan). Esophageal balloon catheters were passed through the nose till the depth of balloons reached the esophagus. All air was removed from the balloon by having participants perform a Valsalva maneuver. The balloon was then inflated with approximately 0.2–0.5 mL of air such that the intrapleural pressure was approximately −5cmH_2O at the end of tidal expiration. Slight adjustments were made to the position of the catheter to minimize artifacts due to cardiac oscillations.

The lung volume and intrapleural pressure were examined using an analyzing system (PowerLab, ADInstruments, Dunedin, New Zealand). All data were sampled at 100 Hz. The last three breaths during QB and CWC were analyzed, and the mean values for tidal volume (TV), end-inspiratory lung volume (EILV), and end-expiratory lung volume (EELV) from the lung volume change were obtained for each participant. EILV and EELV were normalized according to the vital capacity of each participant. From intrapleural pressure change, the mean value for intrapleural pressure at EILV (EIPpl) and that for intrapleural pressure at EELV (EEPpl) were obtained for each participant.

We studied the pressure-volume loops (P-V loop) from the last three breaths during CWC (Fig. 2). P-V loops were

a. b. c.

Fig. 1. Application of chest wall compressions by a physiotherapist.
a: supine position, b: right decubitus position, c: left decubitus position

represented with intrapleural pressure on the X-axis and lung volume on the Y-axis. As to P-V loop analysis during CWC, we judged the presence or absence of low inflection points (LIP) visually. LIP was the point to corresponding to an upward shift in the slope of the inspiratory curve, which indicates an increase in lung compliance.

For statistical analysis, the differences in each value between the three positions were using repeated-measures analysis of variance. The statistical analysis was carried out using SPSS 15.0 for Windows using that 5% level of significance.

RESULTS

Table 1 shows lung volume and Ppl during QB and CWC. QB in the bilateral decubitus position had significantly higher EILV and EELV and lower EIPpl and EEPpl, as compared with QB in the supine position ($p<0.05$). CWC in the bilateral decubitus position had significantly higher EELV and lower EEPpl, as compared with that in the supine position ($p<0.05$).

Figure 3 shows P-V loops during CWC of each participant. All participants had LIP in the supine position, whereas no subject had LIP on the right decubitus position; however, two participants had LIP in the left decubitus position.

DISCUSSION

Different postures did not have a significant effect on the TV, but EILV and EELV in the bilateral decubitus position were lesser than that in the supine position. Behrakis et al.[9] proposed that expiratory reserve decreases in the supine position as compared with the decubitus position. In the supine position, the airway is easily obstructed because of a decrease in the lung compliance during the compression of the lung through the diaphragm, and FRC and closing capacity approach the same value[9, 10]. On the contrary, the lung volume during the decubitus position increases because of the decrease in the FRC of the lower lung similar to that during the supine position. However, there is an increase in the FRC of the upper lung is as compared with that in the supine position[11]. Therefore, this study suggested that the lung volume of QB in the decubitus position was higher than that in the supine position. Also, this study suggested that the intrapleural pressure at both EELV and

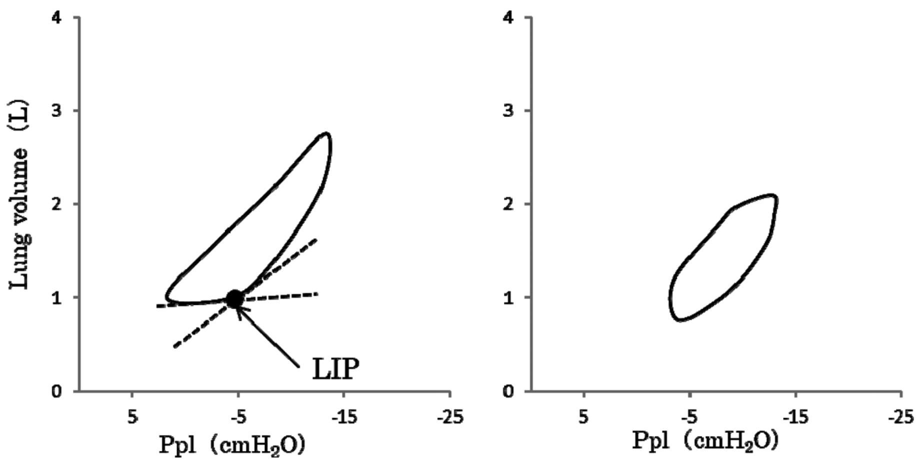

Fig. 2. Analysis methods of Pressure-volume loop (P-V loop) during CWC.
Left: P-V loop had LIP during inspiratory curve, Right: P-V loop had no LIP.
Ppl: intrapleural pressure; LIP: low inflection point.

Table 1. Lung volume, Ppl during QB and CWC (N=7)

	Supine position		Right decubitus position		Left decubitus position	
	QB	CWC	QB	CWC	QB	CWC
TV (L)	0.56 ± 0.18	1.58 ± 0.62	0.51 ± 0.12	1.24 ± 0.31	0.53 ± 0.16	1.17 ± 0.36
EILV (%)	40.1 ± 8.4	44.1 ± 12.1	50.3 ± 8.5*	51.4 ± 9.2	52.3 ± 8.0*	48.7 ± 6.5
EELV (%)	30.1 ± 8.1	14.2 ± 7.4	40.1 ± 9.4*	27.4 ± 9.6†	42.6 ± 7.7*	26.6 ± 5.1†
EIPpl (cmH_2O)	0.06 ± 2.83	−0.22 ± 1.93	−5.53 ± 1.96*	−6.35 ± 2.26†	−6.75 ± 1.98*	−8.01 ± 3.14†
EEPpl (cmH_2O)	2.10 ± 2.14	8.96 ± 4.38	−3.37 ± 2.56*	−0.58 ± 3.16†	−5.04 ± 2.19*	−2.76 ± 2.61†

Value are presented as mean ± SD. *$p<0.05$ vs. QB in the supine position, †$p<0.05$ vs. CWC in the supine positon.
Ppl: intrapleural pressure; TV: tidal volume; EILV: end inpiratory lung volume; EELV: end expiratory lung volume; EIPpl: intrapleural pressure at end inpiratory lung volume; EEPpl: intrapleural pressure at end expiratory lung volume.

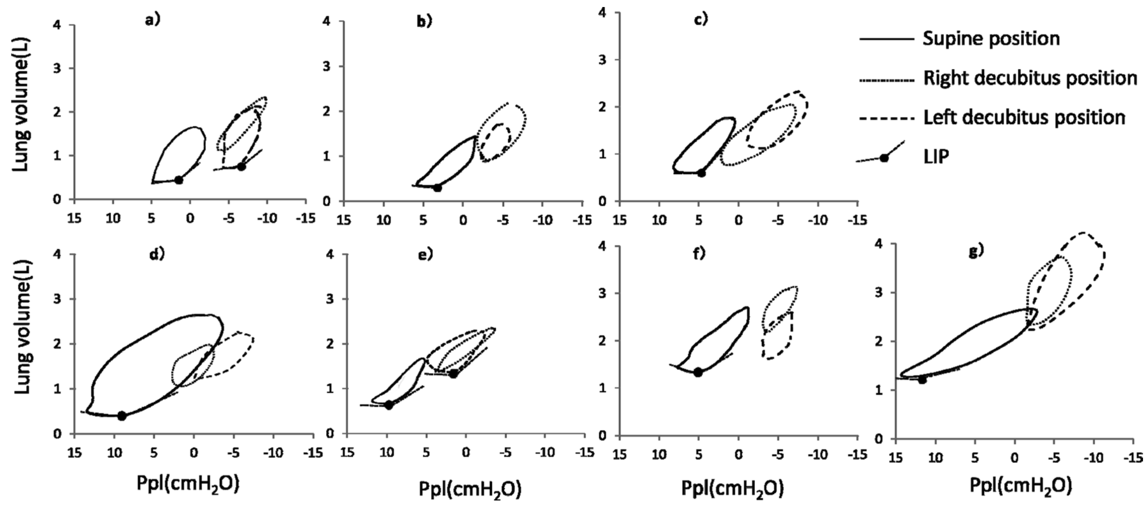

Fig. 3. Pressure-volume loops during CWC, a–g): pressure-volume loops during CWC of each participants.
All participants: LIP occurs during CWC in the supine position, a, e): LIP occurs during CWC in the left decubitus position.
Ppl: intrapleural pressure; LIP; low inflection point.

EILV during CWC was lower at the decubitus position than at the supine position. Therefore, CWC in the decubitus position keeps the intrapleural pressure at EELV negative and does not cause airway and alveolar collapse.

LIP is created at the beginning of the inspiration of P-V loops of ARDS with an increasing point of sudden compliance by collapsed alveolar expansion[12]. Also, because LIP suggests collapsed alveolar presence[13], it is recommended that the level of positive end-expiratory pressure is set just above the LIP in ARDS/ALI. This study showed that all participants had LIP during CWC in the supine position, but only two participants had LIP during CWC in the decubitus position. The intrapleural pressure may become the positive pressure in the end-tidal position during QB in the supine position, as mentioned above. The abdominal organs pressed the thoracic cavity through the diaphragm in the supine position, and this was thought to become the positive pressure; therefore, it was suggested that air vesicle collapse might occur due to pressing of the chest during CWC and adding more positive pressure to the situation in thoracic cavity. LIP was difficult to produce during CWC in decubitus position, keeping negative pressure of the intrapleural pressure at EELV and making it difficult for airway and alveolar collapse to occur.

The limitations of this study are that healthy males were used. In patients with ARDS/ALI, there is a decrease in the lung compliance as compared with a healthy individual. Therefore, it is necessary to examine the effect of CWC in these patients in the future.

In conclusion, this study clarified the effects of postural differences on intrapleural pressure during CWC in healthy males. Because LIP during CWC in the bilateral position was less than CWC in supine position, the decubitus positions may not cause excessive Ppl on the airway and alveolus compared with the supine position.

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Conflict of interest

The authors have no conflicts of interest directly relevant to the content of this article.

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