Using Chest Vibration Nursing Intervention to Improve Expectoration of Airway Secretions and Prevent Lung Collapse in Ventilated ICU Patients: A Randomized Controlled Trial

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Background: Almost 80% of patients in the intensive care unit are intubated and on mechanical ventilation. Thus, their airway clearance ability is compromised and their risk of lung collapse increased. A variety of interventions are used to enhance airway clearance with the goal of preventing atelectasis and infection. The purpose of this study was to evaluate the effect of a chest vibration nursing intervention on the expectoration of airway secretions and in preventing lung collapse among ventilated critically ill patients.

Methods: This was a randomized, single-blind experimental study. A total of 95 patients were enrolled from 2 ICUs and randomly assigned into either the experimental group ($n = 50$) or control group ($n = 45$). Patients in the control group received routine positioning care, which consisted of a change in body position every 2 hours. Patients in the experimental group received routine positioning care plus the use of chest vibration nursing intervention for 72 hours. This intervention consisted of placing a mechanical chest wall vibration pad on the patient's back for 60 minutes when the patient was in a supine position. The chest vibration intervention was performed 6 times a day. Outcome variables were dry sputum weight (DSW) per 24 hours and lung collapse index (LCI); these were measured at 24, 48 and 72 hours.

Results: Patients who received the chest vibration nursing intervention had greater DSW and lower LCI after 24 hours. Pre-test DSW and group could explain 48.2% of the variance in DSW at 24 hours. The LCI at 24, 48 and 72 hours were all significantly improved in the intervention group compared to the control group. The previous LCI measured was the most significant predictor of the next LCI measured. A significant difference was found between the control and experimental groups in their 24-, 48- and 72-hour DSW and LCI after vibration, when monitored by the generalized estimating equation in time sequence.

Conclusion: The results suggest that chest vibration may contribute to expectoration and thus improve lung collapse among ventilated patients in an ICU. Chest vibration nursing intervention is a safe and effective alternative pulmonary clearance method and can be used on patients who are on ventilators in ICUs. [*J Chin Med Assoc* 2009;72(6):316–322]

Key Words: airway clearance, chest vibration, critical care, dry sputum weight, lung collapse index

Introduction

Almost 80% of patients in intensive care units are intubated and on mechanical ventilation, and thus have difficulty in keeping their airway clear. As a result, they face a very high risk of lung collapse complicated by pneumonia because they cannot cough effectively.[1,2] The literature shows that the incidence of lung collapse in ventilated patients can reach 23–30% for those who have undergone upper abdominal operation, 74% for those with acute spinal damage, 85% for those with neuromuscular morbidities, and up to 90% after cardiovascular operation.[3–5] Lung collapse, if untreated, may progress to respiratory failure or acute

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respiratory distress syndrome, which would prolong ventilator use and increase mortality to 33% or 71%.[6,7]

A systematic review of nonpharmacologic protussive therapies found that a combination of more than 1 chest physiotherapy procedure may help to reinflate the collapsed lobe of a lung.[8] Many studies have suggested that postural drainage combined with chest percussion, as well as lung hyperinflation plus suction, are the best ways to quickly solve lung lobe atelectasis.[9,10] However, a head-down leg-elevated position is harmful to the vital signs of unstable patients, and is therefore not recommended for the critically ill.[11] The manual performance of chest wall percussion or the use of a hand-driven chest vibrator is labor-intensive and highly operator-dependent, with its efficacy being quite variable. Auto percussion or auto vibration (1,000–1,200 cycles/min), which can be quantified and timed, is more objective and should provide more reliable data.[12,13] Some studies have shown that high-frequency chest compression leads to more mucus clearance and better lung function compared with conventional chest physiotherapy.[8,14]

The purpose of this study was to test the effectiveness of a mechanical chest vibration pad linked with repositioning every 2 hours when used on mechanically-ventilated critically ill patients with the aim of improving pulmonary secretion clearance and preventing lung collapse.

Methods

This was a randomized, single-blind experimental study. Between April and July 2007, patients were enrolled from 2 ICUs, 1 medical and surgical ICU and 1 neurologic ICU, in a medical center in Taipei. The inclusion criteria were age between 20 and 85 years, expected use of a ventilator for > 3 days, APACHE-II (Acute Physiology and Chronic Health Evaluation, version II) score of 15–40, ability to communicate in Mandarin or Taiwanese, and willingness to participate in the study. Exclusion criteria included skin damage to an area of the back, any tendency towards acute bleeding, presence of a chest drainage tube, fractured ribs or percutaneous emphysema, spinal surgery, unstable intracranial pressure and patients who signed the "do not resuscitate" instruction. Simple randomization was performed using a table of random numbers, and eligible patients were randomly assigned into either a control or an experimental study group. The institutional review board approved the study protocol and informed consent was obtained from all participants.

Patients in the control group received routine positioning care, which included a change of position every 2 hours by the ICU nurses. The position turning sequence was left lateral, supine, right lateral and supine. Patients in the experimental group received routine positioning care plus mechanical chest vibration over 72 hours. The chest vibration nursing intervention included placing a mechanical chest wall vibration pad on the patient's back for 60 minutes when the patient was turned into the supine position. The chest vibration intervention was performed 6 times a day, every 4 hours over the 72 hours. The vibration pad was placed from shoulder to sacrum. The mechanical chest wall vibration used was a Niagara vibrator type H.U.75, frequency 70 Hz, 1,000–1,200 cycles/min. The vibration wave was generated from the pad (40 × 60 cm) in spiral, vertical and horizontal directions. The patients lay on the pad with a blanket covering them. The vibrator was turned on and took just over half a second to reach the maximum frequency and range of vibration.

During vibration therapy, hemodynamic status and vital signs were closely monitored, and if heart beat fluctuated > 20 bpm, blood pressure fluctuated > 20 mmHg, respiration rate fluctuated > 10 bpm, or oxygen saturation dropped to lower than 95%, vibration would be stopped immediately and the study process for that patient ended. However, none of the participants experienced any of the above episodes in this study.

The mechanical ventilator settings for both groups were adjusted by certified respiratory therapists in compliance with the prescription. Tidal volume was set based on the patient's weight (10 mL/kg). The system was in the pressure control mode, with a pressure level of 20–25 cmH_2O, and a plus positive end expiration pressure of 10–15 cmH_2O as the plateau pressure for inspiration was set < 35 cmH_2O. Every ventilator was equipped with heated-wire humidifier, with the temperature set at 37°C and the moisture at 100%. The respiratory therapist checked the ventilator's temperature and moisture every 8 hours. ICU nurses assessed the patient's breath sounds and suctioned out any secretion as needed.

Demographic and clinical data were collected on enrolment and included sex, age, diagnosis on admission, medical history, number of days intubated before enrolment, and APACHE II score. Before the experimental interventions started, the outcome variables, 24-hour dry sputum weight (DSW)[15,16] and lung collapse index (LCI),[17] were evaluated. They were also measured at 24, 48 and 72 hours after the study intervention began.

Twenty-four-hour DSW was calculated from the 24-hour sputum collection,[15,16] which had been dried using a heater set at 80°C for another 24 hours.

Table 1. Demographic and baseline characteristics of the 95 study participants*

	Control group ($n=45$)	Experimental group ($n=50$)	χ^2	p
Male	30 (66.7)	39 (78.0)	1.53	0.22
Diagnosis				
Sepsis	16 (35.6)	20 (40.0)	0.19	0.65
Respiratory failure	16 (35.6)	19 (38.0)	0.06	0.80
Surgery	18 (40.0)	11 (22.0)	3.61	0.06
Past history				
CVA	9 (20.0)	17 (34.0)	0.23	0.13
COPD	7 (15.6)	8 (16.0)	0.00	0.95
			t test	p
Age (yr)	66.8 ± 19.8	73 ± 15.6	−1.84	0.07
PaO_2/FiO_2 ratio	265 ± 205.4	337.9 ± 164.9	−7.22	0.09
APACHE II	25.4 ± 6.6	23.1 ± 7.2	1.47	0.14
Days in hospital	16.6 ± 23.2	11.5 ± 10.4	1.39	0.17
DSW (mg/24 hr)	5.42 ± 3.98	5.74 ± 6.23	−0.31	0.76
LCI	2.09 ± 0.79	2.26 ± 0.63	−1.15	0.25

**Data presented as n (%) or mean ± standard deviation. CVA = cerebrovascular accident; COPD = chronic obstructive pulmonary disease; APACHE II = Acute Physiology and Chronic Health Evaluation version II; DSW = dry sputum weight; LCI = lung collapse index.*

Clinically, the nurse suctioned the sputum into a suction bottle, and every morning, at 7 a.m., the investigator weighed the bottle, stirred it evenly, and drew out 10 mL, which was sent to the laboratory for dry weight analysis. The weight of the dried sputum was then multiplied to give the 24-hour amount. LCI was evaluated by 1 respiratory physician and 1 nurse practitioner independently using a 4-point scale (0 = normal expansion, 1 = single lobe collapsed, 2 = 2 lobes collapsed, 3 = multiple lobes collapsed)[17] and based on changes in routine chest X-ray and the patients' clinical presentation every morning. If there was disagreement between the 2 LCI readings, a face-to-face discussion was held by the physician and the nurse practitioner to achieve consensus.

SPSS version 17.0 (SPSS Inc., Chicago, IL, USA) was used for data analysis. Univariate and multivariate analyses were used to compare the variables between the 2 groups. Multivariate longitudinal regression analyses were performed using the generalized estimating equation (GEE). Continuous variables were compared using Student's test for normally distributed variables. The χ^2 test was used to compare categorical variables. Statistical significance was considered at a p value ≤ 0.05 for all comparisons.

Results

In total, 95 patients participated in the study, including 45 in the control and 50 in the experimental group; 87 were in the general surgical-medical ICU, and 8 were in the neurologic ICU. Table 1 presents the demographic and baseline characteristics of the participants, which had no significant differences between the 2 groups.

In the experimental group, the DSW over the first 24 hours after intervention was significantly increased compared to that of the control group (Table 2). The mean DSW of the experimental group was also greater than that of the control group at 48 and 72 hours, but the difference did not reach statistical significance. An intragroup comparison across the experimental group showed that the best result for sputum excretion was 24 hours after the chest vibration intervention, which was significantly more than the pre-test average of 5.74 ± 6.22 mg. The LCI in the experimental group was significantly improved compared to that of the control group at 48 and 72 hours (Table 2). The intragroup comparison also showed that the LCI in the experimental group was significantly improved after intervention while that of the control group showed no significant differences at the 3 time points.

In addition, analyses of the repeated relationships were performed by GEE. The DSW of the experimental group, monitored by GEE in the time sequence, yielded a β value of significance of 5.419 ($p = 0.000$). At 24 hours after chest vibration in the control and experimental groups, the predictive value for pre-test DSW was 2.985 ± 0.854, which was statistically significant ($p = 0.000$). At 48 hours, the value

Table 2. Changes in dry sputum weight (DSW) and lung collapse index (LCI)*

	Control group ($n = 45$)	Experimental group ($n = 50$)	*t* test	*p*
DSW (mg/24 hr)				
24 hr	5.39 ± 4.39	8.70 ± 6.48	–2.94	0.004
48 hr	4.09 ± 2.96	4.65 ± 3.44	–0.86	0.392
72 hr	3.56 ± 3.10	4.04 ± 3.43	–0.72	0.471
LCI				
24 hr	1.78 ± 0.82	1.52 ± 0.65	1.69	0.096
48 hr	1.56 ± 0.89	1.18 ± 0.72	2.24	0.028
72 hr	1.60 ± 0.91	0.96 ± 0.73	3.75	0.000

**Data presented as mean ± standard deviation.*

Table 3. Changes in dry sputum weight with chest vibration, monitored by generalized estimating equation ($n = 95$)

	β	Standard error	*p*
Group			
Control *vs.* experimental	5.419	0.586	0.000
Time sequence			
24 hr post-test *vs.* pre-test	–1.864	0.594	0.957
48 hr post-test *vs.* pre-test	–1.331	0.594	0.025
72 hr post-test *vs.* pre-test	–0.032	0.647	0.004
Groups in time sequence (experimental *vs.* control)			
24 hr post-test *vs.* pre-test	2.985	0.845	0.000
48 hr post-test *vs.* pre-test	0.241	0.999	0.809
72 hr post-test *vs.* pre-test	0.159	1.008	0.875

was 0.241 ± 0.999, which was not statistically significant ($p = 0.809$). At 72 hours, the value was 0.159 ± 1.008, which was also not statistically significant ($p = 0.875$) (Table 3, Figure 1).

The results of chest vibration, as evaluated by LCI and monitored by GEE in time sequence, showed an average β value of 2.089 ($p = 0.000$). At 24 hours after chest vibration in the control and experimental groups, the predictive value for pre-test X-ray status was –0.429 ± 0.161 ($p = 0.008$). At 48 hours, the predictive value was –0.547 ± 0.188 ($p = 0.004$), while at 72 hours, the value was –0.811 ± 0.211 ($p = 0.000$) (Table 4, Figure 2).

Stepwise regressions were performed by stratifying patients based on their characteristics, and grouping categories in order to find predictors for DSW and LCI at 24, 48 and 72 hours. Firstly, the results showed that the previous DSW measured was the most significant predictor of the next DSW measured and explained 39.6%, 19.1% and 48.4% of the variance in DSW at 24, 48 and 72 hours, respectively (Table 5). Secondly, grouping was a significant predictor of DSW

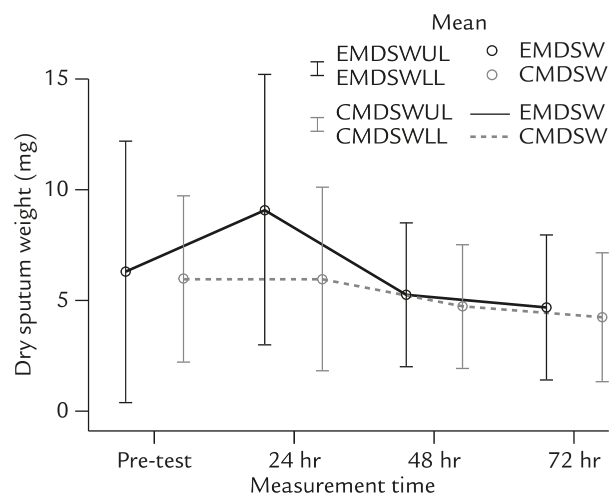

Figure 1. Changes at pre-test, and 24, 48 and 72 hours for dry sputum weight (DSW) across the 2 groups. EMDSWUL = experimental group mean DSW upper limit; EMDSW = experimental group mean DSW; EMDSWLL = experimental group mean DSW lower limit; CMDSWUL = control group mean DSW upper limit; CMDSW = control group mean DSW; CMDSWLL = control group mean DSW lower limit.

Table 4. Changes in lung collapse index with chest vibration, monitored by generalized estimating equation ($n = 95$)

	β	Standard error	*p*
Group			
Control *vs.* experimental	2.089	0.117	0.000
Time sequence			
24 hr post-test *vs.* pre-test	–0.311	0.129	0.016
48 hr post-test *vs.* pre-test	–0.533	0.143	0.000
72 hr post-test *vs.* pre-test	–0.489	0.153	0.001
Groups in time sequence (experimental *vs.* control)			
24 hr post-test *vs.* pre-test	–0.429	0.161	0.008
48 hr post-test *vs.* pre-test	–0.547	0.188	0.004
72 hr post-test *vs.* pre-test	–0.811	0.211	0.000

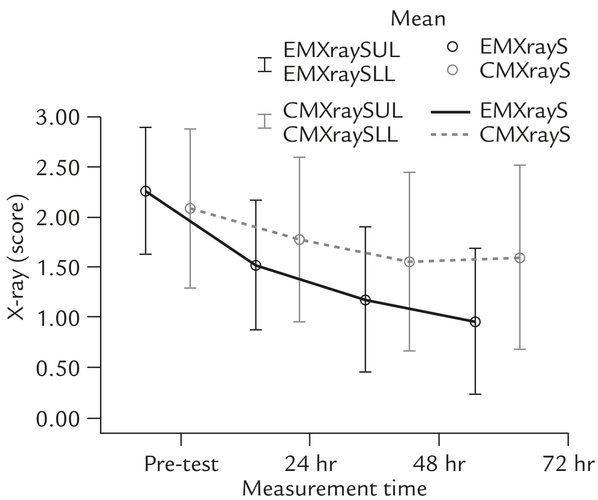

Figure 2. Changes at pre-test, and 24, 48 and 72 hours for X-ray lung collapse index (LCI) across the 2 groups. EMXraySUL = experimental group mean X-ray score upper limit; EMXrayS = experimental group mean X-ray score; EMXraySLL = experimental group mean X-ray score lower limit; CMXraySUL = control group mean X-ray score upper limit; CMXrayS = control group mean X-ray score; CMXraySLL = control group mean X-ray score lower limit.

Table 5. Stepwise regression analysis for prediction of dry sputum weight at the 3 time points after chest vibration nursing intervention ($n = 95$)

	R^2	β	F	p
At 24 hr			34.864	< 0.001
Pre-test DSW	0.396	0.640		
Group classification	0.482	–2.93		
At 48 hr			9.993	< 0.001
DSW at 24 hr	0.191	0.426		
History of surgery	0.245	0.232		
History of COPD	0.288	–0.208		
At 72 hr			42.291	< 0.001
DSW at 48 hr	0.484	0.728		
Pre-test status of LCI	0.530	–0.216		

DSW = dry sputum weight; COPD = chronic obstructive pulmonary disease; LCI = lung collapse index.

at 24 hours. Thirdly, the patient's surgical history and chronic obstructive pulmonary disease (COPD) were significant predictors of DSW at 48 hours. Finally, it was found that pre-test LCI was a significant predictor of DSW at 72 hours.

The previous LCI measured was the most significant predictor of the next LCI measured and explained 11.5%, 59% and 45% of the variance in LCI at 24, 48 and 72 hours, respectively. Group was a significant predictor for LCI at 24 and 72 hours. DSW at 24 hours

Table 6. Stepwise regression analysis for prediction of lung collapse index at the 3 time points after chest vibration nursing intervention ($n = 95$)

	R^2	β	F	p
At 24 hr			8.124	< 0.000
Pre-test LCI	0.115	0.354		
Grouping classification	0.178	0.252		
At 48 hr			45.256	< 0.000
LCI at 24 hr	0.587	0.723		
DSW at 24 hr	0.623	–0.205		
CV history	0.647	–0.155		
At 72 hr			40.766	< 0.000
LCI at 48 hr	0.450	0.604		
Grouping classification	0.521	0.274		

LCI = lung collapse index; DSW = dry sputum weight; CV = cardiovascular.

and cardiovascular history were significant predictors explaining the variance in LCI at 48 hours (Table 6).

Discussion

The performance of effective and safe pulmonary nursing care always poses a challenge for nurses taking care of ventilated ICU patients in light of their critically ill condition. Since manual percussion is no longer used to help excrete sputum, the present study was conducted to provide empirical support for the effectiveness of vibration in preventing lung collapse. The results showed that for ventilated ICU patients, routine positioning care combined with 60 minutes of chest-wall deep vibration performed every 4 hours by auto vibrator at 1,000–1,200 cycles/min when patients were in supine position, plus suction if necessary, was able to achieve a significant difference in 24-hour DSW compared with a control group that received routine care only. The LCI in the experimental group also improved significantly at 48 and 72 hours compared to that in the control group. Our results are consistent with those of previous studies.[1,2,5,18,19]

A significant difference was found between the control and experimental groups at 24, 48 and 72 hours with regard to DSW after vibration, as monitored by GEE in time sequence. The predictive value for pre-test DSW was statistically significant at 24 hours after chest vibration started, but not at 48 and 72 hours. Thus, there was a significantly greater expectoration effect at 24 hours after auto chest vibration in the ventilated patients. At 48 and 72 hours, there was a continuing but only limited increase in excretion compared to the control group; however, this did not reach statistical significance.

A significant difference was also found between the control and experimental groups for LCI at 24, 48 and 72 hours after chest vibration, when monitored by GEE in time sequence. The statuses of lung collapse at the 3 time points were all able to predict pre-test LCI. We believe that chest vibration made a significant improvement to the rate of lung collapse at 24 hours for the ventilated patients with sputum retained in their airway because of the increase in sputum secretion. Later, at 48 and 72 hours, since there was no continuing increase in sputum secretion, the improvement at 24 hours remained significantly different relative to the pre-test state of lung collapse.

In the regression analysis, pre-test DSW and grouping classification were the 2 significant predictors of 24-hour DSW. This result supports the idea that chest physiotherapy can have an immediate effect on the first day. In addition, the predictive factors of DSW at 48 hours included DSW at 24 hours, the postoperative status of the patient and COPD history. In other words, the DSW at 48 hours seemed to be affected by the amount of sputum excreted the day before, whether the patient had been operated on, and whether the patient had a history of COPD. The 2 most important predictors of DSW at 72 hours were the DSW at 48 hours and pre-test LCI (when patients were enrolled into the study). In summary, whether monitored at 24, 48 or 72 hours, the DSW of that day was always an important predictor of the following day's DSW. In addition, the DSW at 48 and 72 hours were affected by a previous history of pulmonary disease and pre-test lung collapse condition. Thus, it is clear that chest physiotherapy needs to be performed when patients have pulmonary morbidities or have had serious lung collapse.

When monitoring LCI at 24, 48 and 72 hours, we found that the predictive factors for lung collapse at 24 hours included the pre-test status and grouping classification. This finding confirms the idea that there is an immediate effect of chest vibration on the first day of treatment. The predictive factors of LCI at 48 hours included the LCI and DSW at 24 hours, and history of cerebrovascular accident. The predictive factors of LCI at 72 hours included lung collapse status at 48 hours and grouping classification. These results indicate that, whatever the time point, the LCI of that day was always a predictor of the following day's LCI. In addition, LCI at either 24 or 72 hours was also related to chest vibration, which again confirms the effectiveness of chest vibration in these circumstances, especially for patients with serious chest morbidities or lung collapse.

The chest vibration nursing intervention in this study was designed to be simple and easily carried out by the nurses who would perform these procedures. This is different from the study of Templeton and Palazzo, who applied very complicated chest physiotherapy to their critically-ill ventilated patients, which included inflating the lung manually, vibration, suction in a sitting position, inspiration and muscle movement, postural drainage and ventilated suction.[7] Such an approach places an extremely heavy burden on the patients and nurses. In contrast, our intervention created no extra burden on either the patients or nurses. Our study showed that chest vibration nursing intervention is able to reduce lung collapse among critically-ill and mechanically-ventilated patients and does this quickly within 24 hours; furthermore, patients' condition continues to improve with intervention up to 72 hours.

The present study shows that there is an obvious effect of the intervention when it is used on ventilated adult patients. Although intragroup matching was performed between the experimental and control groups of patients with cerebrovascular accident and COPD history, regression analysis found that these patients required a specific type of chest physiotherapy that fits their unique needs; this is because it is necessary to consider their overall poorer ability to excrete sputum and inflate their lungs.

One limitation of this study is that the study participants were from 2 units in 1 hospital, which limits the generalizability of the study to other types of units and healthcare sectors in Taiwan. Nevertheless, this study shows that chest vibration nursing intervention is a safe and effective alternative method of pulmonary clearance and can be used on patients who are on ventilators in an ICU. The present study established a standardized chest vibration nursing intervention based on a literature review and clinical observation. The study results confirm the feasibility of this approach in an ICU setting. The addition of this intervention to conventional positioning care appears to be better in preventing lung collapse than conventional positioning care alone. Thus, positioning care with the use of auto vibration performed every 4 hours is an effective intervention.

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