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Original Article

Lung Volume Recruitment Technique Promotes Cough Augmentation in Patients with Acquired Ineffective Coughing Post-Extubating from Mechanical Ventilation: A Randomized Trial

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Abstract:
Background Ineffective coughing commonly occurs post-extubating from mechanical ventilation. **Methods**: In total, 50 patients from both sexes aged 40–60 years who were extubated from mechanical ventilation after ≥ 48 hours were randomly assigned to two equal groups [n = 25]. The experimental group [A] received the lung volume recruitment technique, whereas the control group [B] received routine chest physiotherapy only. The programme was applied for [30 to 45] minutes per treatment session, two times a day for four consecutive days. The dependent variables, namely, peak expiratory flow rate, cough peak flow rate, and oxygen saturation were assessed at the beginning and ending of this trial while the extubating success rate was evaluated at the end of this study. **Results** Parametric tests were administered for pairwise comparisons of the study variables within and between groups. The pairwise within both groups [A] and [B] analysis showed a significant difference between pre- and post-treatment values. The pairwise between the two groups' analysis revealed no significant difference at pretreatment; however, there was a significant difference at post-treatment in all dependent variables in favor of group [A]. Also, the chi-square analysis showed a significant difference of extubating success rate in favor of group [A]. **Conclusions** Lung volume recruitment was an effective technique for cough augmentation in critically ill patients who were extubated from mechanical ventilation with ineffective coughing. **Trail registration:** NCT05128552

Keywords Lung volume recruitment technique, Cough augmentation, Cough peak flow, Mechanical ventilation.

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1. Introduction

A prevalent consequence of critical illness [26–65 %], intensive care unit-acquired weakness [ICUAW] impairs the muscles of respiration and extremities, which contributes to weaning failure [1]. It has been proven that mechanical ventilation featuring high positive pressure delivery decreases lung compliance. As a consequence, the lungs' expandability decreases, and they become more inflexible and stiffer. As a result, the cough becomes less effective since it takes more effort to breathe during expiration to force air out of the lungs [2].

People who are critically ill and have a history of neuromuscular disorders typically demonstrate inadequate peak cough flows, which hinders their coughing ability [3]. The combined impacts of sedation, along with a patient's diminished cooperation or effort due to delirium or cognitive impairment, are prevalent among patients with critical illness [4, 5] and are additional causes of ineffective coughs [6]. Additionally, endotracheal intubation or glottic muscle weakness prevents the closure of the glottis, which is necessary for an effective cough. Ineffective coughing causes secretion pooling, atelectasis, and respiratory tract infections, all of which might make it difficult to wean the patient off the ventilator resulting in weaning failure and might need reintubation [6-8].

Techniques that either encourage coughing or substitute it are recommended when a patient does not have the ability to cough properly in order to enhance inspiratory capacity or to move the secretions to the spot where they may be expelled by the patient or by physical methods [9-11]. The most beneficial way to guard against respiratory tract infections is to cough effectively. The importance of a proper cough mechanism becomes evident due to the high incidence of respiratory problems. Among patients with weakened respiratory muscles unable to cough efficiently, respiratory problems stand as the primary leading cause for hospital admission [12, 13].

Weaning and extubation failure may be caused by a variety of factors, even though inefficient coughing and secretion retention can be major contributors [14]. Lung volume recruitment, also referred to as breath stacking or air stacking, encompasses manual assisted coughing as well as mechanically assisted coughing through the use of a mechanical insufflation-exsufflation [MI-E] device. They are all examples of cough augmentation approaches [15]. Acute respiratory failure patients who are hospitalized may benefit from the application of cough augmentation methods, which have been used substantially for both preventing and treating respiratory issues linked to chronic illnesses, notably neuromuscular disease [16].

Lung volume recruitment [LVR] is employed as a supportive rehabilitation strategy for patients with respiratory muscular weakness [RMW] to passively increase lung volume, enhance cough mechanism effectiveness, and reduce the risk of pulmonary complications. [17-20]. LVR causes the lungs to expand to a capacity greater than is possible during spontaneous breathing by delivering positive inspiratory mouth pressure. Maximum expired flow rises with increasing lung capacities due to an increase in the static recoil pressure of the lung [21]. According to studies, LVR enhances cough peak flow [CPF] by assisting the expiration immediately following the inflation [22] and promoting unassisted CPF thereafter [23].

The purpose of this study was to implement the lung volume recruitment technique as an effective chest physiotherapy method in critically ill patients who had been extubated from mechanical ventilation. The successful completion of weaning is promoted by this cough-augmented method, which also helps to avoid tracheostomy and reintubation [3, 7, 9, 24, 25]. Extubation failure must be avoided since it increases the time a patient spends on mechanical ventilation, lengthens their stay in the intensive care unit and hospital, and increases their risk of death and nosocomial pneumonia [26, 27].

2. Materials and Methods

All patients provided written informed consent to participate in the study and for the publication of the results. Ethical approval was taken from the Institutional Review Board of the Faculty of Physical Therapy, Cairo University [NO: P.T.REC/012/003098]

2.1. Participants:

This research was conducted at selected intensive care units at Kasr Al-Ainy Hospital, Cairo University, Giza, Egypt on critically ill patients who were extubated from mechanical ventilation in the period between December 2020 and October 2021. All the patients admitted to the intensive care unit due to critical illness and extubated from mechanical ventilation after ≥ 48 hours throughout the study period were eligible to participate in this study if they met the inclusion criteria. The study was conducted on 50 patients from both sexes who were randomized into experimental [A] and control [B] groups; both groups had an equal number of patients [n = 25]. Measurements were taken at two time periods: before and after the four-day duration of the study. All patients were given similar medical and traditional chest physiotherapy programs during their hospital stay period.

2.2. Selection criteria:

The inclusion criteria of this study involved patients aged between 40 and 60 years, both sexes, and who were mechanically ventilated in a controlled mode for ≥ 48 hours and less than 21 days due to critical illness caused by moderate to severe pneumonia. They were weaned following a successful trial of spontaneous breathing. Also, they had ineffective cough mechanism assessed by measuring cough peak flow [CPF < 270 L/min]. They could assume sitting upright position either actively or with assistance. Also, they were conscious, cooperative and had the ability to follow instructions throughout the testing and treatment processes, as well as adhering to treatment protocols. The exclusion criteria included patients who were unable to communicate due to disturbed level of consciousness, and visual, and auditory disorders; patients who had undergone tracheotomy before extubation; pulmonary embolism, active hemoptysis; past medical history of lung injury, pneumothorax, barotrauma, emphysematous bullae of the lung, or recent lobectomy; bronchial asthma, bronchospasm, and uncontrolled severe chronic obstructive pulmonary disease [COPD]; additional underlying health conditions that may impede the successful weaning from mechanical ventilation as fluctuating hemodynamics, cardiac arrhythmias, congestive heart failure, or pericardial effusion; and neuromuscular disorders that hindered the implementation of routine chest physical therapy interventions, including myopathy or neuropathy.

2.3. Outcome measures

2.3.1. Primary outcome measures

2.3.1.1. Peak expiratory flow and Cough peak flow rates measurement:

The Mini-Wright peak flowmeter device was used to assess the peak expiratory flow and cough peak flow rates. For peak expiratory flow rate measurement, each patient assumed a relaxed comfortable high lying supine at 45º body inclination or sitting positions. The patient was directed to take the deepest breath possible and then exhale forcefully with an open glottis through a mask attached to the Mini-Wright peak flowmeter. For cough peak flow rate measurement, each patient assumed the same position mentioned before. Similarly, the patient was directed to take the deepest breath possible and then cough as forcefully as possible with a closed glottis through an oronasal mask attached to the Mini-Wright peak flowmeter. The mask was securely sealed onto the patient's face to reduce leakage of the air. Each procedure was repeated a minimum of three times. The measurements were recorded using the displaced marker on the gradient peak flowmeter. The obtained results, measured in liters per minute, consisted of the highest of the three readings for both peak expiratory flow [PEF] and peak cough flow [CPF] rates. A ten-minute break was provided between the assessment of PEF and CPF rates for each patient [28].

2.3.1.2. Oxygen saturation measurement:

The pulse oximeter device was employed to quantify the percentage of blood oxygen saturation. Each patient assumed a relaxed comfortable sitting position. The pulse oximeter probe was connected to the patient's thumb or index fingers while the percentage of oxygen saturation was recorded at the beside bed monitoring screen. The computer within the monitor connected with the pulse oximeter had the capability to differentiate pulsating blood flow from other relatively static signals, thereby presenting only the arterial blood flow [29].

2.3.2. Secondary outcome measures

2.3.2.1. Extubation success rate assessment

The extubation success rate was determined by calculating the ratio of patients who neither died nor required reintubation within 48 hours following scheduled extubation and commenced their interventions to the total number of patients in the study. Requiring reintubation within 48 hours of extubation was regarded as an instance of extubation failure.

2.4. Intervention

2.4.1. Lung volume recruitment [air stacking] technique

The lung volume recruitment technique was administered to every patient in the experimental group through the use of a resuscitation or manual hyperinflation bag modified with a one-way valve to aid in gas retention into both lungs [15]. Each patient assumed a relaxed comfortable high lying supine with a 45-degree inclination or in a seated position. Both nose and mouth were sealed tightly using the oronasal mask to prevent possible air leaks, and then the ambo bag was gently squeezed with coordinating the patient's inspiration at the time of its application.

The bag was compressed two to four consecutive times, each time to about one-third of its capacity, while maintaining a low inspiratory flow. This was followed by an inspiratory pause to achieve maximal lung inflation capacity before quickly releasing the bag to produce a high expiratory flow. If the patient was able to perform this maneuver, he/she was instructed to hold the maximum inflation up to three to five seconds. Once the patient's lungs were fully inflated, or he/she signaled by hands to indicate that maximum inflation capacity had been fulfilled, or the patient experienced a stretch sensation over the chest to its limit with slight discomfort, the mask was taken off, and the patient was instructed to perform a forceful cough. These technique prescriptions were a set of two to four breaths for three to five sets with an in-between rest time of 30 seconds to one minute, two sessions daily, for four consecutive days. The total session time duration was 30-45 minutes including the added routine chest physical therapy programme.

3.Data analysis

3.1 Calculation of sample size

The number of patients was calculated using G*Power [version 3.1.9.4]. t-test was used in this study. Type I error was 5% [alpha level: 0.05], and type II error was at 80% power. The effect size of the main dependent variable [Cough peak flow] was 0.79. This number was calculated from the pilot study on patients with ineffective cough. The minimum number for this analysis was 42 patients.

3.2 Assessment of eligibility

A total of 55 patients, including both sexes, were enrolled in this study. Following the eligibility assessment, five patients were excluded because two patients refused to participate in the study and three patients had post intubation infection complications. In all, 50 patients from both sexes were randomly assigned via the sealed envelopes into two groups of equal size [25 in each group] [**Figure 1**].

3.3 Statistical Analysis Methods:

The data were subjected to the normality test [Shapiro–Wilk test] by statistical SPSS Package program version 25 for Windows [SPSS, Inc., Chicago, IL]. The dataset included age, gender, duration of intubation, CPF rate, PEF rate, oxygen saturation, and success rate of extubation. The data exhibited a normal distribution, and parametric analysis was performed. An independent [unpaired] t-test was employed to compare the age and duration of intubation variables between group [A] and group [B] while, the Chi-square test [$\chi 2$-test] was utilized to compare gender and extubation success variables between the two groups. Multivariate analysis of variance test was employed to compare the major variables of interest across various groups and measurement periods. The dependent variables of the study considered were cough peak flow, peak expiratory flow, and oxygen saturation. The Bonferroni correction test, employed as post hoc analyses, was utilized to compare pairwise differences within and between groups of the tested variables that exhibited significant F-values from the multivariate analysis of variance test. The level of significance was controlled at 0.05 [$P < 0.05$].

4. Results

4.1 Physical characteristics of patients:

The unpaired t-test and Chi-square test revealed no significant difference between the two groups regarding age, intubation period, and gender distribution respectively [$p > 0.05$] **Table [1].**

Quantitative data such as age and period of intubation are presented as mean ± standard deviation and compared using an independent t-test. Qualitative data like gender are presented as numbers [percentage] and compared using the chi-square test. The p-value represents the probability value. The p-values were non-significant [$P > 0.05$].

4.2 Within-group analysis

Pairwise comparison tests [Post hoc test] indicated a significant difference between pre- and posttreatment values of both groups [A] and [B] for CPF, PEF, and oxygen saturation variables as p-value < 0.05 **[Table 2].**

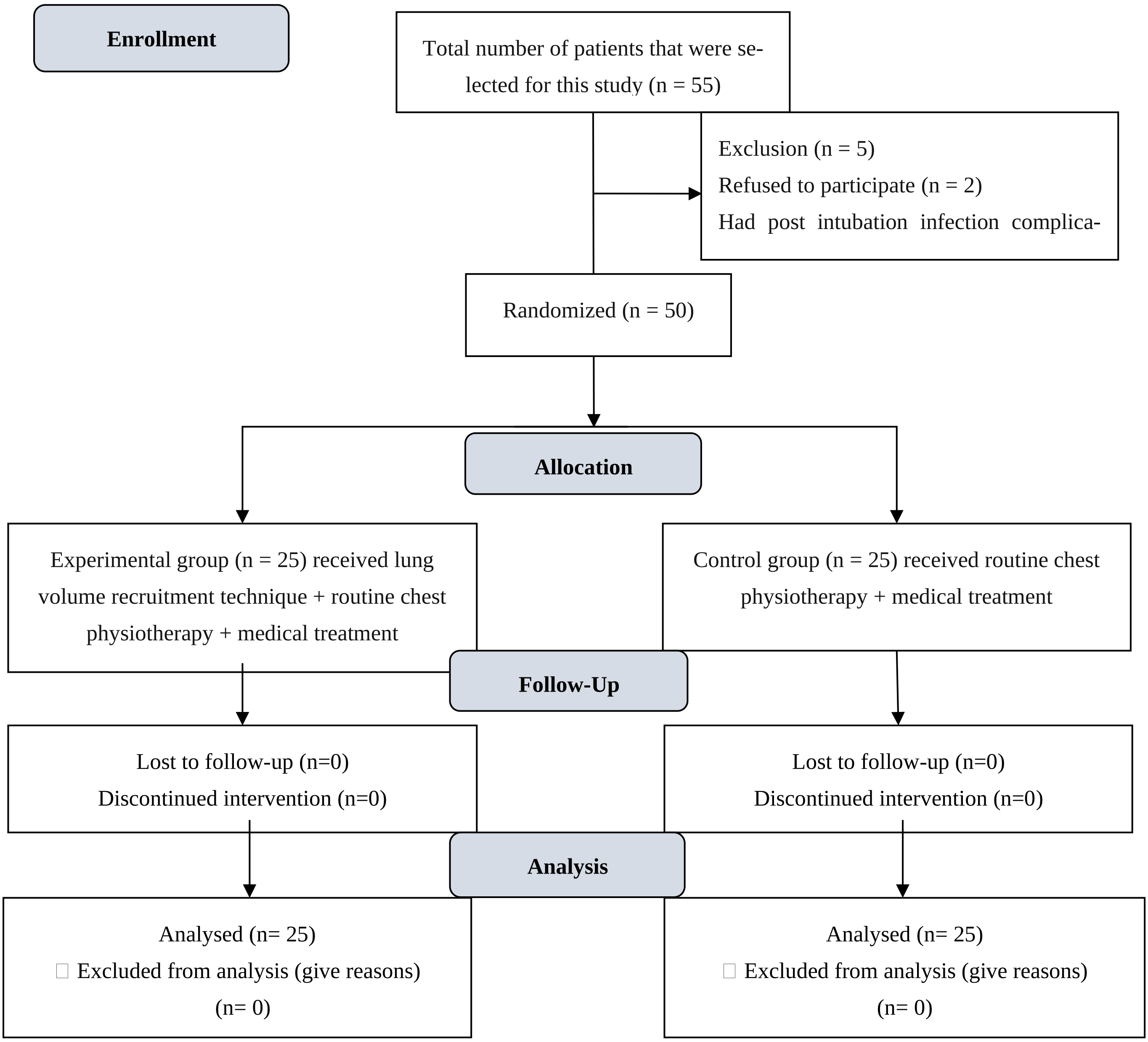

Figure (1): Study flow chart.

Table (1): Demographic data of patients in both groups:

Items	**Groups**		**P-value**
	Group (A) (n=25)	Group (B) (n=25)	
Age (year)	54.88 ±4.72	53.64 ±5.05	0.375
Gender (males: females)	15 (60%): 10 (40%)	15 (60%): 10 (40%)	1.000
Period of intubation (Days)	7.20 ±1.22	7.24 ±1.26	0.910

4.3 Between groups analysis

The Pairwise comparison tests [Post hoc test] indicated that there was no significant difference between pretreatment values for CPF, PEF, and oxygen saturation variables of both groups [A] and [B] as p-value > 0.05, but there was a significant difference between posttreatment values for such variables as p-value < 0.05 [**Table 2].**

Extubation success rate:

Chi square tests indicated a significant difference in extubation success rates between group [A] and group [B] [p > 0.05] **Table [3].**

Table (2): Mixed MANOVA test within and between group comparison for outcomes variables

Outcomes variables	Items	Groups (Mean ±SD)		*P*-value*
		Study group (n=25)	Control group (n=25)	
CPF	Before-treatment	179.40 ±17.03	176.40 ±15.78	0.572
	After-treatment	272.20 ±24.92	202.40 ±15.35	0.0001*
	Mean Difference	92.80	26.00	
	Improvement %	51.73%	14.74%	
	95% CI	82.31 – 103.28	15.51 – 36.48	
	P-value	0.0001*	0.0001*	
PEF	Before-treatment	160.20 ±20.23	155.00 ±13.46	0.354
	After-treatment	252.00 ±27.68	179.40 ±14.23	0.0001*
	Mean Difference	91.80	24.40	
	Improvement %	57.30%	15.74%	
	95% CI	80.71 – 102.88	13.31 – 35.48	
	P-value	0.0001*	0.0001*	
Oxygen saturation	Before-treatment	95.28 ±0.61	95.48 ±0.82	0.329
	After-treatment	99.20 ±0.76	97.12 ±0.66	0.0001*
	Mean difference	3.92	1.64	
	Improvement %	4.11%	1.72%	
	95% CI	3.51 – 4.32	1.23 – 2.04	
	P-value	0.0001*	0.0001*	

* Data are expressed as mean ± standard deviation (SD) CI: confidence interval P-value: probability value * Significant (P<0.05).

Table (3): Comparison of extubation's success distribution between both groups

Items	Groups		P-value *
	Study group (n=25)	Control group (n=25)	
Extubation (successful: failed)	23 (92%): 2 (8%)	18 (72%): 7 (28%)	0.046*

* Data are expressed as number (percentage), P-value: probability value, * Significant (P<0.05)

5. Discussion

Critically ill patients receiving mechanical ventilation through endotracheal intubation or tracheostomy may have compromised airway clearance during intubation and after extubation owing to ineffective coughing, respiratory muscle weakness, or paralysis brought on by intensive care unit-acquired weakness [ICUAW], neuromuscular diseases, spinal cord injuries, and restrictive lung disease [6-8].

The respiratory muscles are significantly impacted by critical illness and mechanical ventilation [30]. Controlled mechanical ventilation results in respiratory muscle dysfunction, which reduces an individual's ability to cough effectively. This dysfunction is manifested as diaphragmatic atrophy and contractile dysfunction [also known as "ventilator-induced diaphragmatic dysfunction" or "VIDD"]. The development of VIDD occurs quickly in both people and animals because considerable diaphragmatic proteolysis, contractile dysfunction, and atrophy, all of which occur within the initial 24 to 48 hours after mechanical ventilation [MV] begins. [31].

Endotracheal intubation can lead to various adverse effects, including disruptions to mucociliary clearance mechanism and suppression of the cough reflex, which promote zones of hypoventilation and atelectasis, and boost the potential for ventilator-associated pneumonia [32]. Weakness in the respiratory muscles has been seen both while undergoing mechanical ventilation and following successful extubation [33].

Despite the well-established negative consequences of reintubation and its link to impaired clearance of the accumulated secretions, the significance of enhancing cough mechanism in patients experiencing critical illness of acute respiratory failure that require intubation and in managing respiratory failure occurring after extubation remains uncertain. As a result, it is uncommonly employed for avoiding intubation or re-intubation in critically ill patients [16]. So, the purpose of this research was to find out how the lung volume recruitment strategy affected patients whose coughing ability had been compromised after extubation and who had been receiving continuous mechanical ventilation in a controlled mode for less than 21 days or more than 48 hours owing to moderate or severe pneumonia. According to the study's outcomes, group A, who underwent the lung recruitment method, significantly improved their CPF rate, PEF rate, and O2 saturation.

The employing of cough augmentation strategies for the treatment of respiratory failure, triggered by an infection occurring in patients with a neuromuscular disorder or spinal cord injury who live in either community settings or long-term care facilities, has been shown to be both safe and effective in several primarily observational research conducted over the last 20 years [34-36]. Lung volume recruitment involves providing a patient with an inspiratory volume during inhalation at a low flow rate, followed immediately by an inspiratory pause to reach the maximum lung insufflation capacity and expand the chest wall, and then a quick release to provide a high expiratory flow, allowing for the development of an effective cough [19, 37]. By avoiding atelectasis and thoracic cage muscle contractures, insufflation may postpone the occurrence of ventilatory failure while simultaneously enhancing the efficiency of coughing and clearing the airways. It may help preserve lung compliance and thoracic wall mobility. The LVR approach should be introduced early in clinics where it is used, when patients have a CPF of 270 l/min or less, to provide instruction to individuals on proactive airway clearance techniques prior to the requirement for mechanical ventilation [38].

The effectiveness of the lung volume recruitment technique for recruiting lung capacity and its impact on the cough effectiveness has been supported by research. For 22 Duchenne muscular dystrophy [DMD] patients who were selected for a routine LVR [breath-stacking], McKim et al., [2012] [19] undertook a retrospective cohort analysis of pulmonary function test data, incorporating measures such as forced vital capacity [FVC] and cough peak flow [CPF]. They reach the conclusion that when regular LVR is initiated, the rate of FVC drop and cough efficiency in DMD patients both significantly improve. To ascertain the impacts that regular daily home air-stacking maneuver had on the pulmonary function of 18 NMD patients with restrictive respiratory diseases evaluated by Marques et al., [2014] [39], ten of whom had congenital muscular dystrophy [CMD] and eight of whom had spinal muscular atrophy [SMA]. They discovered that the assisted CPF and unassisted CPF both improved following the usage of home air-stacking maneuvers.

In a randomized controlled experiment done by An and Shin [2018] [40], 24 patients with cervical spinal cord injuries were randomly allocated to either the lung volume recruitment [LVR] group or the incentive spirometry training [IST] group. They discovered that after the training sessions, significant improvements were observed in both groups in the study outcomes including FVC, FEV1, MEP, MIP, and CPF. LVR group compared to IST group, the FVC in the post-test and the mean change in CPF, FEV1, and MIP were both substantially greater. They came to the conclusion that LVR helped those with CSCI breathe more easily and led to much better pulmonary functions involving the CPF and respiratory strength. Lung Volume Recruitment should be integrated into respiratory rehabilitation strategies because it has the potential to enhance respiratory muscle strength, coughing ability, and pulmonary functions. In cross-sectional research with matched pairs of 24 participants, Sarmento A., et al. [2017] [41] evaluated the immediate impacts of the air stacking technique on cough peak flow [CPF] and chest wall compartmental volumes of twelve patients diagnosed with amyotrophic lateral sclerosis [ALS] compared to twelve normal persons. CPF and compartmental inspiratory capacity of the chest wall were considerably increased following air stacking in both groups. They reached the conclusion that air stacking helps people with ALS have higher CPFs as well as higher compartmental inspiratory and vital capacities in their chest walls.

The mechanical properties of the chest wall or the lung tissues are altered naturally as a result of applying the recruitment of lung volume. According to Molgat-Seon et al., [2017] [42], chest wall articulations may benefit from range-of-motion exercises with significant gains in lung capacity caused by the inflations that are applied by the LVR technique. This will enhance the extensibility of the chest wall. As a result of positive airway pressures delivered manually and augmenting inspiratory lung volumes [hyperinflation] at the initial inspiration phase of cough mechanism, LVR promptly enhances expiratory flow and facilitates cough production. The FVC essentially stores elastic energy in both the lung and chest wall, particularly at a volume that exceeds the internal muscle capacity, increasing the elastic recoil, enlarging the airway caliber, and placing the weakened muscles of expiration to a somewhat enhanced length-tension relationship, and consequently improving the expiratory flows at the expulsive phase and significantly enhancing CPFs, thereby promoting sputum expectoration [19]. After employing the technique, the immediate enhancement may persist for approximately thirty minutes [Armstrong, 2009]. These earlier mechanisms support the positive impact of the lung volume recruitment strategy on the effectiveness of cough in patients with inefficient cough mechanisms, hence preventing significant post-extubation pulmonary consequences.

Acute alterations in lung compliance can also be attained through the redistribution of alveolar surface forces, even without augmenting static lung volumes, as observed with deep breathing. Conversely, repetitive inflations beyond voluntary vital capacity may yield a similar response. Given that lung volume recruitment is a passive intervention unrelated to muscle strengthening, the mechanism behind long-term enhancement of cough peak flow likely involves changes in lung and chest wall compliance. Manually induced supra-maximal lung expansion enhances lung compliance, potentially by reversing atelectasis [partial lung collapses due to reduced airflow]. According to studies by Molgat-Seon et al. [2017] [42] and McKim et al., [2012] [19], using stacked breaths can relieve atelectasis, boost inspiratory lung volume, enhance mobility of the thoracic cage, and raise the volume of the voice. Consequently, hyperinflation procedures may be deemed acceptable for patients with compromised inspiratory muscle strength or reduced vital capacity of the lung [43].

Reyes, et al. [2020] studied how the air stacking [AS] technique and an expiratory muscle training [EMT] program impacted the enhancement of both voluntary and reflex cough peak flow [CPF] [44] among 33 patients diagnosed with Parkinson's disease. They were randomly assigned to control, EMT, or EMT+AS groups. They discovered that for enhancing reflex and voluntary CPF, EMT with AS was preferable to EMT alone. For reflex CPF as opposed to voluntary CPF, the combined effect of the EMT and AS was greater. In order to determine how air stacking exercise affected senior persons' ability to walk, carry out daily living activities, and cough, Cha et al. [2016] [45] examined cough peak flow, oxygen saturation, and pulmonary functions in a cohort of 27 elderly patients. Following the intervention, significant differences were observed between the groups in terms of cough peak flow [CPF], oxygen saturation, forced expiratory volume in one second [FEV1], and forced vital capacity [FVC] values.

Conclusion

Lung volume recruitment proves to be an effective technique for enhancing cough efficacy in critically ill patients who were extubated from mechanical ventilation with ineffective coughing. Therefore, augment cough effectiveness prevents serious pulmonary complications, and decreases morbidity and mortality rates of such patients.

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Conflict of interest: The authors state that they have no conflicts of interest to declare.

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