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Effects of pursed-lip breathing and forward trunk lean postures on total and compartmental lung volumes and ventilation in patients with mild to moderate chronic obstructive pulmonary disease

An observational study

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Abstract

This study identified the effects of pursed-lip breathing (PLB), forward trunk lean posture (FTLP), and combined PLB and FTLP on total and compartmental lung volumes, and ventilation in patients with chronic obstructive pulmonary disease (COPD). Sixteen patients with mild to moderate COPD performed 2 breathing patterns of quiet breathing (QB) and PLB during FTLP and upright posture (UP). The total and compartmental lung volumes and ventilation of these 4 tasks (QB-UP, PLB-UP, QB-FTLP, PLB-FTLP) were evaluated using optoelectronic plethysmography. Two-way repeated measures ANOVA was used to identify the effect of PLB, FTLP, and combined strategies on total and compartmental lung volumes and ventilation. End-expiratory lung volume of ribcage compartment was significantly lower in PLB-UP than QB-UP and those with FTLP ($P < .05$). End-inspiratory lung volume (EILV) and end-inspiratory lung volume of ribcage compartment were significantly greater during PLB-FTLP and PLB-UP than those of QB ($P < .05$). PLB significantly and positively changed end-expiratory lung volume of abdominal compartment ($EELV_{AB}$) end-expiratory lung volume, $EILV_{AB}$, tidal volume of pulmonary ribcage, tidal volume of abdomen, and ventilation than QB ($P < .05$). UP significantly increased tidal volume of pulmonary ribcage, tidal volume of abdomen, and ventilation and decreased $EELV_{AB}$, end-expiratory lung volume, and $EILV_{AB}$ than FTLP ($P < .05$). In conclusion, combined PLB with UP or FTLP demonstrates a positive change in total and compartmental lung volumes in patients with mild to moderate COPD.

Abbreviations: COPD = chronic obstructive pulmonary disease, EELV = end-expiratory lung volume, $EELV_{AB}$ = end-expiratory lung volume of abdominal compartment, $EELV_{RC}$ = end-expiratory lung volume of ribcage compartment, EILV = end-inspiratory lung volume, $EILV_{RC}$ = end-inspiratory lung volume of ribcage compartment, FTLP = forward trunk lean posture, PLB = pursed-lip breathing, QB = quiet breathing, UP = upright, V_{TAB} = tidal volume of abdomen, V_{TRCp} = tidal volume of pulmonary ribcage.

Keywords: chronic obstructive pulmonary disease, forward lean, optoelectronic plethysmography, pursed-lip breathing

1. Introduction

Chronic obstructive pulmonary disease (COPD) directly affects the respiratory system. As the disease progresses, there is an increase in the work of breathing, abnormal ventilation, accumulation of air trapping, and dyspnea experienced by patients with COPD.[1,2] Without appropriate intervention, these

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adverse consequences of COPD will significantly interfere with patients' ventilation, particularly during physical activities, and negatively impact patients' quality of life (QoL).[3,4] Identifying effective interventions to improve respiratory function and dyspnea is essential to promoting QoL of patients with COPD.

Pursed-lip breathing (PLB) is commonly used to improve ventilation and alleviate dyspnea[5,6] as it increases the tidal volume (V_T) and reduces respiratory rate (RR) in patients with COPD.[7–11] However, it was found that the effect of PLB on the changes in compartmental lung volumes differed among patients with COPD.[7,8] Patients who responded positively to PLB decreased end-expiratory lung volume of the abdominal compartment ($EELV_{AB}$) and the total chest wall end-expiratory lung volume (EELV), and an increase in end-inspiratory lung volume of the ribcage ($EILV_{RC}$) compartment and the total chest wall (EILV). In contrast, patients who did not respond to PLB increased end-expiratory lung volume of ribcage compartment ($EELV_{RC}$), EELV, $EILV_{RC}$, and $EILV_{AB}$. As a result, their V_T was significantly lower than that of the patients with a positive response to PLB. The decrease in EELV was also related to a decreased dyspnea score in patients with a positive response to PLB.[7] Thus, the compartmental EELV and EILV changes were found to be significantly correlated with improvement in ventilation resulting from PLB.[8] Collectively, these studies indicate that the ability to detect compartmental lung volumes provides us with a better understanding of the control of the respiratory system, which in turn allows us to make better clinical decisions when selecting treatment strategies for patients with COPD.[12]

A forward trunk lean posture (FTLP) is also a common strategy used to relieve dyspnea,[5,9,13] and improve lung volume and ventilation in patients with COPD.[14,15] However, little is known about the effects of FTLP or combining FTLP with PLB on the compartmental lung volumes and ventilation. The inability to identify changes in the compartmental lung volumes in a previous study[9] was primarily due to limitations associated with respiratory inductive plethysmography.[16] To overcome these limitations, an optoelectronic plethysmography (OEP) was used to measure both compartmental and total lung volumes.[17,18] This system has been shown to have good validity in measuring compartmental lung volumes in various body positions among a healthy population.[19,20] However, to our knowledge, no study has used an OEP to identify the effect of FTLP alone, or in combination with PLB, in patients with COPD.

This study aimed to identify the effects of PLB, FTLP, and combined PLB and FTLP on total and compartmental lung volumes, and ventilation in patients with COPD. This study took advantage of the recent developments in OEP technology to overcome the technical difficulties associated with the previously used respiratory inductive plethysmography. The knowledge gained from this study will provide clinicians with rationales to support the use of these strategies to improve lung volume and ventilation in patients with mild to moderate COPD.

2. Material and methods

2.1. Design

This cross-sectional study with repeated measure design was approved by The Research Ethics Review Committee for Research Involving Human Research Participants, Health Sciences Group, Chulalongkorn University (Protocol number 031.1/61), and The Research Ethics Review Committee of The Central Chest Institute of Thailand. During screening sessions, participants were recruited using a convenience sampling method at The Central Chest Institute of Thailand. Demographic data collection and testing sessions occurred at the Department of Physical Therapy, Faculty of Allied Health Sciences, Chulalongkorn University. Each patient read and signed an informed consent form prior to participating in the study.

2.2. Participants

The sample size was calculated based on our pilot study results using ten subjects with COPD with the inclusion and exclusion criteria and research protocol similar to those used in this current study. The pilot study results indicated that the tidal volume of the pulmonary ribcage (V_{TRCp}) was greater during PLB-UP than in other tasks. V_{TRCp} during PLB-FTLP was also found to be higher than quiet breathing (QB-UP and QB-FTLP). With a moderate effect size (ES=.65) of V_{TRCp} based on the pilot study, a significance criterion of 0.05, and power of 0.80, the total sample size required for this study was determined to be 16.

Patients with COPD were included in this study if they were:

(1) diagnosed as mild to moderate COPD[21] by a pneumologist at The Central Chest Institute of Thailand,
(2) clinically stable without exacerbation for at least 4 weeks before the screening test,
(3) with a mild to moderate dyspnea score (Medical Research Council dyspnea score = I-III),
(4) with a history of smoking, and
(5) without other conditions that prevented them from completing the study protocol.

Potential patients were excluded if they met 1 of the following criteria:

(1) having pain or discomfort, or had a history of chest wall operation,
(2) unable to perform the FTLP in sitting position, or
(3) receiving ventilatory support or long-term oxygen therapy.

The exclusion criteria allowed us to complete our data collection while minimizing confounding factors such as pain limiting chest wall movements and lung volume and maximizing patients' comfort and safety during the data collection.

2.3. Intervention

During the preparatory session, the demographic data were collected. The level of dyspnea at baseline and during physical activity were assessed using a modified Borg scale score and the modified medical research council, respectively. Physical activity level was recorded using the Baecke physical activity questionnaire.

During the testing session, an OEP system was used to measure total and compartmental lung volumes and ventilation during 2 different body postures of self-selected upright posture (UP) and FTLP in a sitting position, and 2 breathing patterns of QB, and PLB. The FTLP was defined as a 45° anterior inclination of the trunk.[9,13,22] While sitting in a chair, patients placed their forearms on their thighs such that the trunk was at a 45° forward lean posture with knee flexion at 90° and both feet on the floor. QB was defined as spontaneous breathing where patients were breathing in and out through the nose. For the PLB, the patients

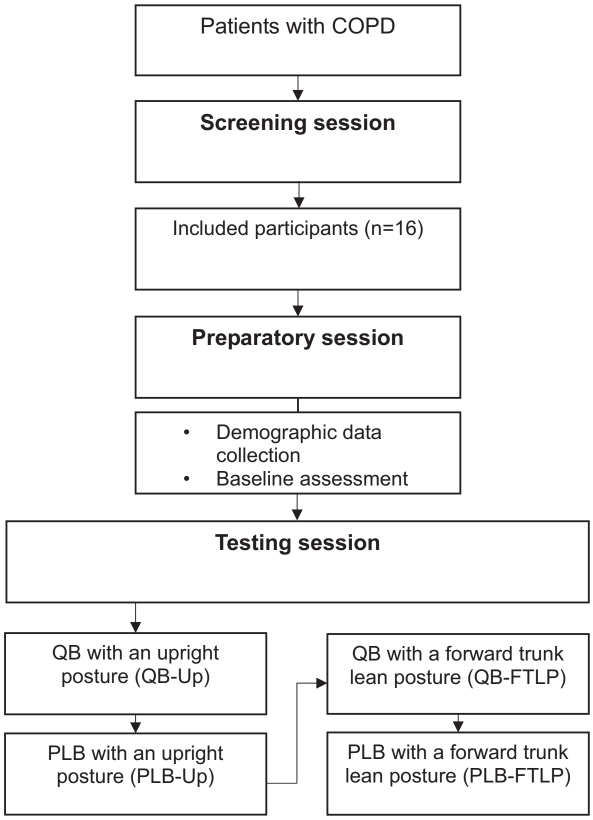

Figure 1. Flow chart of patients.

were asked to breathe in through the nose and breathe out through partially closed-lips. The duration of breathing-out was approximately 2 times longer than that of breathing-in.[23,24]

The combination of 2 breathing patterns (QB and PLB) and 2 body postures (UP and FTLP) allowed 4 testing tasks:

(1) QB with UP (QB-UP),
(2) PLB with UP (PLB-UP),
(3) QB with FTLP (QB-FTLP), and
(4) PLB with FTLP (PLB-FTLP) (Fig. 1).

The patients were asked to perform 3 trials of each testing task without speaking or coughing. Each trial lasted 1 minute. The resting period was 1 minute between trials, and 2 minutes between tasks or until dyspnea returned to the baseline.

2.4. Measurement and outcomes

An OEP system (BTS engineering, Milan, Italy) was used to capture chest wall movement by tracking 89 reflective markers placed on the patient's chest wall.[17] The positions of the reflective markers were tracked by the SMART Tracker software (BTS engineering, Milan, Italy) and then were used to compute chest wall movements. These data were used to derive the 3 compartmental lung volumes of RC_p, RC_a, and AB (Fig. 2) as well as the total lung volume using Gauss theorem.[12] All variables were extracted by a custom software written in MATLAB (The MathWorks, Massachusetts, United State).

The outcomes related to lung volume were EELV, EILV, and V_T. EELV and EILV consisted of 2 compartments of ribcage ($EELV_{RC}$ and $EILV_{RC}$) and abdomen ($EELV_{AB}$ and $EILV_{AB}$). V_T had 3 compartments of pulmonary ribcage (V_{TRCp}), abdominal

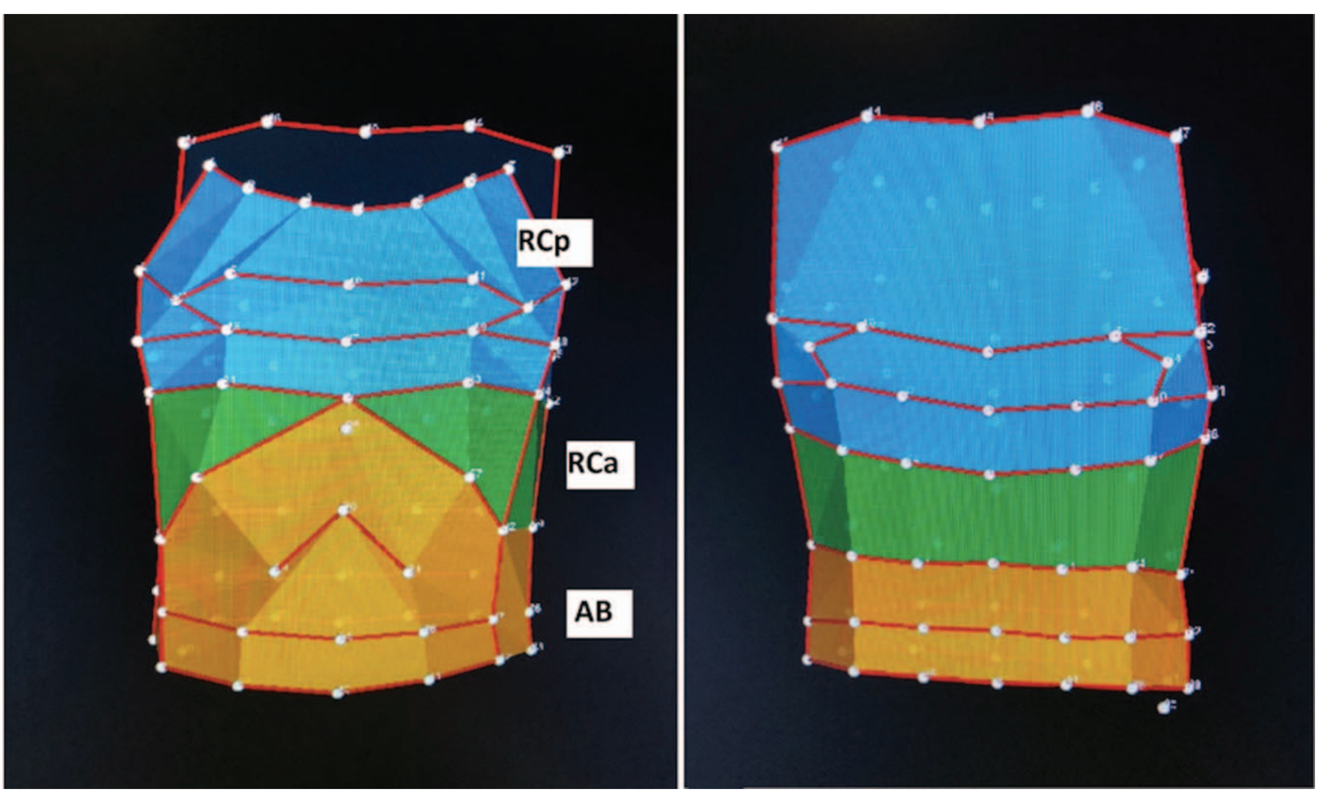

Figure 2. Chest wall compartment divided by OEP: Pulmonary rib cage (RCp), Abdominal rib cage (RCa), and Abdomen (AB).

Table 1

Demographic characteristics of the 16 patients with COPD.

Characteristics	Mean ± SD	% (N)
Age (yr)	63.69 ± 6.34	
Weight (kg)	63.05 ± 9.47	
Height (m)	1.67 ± 0.06	
BMI (kg/m^2)	22.73 ± 3.1	
FEV_1 (%)	73.13 ± 18.64	
FEV_1 (L)	1.88 ± 0.46	
FVC (L)	3.24 ± 0.63	
FEV_1/FVC (%)	60.81 ± 11.38	
Stage of COPD		
- Mild		31.25% (5)
- Moderate		68.75% (11)
Year of COPD (yr)	5.69 ± 5.5	
Smoking (Pack-Year)	39 ± 13.52	
Co-morbidity		
- Cardiac disease		18.75% (3)
- Metabolic disease		56.25% (9)
- Musculoskeletal disorder		25% (4)
Dyspnea level		
- MMRC score	1.19 ± 0.4	
- Modified Borg scale	0 ± 0	
Physical activity level	7.64 ± 1.34	
(Baecke physical activity)		
- Sedentary		0% (0)
- Active		56.25% (9)
- Athlete		43.75% (7)

Data expressed as mean and standard deviation (SD).
BMI = body mass index, COPD = chronic obstructive pulmonary disease, FEV_1% = Percentage of force expiratory volumes in 1 second, MMRC = modified medical research council dyspnea score.

ribcage (V_{TRCa}), and tidal volume of abdomen (V_{TAB}). Ventilation-related outcomes were respiratory rate (RR), inspiratory time (T_i), expiratory time (T_e), mean inspiratory flow (V_T/T_i), and mean expiratory flow (V_T/T_e).

2.5. Data analysis

Demographic characteristics and outcome measurements are presented in mean±standard deviation (SD) for continuous data, and in percentage of sample size (%N) for categorical data. Two-way repeated measured analysis of variance (2 breathing patterns x 2 postures) was used to compare the effects of breathing patterns and body postures on outcome measures. Post-hoc analysis with Bonferroni adjustment was used to control for type I error during multiple comparisons. The significance level was set at .05. All data analysis was done using SPSS software version 22 (SPSS Inc., Chicago, Illinois).

Table 3

Combined effects of breathing pattern and body posture on ventilation.

	Upright Posture		FTLP		
Parameters	QB (a)	PLB (b)	QB (c)	PLB (d)	*P*-value
T_i (s)	1.33 ± 0.45	2.58 ± 0.99	1.36 ± 0.48	2.49 ± 1.05	.490
T_e (s)	2.11 ± 0.5	5.21 ± 4.41	2.21 ± 0.7	4.79 ± 3.69	.081
RR (bpm)	18.4 ± 3.72	9.48 ± 3.23	17.95 ± 4.11	10.11 ± 3.57	.252
V_T/T_i (L/s)	0.41 ± 0.18	0.76 ± 0.26	0.26 ± 0.29	0.68 ± 0.24	.432
V_T/T_e (L/s)	0.31 ± 0.1	0.44 ± 0.17	0.27 ± 0.1	0.4 ± 0.16	.971

Data expressed as mean and standard deviation. Upright (Up); Forward trunk lean posture (FTLP); Quiet breathing (QB); Pursed-lip breathing (PLB); Inspiratory time (Ti); Expiratory time (Te); Second (s); Respiratory rate (RR); breath per minute (bpm); Mean inspiratory flow (VT/Ti); Mean expiratory flow (VT/Te); ratio of liters per second (L/s).

3. Results

Table 1 describes the demographic data of the sixteen subjects. The effect of breathing patterns, postures, and their combinations on total and compartmental lung volume and ventilation are represented in Tables 2–4.

EELV and $EELV_{AB}$ were significantly lower during PLB as compared to QB ($P < .01$), and during UP as compared to FTLP ($P < .01$) (Table 2). $EELV_{RC}$ was significantly lower during PLB-UP as compared to PLB-FTLP and QB-FTLP ($P < .05$, ES = 1.16) and during QB-UP as compared to QB-FTLP ($P = .04$) (Fig. 3).

$EILV_{AB}$ was significantly greater during PLB as compared to QB ($P < .001$), and during FTLP as compared to UP ($P = .008$) (Table 2). EILV and $EILV_{RC}$ were significantly greater during PLB-UP and PLB-FTLP than those with QB-UP and QB-FTLP ($P < .01$; Fig. 4). The effect sizes of these comparisons were large (ES = 1.55–2.51).

V_{TAB} and V_{TRCp} were significantly greater during PLB than QB ($P < .001$), and greater during UP than FTLP ($P < .05$) (Table 2). Additionally, V_T and V_{TRCa} were significantly greater for PLB-UP as compared to other positions ($P < .05$; Fig. 5). The effect size ranged from 1.48 to 2.36.

T_i, T_e, RR, V_T/T_i, and V_T/T_e were significantly greater during PLB than QB ($P < .05$; Table 4). Additionally, V_T/T_i was significantly greater during UP as compared to FTLP ($P = .01$; Table 4). There was no significant combined effect of breathing patterns and body postures on all ventilation parameters ($P > .05$; Table 3).

Table 2

Main effect of breathing pattern and body posture on lung volume.

	Breathing Pattern				Body Posture			
Parameters	QB	PLB	Effect size	*P*-value	Up	FTLP	Effect size	*P*-value
$EELV_{AB}$ (L)	7.53 ± 1.87	7.31 ± 1.83	3.01	<.001*	7.26 ± 1.86	7.58 ± 1.86	2.18	.001#
EELV (L)	22.71 ± 3.64	22.41 ± 3.55	2.19	.001*	22.26 ± 3.63	22.86 ± 3.56	2.77	>.001#
$EILV_{AB}$ (L)	7.86 ± 1.91	8.22 ± 2.02	3.67	<.001*	7.93 ± 2.04	8.15 ± 1.89	1.59	.008#
V_{TRCp} (L)	0.16 ± 0.12	0.46 ± 0.2	4.28	<.001*	0.33 ± 0.16	0.29 ± 0.14	1.17	.038#
V_{TAB} (L)	0.33 ± 0.09	0.92 ± 0.26	5.37	<.001*	0.67 ± 0.23	0.58 ± 0.12	1.13	.045#

Data expressed as mean and standard deviation. Quiet breathing (QB); Pursed-lip breathing (PLB); Tidal volume (VT); End-expiratory lung volume (EELV); End-inspiratory lung volume (EILV); Pulmonary ribcage (RCp); Abdominal ribcage (RCa); Ribcage (RC); Abdomen (AB); liter (L); Upright (UP); Forward trunk lean posture (FTLP).
* Significant of main effect of breathing pattern.
# Significant of main effect of body posture.

Table 4

Main effect of breathing pattern and posture on ventilation.

	Breathing Pattern				Body Posture			
Parameters	**QB**	**PLB**	**Effect size**	***P*-value**	**Up**	**FTL**	**Effect size**	***P*-value**
T_i (s)	1.34±0.4	2.54±1	2.46	<.001*	1.96±0.62	1.92±0.57	0.20	.701
T_e (s)	2.16±0.54	5±4.04	1.50	.011*	3.66±2.29	3.5±1.97	0.56	.294
RR (bpm)	18.17±3.62	9.8±3.28	4.18	<.001*	13.94±2.76	14.03±3.02	0.11	.830
V_T/T_i (L/s)	0.34±0.19	0.72±0.24	4.04	<.001*	0.59±0.19	0.47±0.23	1.42	.015#
V_T/T_e (L/s)	0.29±0.09	0.42±0.16	2.31	<.001*	0.37±0.12	0.34±0.11	0.99	.073

Data expressed as mean and standard deviation. Quiet breathing (QB); Pursed-lip breathing (PLB); Inspiratory time (Ti); Expiratory time (Te); Second (s); Respiratory rate (RR); breath per minute (bpm); Mean inspiratory flow (VT/Ti); Mean expiratory flow (VT/Te); ratio of liters per second (L/s).

* Significant of main effect of breathing pattern.

\# Significant of main effect of body posture.

4. Discussions

This study described and compared the effect of PLB, FTLP, and combined PLB-FTLP on total and compartmental lung volumes and ventilation in patients with mild to moderate COPD. Significant changes in $EELV_{AB}$, EELV, $EILV_{AB}$, V_{TRCp}, V_{TAB}, and all ventilation parameters were demonstrated with PLB compared to QB. UP significantly increased V_{TRCp}, V_{TAB}, and V_T/T_i as compared to FTLP. However, $EELV_{AB}$, EELV, and $EILV_{AB}$ were significantly increased during FTLP as compared to UP. The combined PLB-UP significantly lowered $EELV_{RC}$ as compared to QB-UP and compared to both breathing patterns with FTLP. The combined PLB-FTLP and PLB-UP each demonstrated significantly higher EILV and $EILV_{RC}$ than those observed during QB-FTLP and QB-UP. Additionally, PLB-UP demonstrated significantly greater V_{TRCa} and V_T as compared to other testing tasks.

Our results are consistent with previous studies where PLB-UP was found to positively impact total (V_T), 2 compartmental (V_{TRC}, V_{TAB}) lung volumes and ventilation (RR, T_i, T_e, V_T/T_i) as compared to QB.[7–9,11] Furthermore, a positive end-expiratory pressure (PEEP) generated during PLB prevents airway collapse and air trapping in the lungs.[25,26] An increase in airway PEEP with longer T_e results in a decrease in RR and an increase in V_T/T_e.[24] All of these lead to an increase in V_T, compartmental volumes, and all ventilation parameters during PLB. Additionally, our study demonstrates that, during PLB, V_{TAB} has the largest contribution to the VT, followed by V_{TRCp} and V_{TRCa}. Since the changes in V_{TAB} and V_{TRCp} are closely related to diaphragmatic function[27] and accessory muscle activities,[16] respectively, these results suggest a synergistic function of the diaphragm and accessory muscles during PLB. Thus, the PLB pattern may prevent the diaphragm from getting fatigued.[28] However, our study did not directly

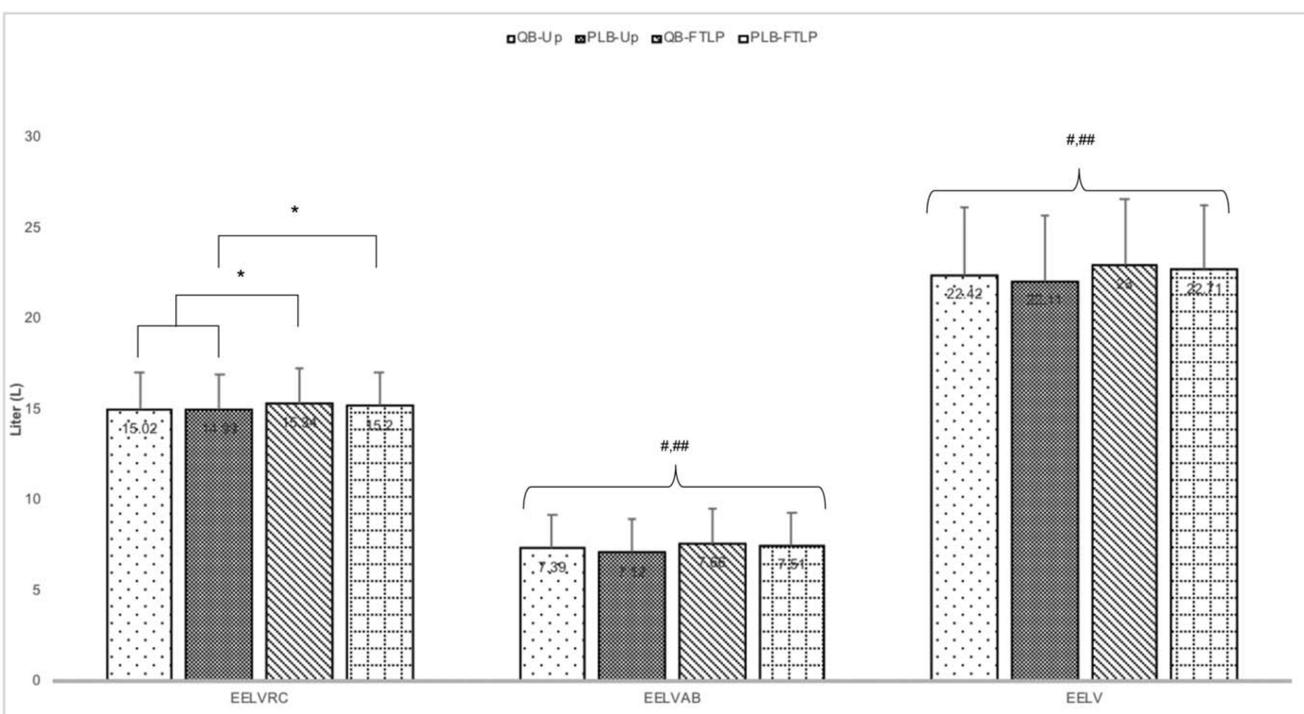

Figure 3. End-expiratory lung volume and its compartment during performed breathing patterns and postures. Upright (Up); Forward trunk lean posture (FTLP); Quiet breathing (QB); Pursed-lip breathing (PLB); End-expiratory lung volume (EELV); Ribcage (RC); Abdomen (AB). *significance interaction effect of breathing patterns and postures at $P<.05$; #significance main effect of breathing patterns at $P<.05$; ##significance main effect of body postures at $P<.05$.

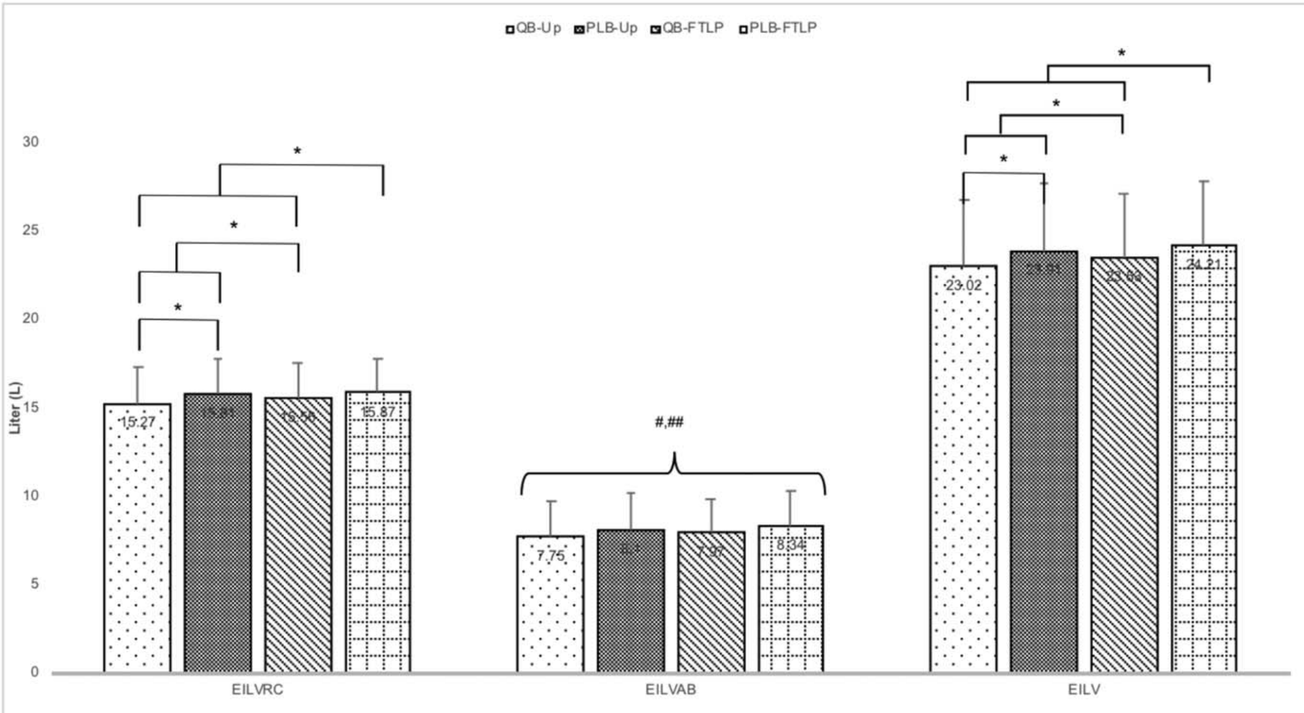

Figure 4. End-inspiratory lung volume and its compartment during performed breathing patterns and postures. Upright (Up); Forward trunk lean posture (FTLP); Quiet breathing (QB); Pursed-lip breathing (PLB); End-inspiratory lung volume (EILV); Ribcage (RC); Abdomen (AB). *significance interaction effect of breathing patterns and postures at $P<.05$; #significance main effect of breathing patterns at $P<.05$; ##significance main effect of body postures at $P<.05$.

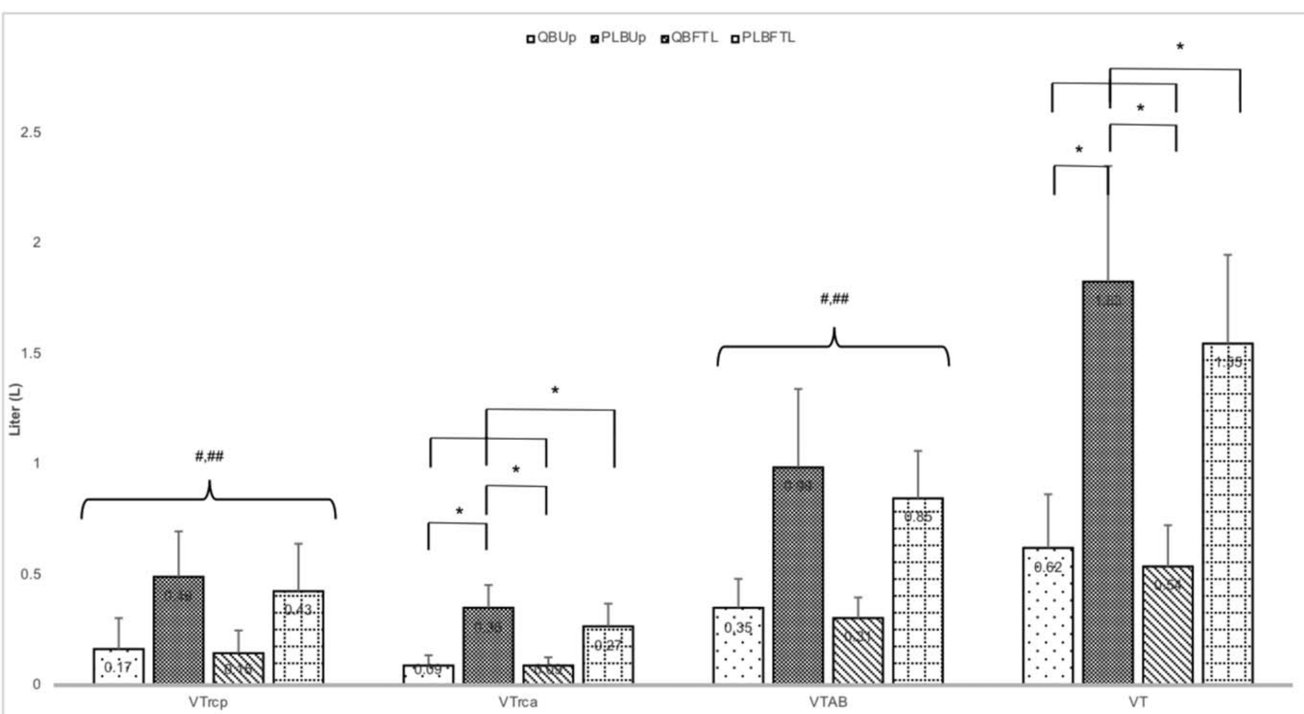

Figure 5. Tidal volume and its compartment during performed breathing patterns and postures. Upright (Up); Forward trunk lean posture (FTLP); Quiet breathing (QB); Pursed-lip breathing (PLB); Tidal volume (VT); Pulmonary ribcage (RCp); Abdominal ribcage (RCa); Ribcage (RC); Abdomen (AB). *significance interaction effect of breathing patterns and postures at $P<.05$; #significance main effect of breathing patterns at $P<.05$; ##significance main effect of body postures at $P<.05$.

measure diaphragm activity. Further study is needed to identify the diaphragm activity during PLB in patients with COPD.

The decreased EELV and $EELV_{AB}$ and increased EILV and $EILV_{RC}$ during PLB-UP observed in our results are similar to those previously reported in patients with severe COPD.[7] In a previous study, patients with severe COPD who responded well to PLB demonstrated a significant increase in EILV and a significant decrease in EELV during PLB.[7] The changes in EELV and $EELV_{AB}$ were associated with a longer T_e and an increase of tidal volume. As a result, the patients who responded positively to PLB had relatively lower air trapping and experienced less dyspnea with PLB.[7] Our results extend the potential effect of PLB to patients with mild to moderate COPD.

The severity of lung hyperinflation impacts the effectiveness of PLB on lung volume in patients at different stages of COPD.[7] Although the positive effect of PLB on EELV and EILV was observed in the patients with mild to moderate COPD, our study did not measure lung hyperinflation or air trapping. Lung hyperinflation can be present in an early stage of COPD, and it progressively worsens as the disease progresses.[29] A ratio of residual volume (RV) to total lung capacity (TLC) greater than 120% of the predicted value was used to indicate lung hyperinflation.[30] In patients with mild COPD, TLC and RV were significantly higher than the predicted values, while inspiratory capacity, vital capacity, and FEV_1 decreased.[29] Thus, further study is needed to confirm the effect of PLB on lung volume, along with assessment of lung hyperinflation. The resulting knowledge will provide more detail for clinical decision-making when using PLB in patients at different stages of COPD.

Positive changes in EILV and $EILV_{RC}$ were noted during PLB-FTLP. PLB promotes a reduction of EELV and longer T_e, while FTLP has a positive effect on respiratory muscles and increased $EILV_{RC}$.[9] Moreover, significant increases in $EELV_{AB}$, EELV, and $EILV_{AB}$ were observed during FTLP compared to upright posture. During FTLP, gravity pulls the abdominal wall forward, resulting in lengthening of abdominal muscles,[15] which leads to an increase in abdomen circumference and EELV. Although our result was consistent with the previous study,[15] an increase in EELV has usually been reported as a factor inducing dyspnea.[15] Although no adverse effect of high EELV was founded in this study or previous study,[15] our study investigated the effect of FTLP for a duration of only 1 minute. A longer duration of performing FTLP may provide a different result on EELV and dyspnea in patients with COPD. Thus, a further study focusing on the effect of the time duration of FTLP may confirm that there is no adverse effect of increase EELV during a long period of FTLP. According to our results, FTLP should be used along with PLB to improve lung volume in patients with mild to moderate COPD.

There was no significant impact found from either UP or FTLP on any ventilation parameters except V_T/T_i. The changes in V_T/T_i may have occurred due to a greater increase in V_T/Ti during UP posture than during FTLP. For the other ventilation parameters, our results were consistent with previous studies.[9,15] No significant difference was found between V_T and ventilation during performed FTLP as compared to upright posture.[9,15] Taken together with previous studies, ventilation was found to be positively changed by the change in the breathing pattern of PLB, but not by the body postures.

In this study, the combined effect of PLB-UP and PLB-FTLP resulted in positive changes in the compartmental and total lung volumes of $EELV_{RC}$, $EILV_{RC}$, EILV, V_{TRCa}, and V_T as compared to those with QB. Our positive combined effect of PLB-UP and PLB-FTLP contradicts the non-significant interaction effect between body postures and breathing patterns on V_T and RR in patients with moderate COPD previously reported.[9] The previous results showed that V_T and RR were positively changed during PLB compared to QB, regardless of the body posture.[9] Additionally, lung volume and other ventilation parameters were not measured in the earlier study due to instrument limitations.[9] In our study, PLB-UP significantly increased V_T and positively changed lung volumes compared to all other testing tasks. The ability to detect small but significant changes in compartmental lung volumes in our study is most likely due to the advantages provided by the OEP. Based on our results, PLB-UP and PLB-FTLP should be used in pulmonary rehabilitation programs to improve total and compartmental lung volumes in patients with mild to moderate COPD.

4.1. Limitations

Firstly, our patients were mild to moderate COPD and quite active, as indicated by their activity level and self-reported non-significant dyspnea prior to and during the testing tasks. Therefore, our results apply to patients with minimal dyspnea related to COPD. Secondly, this study did not focus on the effect of interventions on the activities of the chest wall and trunk muscles. In contrast, our study infers the functions of the involved muscles based on the changes of compartmental lung volumes. Adding a direct method of electromyography (EMG) to an OEP should provide a clearer picture of these breathing patterns and body postures in patients with COPD. Lastly, our study sample size is relatively small and has a combination of patients with mild and moderate COPD. Due to this small sample size, the results of this study should be considered preliminary, and further studies will be needed to confirm its results. Additionally, this small sample size also limited our ability to perform sub-group analysise. Further studies with a larger sample size and separate groups of patients with mild and moderate COPD are needed to confirm the effect of PLB, FTLP, and combined strategies.

4.2. Clinical Implications

PLB is an effective strategy for positively changing the total and compartmental lung volumes and ventilation in patients with mild to moderate COPD. It can be used in combination with UP or FTLP since there was no significant difference observed between these 2 postures. During FTLP, PLB is be recommended over QB since it significantly and positively due to its significantly greater positive change in the total and compartmental lung volumes.

In conclusion, a combination of PLB with UP or FTLP demonstrates a positive change in the total and compartmental lung volumes in patients with mild to moderate COPD. In these patients, PLB is more beneficial than QB in improving ventilation. Further studies with subgroup analyses and a relatively larger sample size are needed to confirm these effects in patients with specific stages of COPD. Additional measurements of lung hyperinflation and muscle activity during PLB and FTLP will further elucidate the effect of these strategies in patients with different stages of COPD.

Author contributions

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