

# Efficacy of Pursed Lips Breathing with Forced Expiration Techniques and Active Cycle of Breathing Technique on Pulmonary Mucus Clearance in Healthy Subjects

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**Abstract.** [Purpose] To investigate the efficacy of pursed lips breathing with forced expiration techniques (PLB & FETs) and the active cycle of breathing technique (ACBT) on pulmonary mucus clearance in healthy subjects. [Methods] Three healthy subjects volunteered for the study. Pulmonary mucus clearance was measured over 70 minutes on three different days by a radioaerosol technique. Each subject attended three sessions, one each of control (normal breathing), PLB & FETs and ACBT. [Results] The efficacy of both airway clearance techniques was similar, but better than that of normal breathing. In the central lung zone, PLB & FETs demonstrated a slight enhancement of mucus clearance as compared with ACBT and normal breathing. In the intermediate and peripheral zones, PLB & FETs and ACBT resulted in a relatively high mucus clearance as compared with normal breathing. Overall mucus clearance of normal lungs was remarkably improved by PLB & FETs and ACBT. [Conclusion] Enhanced mucus clearance in healthy subjects, particularly in the intermediate and peripheral lung zone, can be achieved by PLB & FETs and ACBT.

**Key words:** Pursed lips breathing with forced expiration techniques, Active cycle of breathing technique, Radioaerosol tracer technique

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## INTRODUCTION

Techniques for augmenting the normal mucociliary and cough clearance mechanisms of the lungs are not new. Over the past 35 years, a multitude of airway clearance techniques (ACTs) have been developed, introduced, refined, researched and used in patient populations to help

assist normal mucus clearance mechanisms. Postural drainage with chest clapping and chest shaking has been replaced by the more effective techniques of the active cycle of breathing, autogenic drainage, R-C Cornet<sup>®</sup>, Flutter<sup>®</sup>, positive expiratory pressure mask, high frequency chest wall oscillation and intrapulmonary percussive ventilation in most parts of the world<sup>1,2)</sup>. Desirable

features of any ACT relate to its effectiveness in the clinical application. Techniques should also be easy to teach to patients and should be easy for patients to perform independently or with assistance, depending on the patient's age and physical condition. Cost-effective treatments that rely upon patient participation rather than expensive equipment are even more important in health management<sup>3)</sup>. Therefore, the possibility of modifying the active form of techniques to facilitate airway clearance is likely to be a topic of great interest.

Different ACTs have developed independently in different parts of the world. The evidence in support of these techniques is variable and the literature is confusing and conflicting<sup>1,4)</sup>. However, the results of different studies indicate that active forms of forced expiratory manoeuvres of "huff" are the most effective physiotherapy interventions<sup>1,5-7)</sup>. Therefore, many regimens now include forced expiratory manoeuvres and this has probably increased the effectiveness of airway clearance<sup>1,7)</sup>. In 1979, the forced expiration technique (FET) was defined. It typically consists of one or two huffs followed by a period of relaxed, controlled breathing. This combination will bring secretions further up the bronchial tree without the distress of paroxysmal coughing. Also, FET may change the position of the equal pressure point in the airways allowing for greater clearance of mucus from further down the airways<sup>3,8,9)</sup>. In 1992, the active cycle of breathing technique (ACBT) was developed as method for emphasizing that forced exhalations or huffs are to be performed in conjunction with breathing exercises. There are three essential components in an active set of cycle: 1) breathing control, 2) thoracic expansion exercises and 3) FET<sup>3,6,8)</sup>. The theory behind ACBT utilizes the benefit of the FET and the improvement of alveolar aeration to decrease inhomogeneity and improve the driving pressure in alveoli behind blocked airways.

One of the concerns regarding the use of breathing techniques is the important aspect of airway clearance. There are a wide variety of breathing techniques that may be useful adjuncts with FET for enhancing the movement and expectoration of mucus. Pursed lips breathing (PLB) is considered to be the cornerstone of breathing retraining in pulmonary rehabilitation. It works to improve expiration, both by requiring

active and prolonged expiration and by preventing airway collapse<sup>10-13)</sup>. Indeed, PLB represents a functional predecessor to many modern strategies of applying positive expiratory pressure to the airway. It is believed that the resistance at the mouth during a pursed-lips exhalation transmits back pressure that splints the airways open, preventing compression and premature closure, which is the same principle of operation as the fixed-orifice resistor of positive airway pressure techniques<sup>14,15)</sup>. The subject performs a moderately active expiration through the half-opened lips, inducing expiratory mouth pressures of about 5 cmH<sub>2</sub>O<sup>10,11,15)</sup>. Thus, the positive expiratory pressure of PLB may be an important additional effect for airway clearance.

Recently, clinical trials of airway clearance techniques have shown little evidence. There are no studies of ACTs using PLB combined with FET focusing on the improvement of airway clearance, and it is unknown whether it has any effect on mucus clearance from the airways. Therefore, this study investigated the efficacy of PLB & FETs and ACBT for pulmonary mucus clearance in healthy subjects.

## SUBJECTS AND METHODS

Three healthy male subjects were enrolled for the study. The participants's ages were nearly identical and ranged from 33–35 years. The baseline characteristics of the subjects are shown in Table 1. All the subjects were non-smokers, had no history of chronic respiratory diseases and had a stable health condition throughout the experimental period. Ethical approval for the study was granted by Ethics Committee of Faculty of Medicine Siriraj Hospital, Mahidol University, Committee on Human Rights Related to Researches Involving Human Subjects, Faculty of Medicine Ramathibodi Hospital, Mahidol University and the Ethics Committee of Chest Disease Institute, Department of Medical Services, Ministry of Public Health, Thailand.

Each subject signed informed consent prior to undergoing three mucus clearance study sessions, one for each breathing technique: control (baseline study), PLB & FETs and ACBT. A mucus clearance study without intervention was carried out on the first study day to serve as a baseline. A randomized crossover study was performed so that intervention I, PLB & FETs, and intervention II,

ACBT, were used in a random order. All experiments on an individual subject were performed within 3 days at the same time of day within one week.

The study began with baseline camera data collection immediately after inhalation of the radioaerosol (time zero) and lung radioactivity measurements were made every 10 minutes throughout the 70 minutes of study.

Mucociliary transport and mucus clearance associated with ACTs were measured by quantifying the removal of inhaled radiolabelled aerosol deposited on the bronchial mucosa. Twenty mCi (740 MBq) Technetium-99 m human serum albumin aerosol was administered via the Venti-Scan III<sup>TM</sup> radioaerosol administration system (Biodex Medical System, Inc. NY, USA). The subject inhaled the aerosol via a mouthpiece while wearing a nose clip and sitting upright. He was asked to breathe slowly in normal tidal breathing then deeply with three-seconds breath-hold approximately every 10 breaths until the material inhaled with the total activity over the posterior chest was around 100,000 counts. This indicated that 0.5–1.0 mCi was retained. The inhalation period required to obtain this count rate was usually 4–6 minutes. A single head gamma camera (Genesys, Philips Medical Systems, Milpitas, CA) linked to a computer was used to assess the initial topographical distribution and subsequent clearance of the radioaerosol particles from the lungs. Each set of static scintigraphic images consisted of 8 chest images acquired in the posterior view at 10-minute intervals for 1 minute and each was stored in a 128 × 128 matrix. Regions of interest (ROI) were drawn by a radiologist to obtain counts in each lung region on each image. Division of the lung image into central, intermediate and peripheral zones was performed according to description of Bateman et al.<sup>16)</sup> The data from the right lung were analyzed. All counts were corrected for radionuclide decay and background radioactivity.

Heart rate and oxygen saturation were recorded before, during and after the experimental period by using a Nonin 9550 Onyx II Finger Pulse Oximeter (Nonin Medical, Inc. USA). Peak expiratory flow rate (PEFR) was measured using a Mini-Wright<sup>TM</sup> peak flow meter (C3103104, Clement Clarke International Limited, UK). The highest of three acceptable measurements was recorded before and after the experimental period. Also, each subject

**Table 1.** Baseline characteristics of subjects

Characteristics	Individual subject number		
	N1	N2	N3
Age (y)	34	33	35
Weight (kg)	80	82	64
Height (cm)	170	174	160
BMI	27.68	27.08	25.00
Spirometer parameters (% predicted value)			
FVC	88	99	103
FEV <sub>1</sub>	89	99	106
ratio FEV <sub>1</sub> /FVC	81	82	86
FEF <sub>25–75%</sub>	29	33	39
PEF	67	90	89

was asked to rate the sensation of breathlessness that they perceived before and after the experimental period using a modified Borg scale 0–10).

Control (normal breathing): quiet breathing was conducted while the subjects rested in an upright position during the experimental period. Subjects were permitted to cough when needed. No physical therapy was performed.

Intervention I-PLB & FETs: subjects rested in the upright position. For the first 10 minutes, they breathed quietly. This was followed by 30 minutes of PLB & FETs. Subjects performed 5 PLB and 1 FET/ minute, approximately 4 minute/set with 1 minute rest between each set. The technique was performed under the supervision of a physical therapist to ensure reliable performance. Thereafter, subjects again breathed quietly for 30 minutes from the 40<sup>th</sup> to the 70<sup>th</sup> minute.

Intervention II-ACBT: subjects rested in the upright position. For the first 10 minute, they breathed quietly. This was followed by 30 minutes of ACBT. Subjects performed a set of the breathing technique for 4 minutes with 1 minute of rest between each set. The technique was performed under the supervision of a physical therapist to ensure reliable performance. Subject then rested again from the 40<sup>th</sup> to the 70<sup>th</sup> minute.

All parameters of the study described an individual's response to each intervention during the experimental period. Transport of the tracer or clearance was expressed as percentage retention of the radioactivity in each zone as a function of time. A lower percentage of retention reflects better lung clearance. Retention curves were drawn for each subject for each study day.

## RESULTS

The relative values of control, PLB & FETs and ACBT for removal of pulmonary mucus clearance were assessed in three healthy subjects. After radioaerosol inhalation, there was little initial inter-subject and intra-subject variation in the distribution of the deposited radioaerosol in the right lung (Table 2) in all 3 interventions.

The patterns of clearance in the central lung zone were slightly different among the three breathing interventions. The PLB & FETs clearance curves of subjects N1 and N3 were greater than the control and ACBT. Only one subject showed enhanced clearance by ACBT. Therefore, PLB & FETs slightly enhanced clearance in this lung zone.

For the intermediate lung zone, the clearances of PLB & FETs and ACBT were clearly greater than that of the control during and after the intervention period from the 20<sup>th</sup> to the 70<sup>th</sup> minute. The PLB & FETs and ACBT clearance curves of all subjects declined substantially with time as compared with each subject's the control curves.

The clearance curves of the peripheral lung zone showed a declining trend with all breathing interventions. Interestingly, there was obviously high clearance of radioactivity by PLB & FETs and ACBT during and after the intervention period, from the 30<sup>th</sup> to the 70<sup>th</sup> minute. Both techniques showed approximately 7–9% clearance difference from the control study after the intervention period, from the 50<sup>th</sup> to the 70<sup>th</sup> minute.

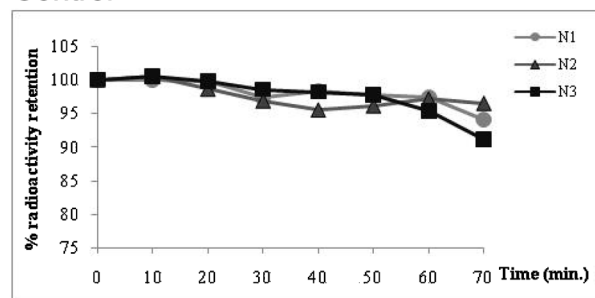
For whole right lung clearance, all curves of all subjects showed decline of radioactivity deposition from the 10<sup>th</sup> to the 70<sup>th</sup> minute (Fig. 1). PLB & FETs and ACBT obviously enhanced clearance of radioactivity during and after the intervention period from the 40<sup>th</sup> to the 70<sup>th</sup> minute, compared with the control. These findings confirm that lung clearance in healthy subjects especially in the intermediate and peripheral zones can be achieved by PLB & FETs and ACBT.

After inhalation of the radioaerosol, there were minor fluctuations in the heart rate during the experimental period. Interestingly, the heart rate declined during and after either PLB & FETs or ACBT was performed as compared with the control study. No differences between the effects of both techniques were observed. Oxygen pulse saturation (SpO<sub>2</sub>) showed stable values during the control study but increased during the period when PLB &

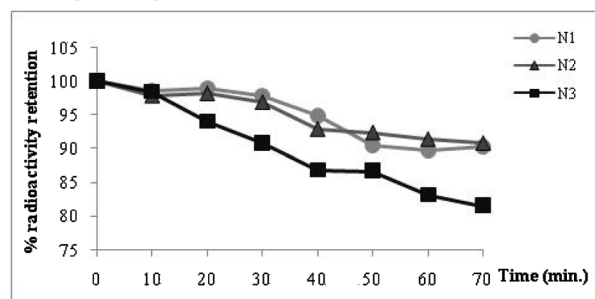
**Table 2.** The baseline deposition of radioaerosol for each study day determined by the ratio of the radioactivity count in the central right lung to the whole right lung zone

Subject No.	Ratio of central lung zone / whole right lung zone		
	Control	PLB & FETs	ACBT
1	0.35	0.35	0.37
2	0.38	0.36	0.37
3	0.40	0.39	0.39

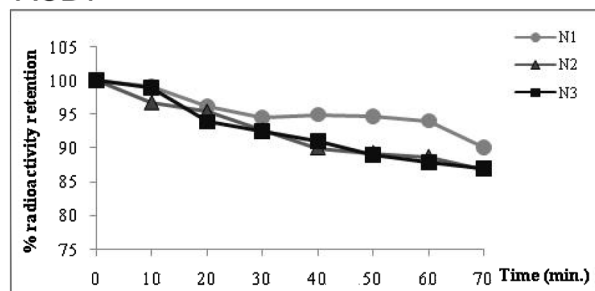
### Control



### PLB&FETs



### ACBT



**Fig. 1.** Clearance of the radioactivity from the whole right lung zone expressed as percentages of the starting values of the control and each intervention (decay corrected data).

FETs or ACBT was being performed. Therefore,

**Table 3.** Individual values of oxygen saturation (%) for the control, PLB & FETs and ACBT in the experimental period

Subject	Interventions	Oxygen saturation (%) in each time							
		0 <sup>th</sup>	10 <sup>th</sup>	20 <sup>th</sup>	30 <sup>th</sup>	40 <sup>th</sup>	50 <sup>th</sup>	60 <sup>th</sup>	70 <sup>th</sup>
N1	Control	98	97	97	97	97	97	97	97
	PLB & FETs	97	99	98	99	99	97	98	98
	ACBT	97	96	99	99	99	95	96	98
N2	Control	99	99	99	98	98	99	98	99
	PLB & FETs	98	98	99	99	98	97	99	99
	ACBT	99	98	100	100	99	99	99	98
N3	Control	97	97	97	98	98	97	97	98
	PLB & FETs	98	99	98	99	99	97	98	98
	ACBT	97	97	98	98	99	97	96	97

the airway clearance techniques used in this study slightly increased SpO<sub>2</sub> in healthy subjects above the baseline values (Table 3).

We observed no significant differences in PEFR and modified Borg scores of dyspnoea among the three breathing protocols. Also there was no significant change in either PEFR or the modified Borg scores immediately after the experimental period.

## DISCUSSION

The results of this study show that there was very little difference in the initial distribution of radioactivity on the three study days. So, the difference in clearance during the period of intervention could not be explained by a difference in radioaerosol deposition. A randomized cross-over design was chosen to minimize the effect of the sequence of the intervention which was conducted at the same time of day to avoid diurnal variation. Therefore, any changes in radioaerosol tracer retention were likely due to the specific interventions per se. With control breathing, the lung clearance of radioactivity observed in our study was very similar to the results of previous studies<sup>17–19</sup>.

Speeding clearance of our subjects occurred toward the end of and after the intervention period. There appeared to be a delay in onset and persistence of the effect after the initial stimulus had ceased. This observed delay in speeding of clearance was in agreement with the finding of Wolff et al. in 1977<sup>19</sup>. They described that it could result from a delay between the initial stimulation of

mucus production and its appearance on the epithelial surface. It could also be due to regional differences in clearance. Clearance from the more peripheral lung zones seemed to increase earlier than clearance from the central zone. A plausible interpretation is that speeding clearance first takes place in the deeper, more peripheral airways, probably due to mechanical factors of lung movement, but then later in the central airways after a substantial amount of mucus has been transported.

Overall, the results of this study show that mucus clearance could be achieved in healthy subjects by PLB & FETs or ACBT, particularly in the intermediate and peripheral lung zone. This finding confirms that enhanced mucus clearance can be achieved in healthy subjects by PLB & FETs. In particular, most previous studies found that successful PLB markedly reduced respiratory rate and dyspnoea, improved tidal volume and increased the vital capacity and oxygen saturation of patients with emphysema<sup>10,11,20,21</sup>. Furthermore, healthy individuals performing volitional PLB have also previously been found to exhibit significant increases in tidal volume during resting breathing and exercise as reported by Spahija et al. in 1996<sup>22</sup>. They suggested that the ability of PLB to promote changes in breathing patterns did not depend on the presence of expiratory flow obstruction. Our study is original research designed to evaluate the effects of PLB combined with FETs on mucus clearance. The increased clearance achieved by PLB & FETs could have resulted from the mechanical effect of PLB<sup>1–3,14,15,23,24</sup>, stimulation of mucociliary clearance resulting from forced expiration techniques<sup>1,5–7,9</sup> or the mechanism of two-phase

gas-liquid flow (TPGLF) facilitated by PLB & FETs.

Due to the mechanical effect of PLB, active expiration through the half-opened lips induces expiratory mouth pressure of about 5 cmH<sub>2</sub>O<sup>10,11,15</sup>. The positive back pressure may splint the airway open, preventing compression or premature closure. It has been theorized that positive pressure is built up distal to an obstruction, promoting the movement of secretions toward the large airways. In addition, airway stability is maintained with positive expiratory pressure breathing which results in improved ventilation and gas exchange as well as in airway clearance<sup>1-3,14,15,23,24</sup>. Moreover, David A<sup>25</sup>) stated that the equal pressure point is moved towards the mouth to avoid compression of a collapsible segment when performing expiration through pursed lips. Therefore, we believe that the positive expiratory mouth pressure of PLB might be an additional effect enhancing the removal of pulmonary mucus from the lung. In considering respiratory mechanics, expiratory muscle recruitment with PLB may improve length-tension relationships of the inspiratory muscles, particularly the rib cage and accessory muscles, improving their mechanical efficiency and leading to greater force generation in ventilation<sup>13,26</sup>. It is possible that the integration of respiratory muscle changes with PLB might enhance mucociliary clearance in the total lung.

A secondary clearance mechanism known as TPGFLF plays an essential role in removing mucus from the lung. In non-ciliary dependent phasic flow, energy is transmitted from the moving air to the static liquid, shearing and moving the liquid in the direction of flow. The cephalad mucus transport can be achieved by keeping the expiratory flow. In addition, the ratio of the expiratory to the inspiratory flow rate of 1.5 with a tidal volume of 500 ml is sufficient to transport mucus in a vertical tube model<sup>27-30</sup>. Therefore, we speculate that the increased mucus clearance achieved by PLB & FETs is the result of this mechanism.

Mucus clearance in healthy subject was enhanced in this study using ACBT. Until recently, there was only one report focusing on ACBT in terms of mucus clearance of radiolabelled aerosol. Miller et al. in 1995<sup>31</sup>) reported that the average clearance rates of ACBT were high in the peripheral lung region, whole lung and central lung, respectively. The regions of interest in their study were drawn

over the right and left lungs and they divided the lungs into central and peripheral lung regions. Their results agree with ours on the effect of ACBT on lung clearance. Moreover, it is postulated that ACBT was developed and renamed from FET<sup>5,6</sup>). Based on previous studies using radioaerosol measurement, FET is also effective in the enhancement of peripheral lung clearance.<sup>32</sup>) Therefore, one explanation for the effective lung clearance with ACBT is the potential effects of FETs. This supports the idea that enhanced lung clearance with ACBT is more effective in the lung periphery than the central lung.

In comparison with ACBT, PLB & FETs showed a trend toward greater clearance in the whole right lung zone in healthy subjects. This finding is possibly related to the differences in the total number of FETs performed during the active treatment sessions. In PLB & FETs, FETs were performed several times more than in ACBT. Slighter better enhanced lung clearance with PLB & FETs as compared with ACBT might be due to the major benefit of FETs.

This study demonstrated that PLB & FETs and ACBT reduced HR and increased SpO<sub>2</sub> from the baseline value. This might be because the components of breathing technique include breathing control and thoracic expansion exercise in ACBT and PLB in PLB & FETs. Our study showed no significant changes in heart rate and oxygen pulse saturation in all three breathing protocols, showing that mucus clearance measurement with radioaerosol is safe. There was no airway obstruction, bronchoconstriction, or any other adverse effect due to particle deposition. Also, there was no significant deterioration in PEFR during and immediately after each intervention period. This contradicts Miller et al.<sup>31</sup>), who reported in 1995 that pulmonary function was decreased after inhalation of aerosol, presumably due to bronchoconstriction. In our study, all subjects seemed to be in stable conditions throughout the study period of three study days and did not have any adverse effect due to bronchoconstriction. Moreover, modified Borg scores of dyspnoea in each subject were stable before, and immediately after the experimental periods of the control, PLB & FETs and ACBT.

This study was conducted in a laboratory setting and was based on radioactivity approach. The results show improved lung clearance on a

quantitative basis when airway clearance techniques using PLB & FETs or ACBT were applied. However, the lung zone of radionuclide imaging was divided on two-dimensional images. Interpretation of images indirectly represents the reality of lung zone clearance. So, the results must be interpreted with caution because of physiological influences. In our study, data was used from the right lung only to avoid interference from activity in the stomach, and a data were corrected for background and radioactive decay. We assume that our sequential lung image shows acute pulmonary mucus clearance and the results shown were ideally obtained as near as possible to an actual situation. However, the study only provides an overall idea of what is happening in mucus clearance of the airways when ACTs were performed. We believe we can obtain a better idea of lung clearance by PLB & FETs and ACBT on a quantitative basis. To the best of our knowledge, the immediate effect of PLB & FETs on mucus clearance in healthy subjects or in patients has never been studied before. Also, we found only one previous study focusing on ACBT in terms of mucus clearance of radioaerosol. A limitation of this study was its small sample size. Therefore, the findings provide insufficient evidence to support the benefit of the use of PLB & FETs or ACBT to improve secretion clearance in patients with chronic respiratory disease or patients with copious sputum. Further research in this area is warranted to compare the effectiveness of PLB & FETs and ACBT in patients with chronic respiratory disease in order to investigate the effectiveness of PLB & FETs as an adjunctive therapy for chest physical therapy programs in chronic respiratory disease.

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