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Cardiorespiratory and metabolic stresses during repeated pursed-lips breathing in chronic obstructive pulmonary disease

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Abstract

Introduction. Pursed-lip breathing (PLB) is a breathing exercise treatment for patients with chronic obstructive pulmonary disease (COPD). The purpose of this study was to investigate the dynamic changes in the cardiorespiratory and metabolic functions during and after repeated volitional PLB and spontaneous breathing (SB) at rest in COPD patients.

Methods. Sixteen patients with moderate-to-severe airflow limitation participated in this crossover study in which the subjects in both the groups randomly received 10 repeated cycles of PLB and SB interventions. Cardiorespiratory and metabolic variables were collected at the baseline, throughout the 10 breathing cycles, and after a recovery period of 5 min.

Results. During PLB, the tidal volume (VT) increased progressively, whereas the breathing frequency (BF) decreased gradually throughout the 10 volitional PLB cycles ($p > 0.05$). However, minute ventilation ($\dot{V}_E$), oxygen consumption ($\dot{V}O_2$), and carbon dioxide production ($\dot{V}CO_2$) remained unchanged during PLB ($p > 0.05$). The VT and BF peaks appeared during the 8th and 7th cycles, respectively, and then plateaued until the 10th breathing cycle. The heart rate (HR) while performing PLB slightly increased ($p < 0.05$) from the 3rd to the 10th cycle compared to SB.

Conclusions. Despite the clinical benefits of PLB in increasing the inspired volume and slowing the rate of breathing, this manoeuvre in COPD patients should be prescribed with an awareness of the risk of cardiac stress, especially the effect on the HR, as well as the respiratory limitations with repeated PLB. Practically, this study recommends limiting repeated PLB in COPD patients to seven breathing cycles.

Key words: pursed-lip breathing, chronic obstructive pulmonary disease, breathing exercise

Introduction

Chronic obstructive pulmonary disease (COPD) is a serious respiratory disease and the fourth leading cause of death in 2010 (2.9 million deaths in developing countries) [1]. It can lead to symptoms of dyspnoea, which are a major problem in COPD patients. Physiologically, COPD is characterised by abnormal gas exchange, increased metabolic cost, breathing insufficiency, and increased work of breathing (WOB) [2, 3]. This decreases oxygen delivery to tissues and impairs muscle efficiency [4–6]. COPD patients experience physical deterioration, which affects their lifestyle, activities of daily living, and exercise ability [7]. One of the non-pharmacologic supportive treatment techniques that is frequently used in COPD patients is pursed-lip breathing (PLB). The PLB technique is especially effective in delaying early bronchial collapse [8–10] due to the extremely fast respiratory rate in COPD patients [4]. As part of the physical exercise, PLB has an active involvement of both the inspiratory and expiratory muscles [11]. This breathing manoeuvre may affect either the cardiovascular or metabolic functions.

To control oxygenation via ventilation, PLB creates and sustains positive intraluminal pressure, known as positive end-expiratory pressure (PEEP), by slow and prolonged exhalation through pursed lips [12, 13]. This technique recruits more active expiratory muscles to maintain a prolonged exhalation phase [14]. On the other hand, the prolonged exhalation method is an unusual manoeuvre for individuals, compared to spontaneous breathing. Without proper awareness, this manoeuvre may exaggerate symptoms in some respiratory disease patients. In addition, repeated PLB might affect the intrathoracic pressure, which can interfere with central haemodynamic control [15].

PLB is routinely prescribed to COPD patients as an adherence treatment with less specific details on the number of repetitions. Practically, most physiotherapists direct COPD patients to practice 5–10 times per set. This breathing technique is known to cause fluctuations in the intrathoracic pressure, which can affect not only the respiratory system but also cardiac function [16]. Previous data has shown that the breathing exercise could alter resting and exercise metabolic rates in healthy adults [17]. Although PLB might alter cardiorespiratory and metabolic functions in COPD patients, the positive and negative effects are still unclear [18–20]. We rely mainly on the positive aspects of the PLB manoeuvre without considering the possible adverse effects. Therefore, the objectives of this study were to determine the possible stress on cardiorespiratory and metabolic functions during repeated PLB compared to spontaneous breathing at rest in patients with COPD.

Subjects and methods

Participants

This study included subjects aged 50–75 years with euhydration status (urine specific gravity of approximately 1.003–1.030) who voluntarily participated in this study. The

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sample size calculation was performed based on a power of 0.95, level of significance of 0.05, and effect size of 0.85 [18]. The drop out was 10%; therefore, the total number of participants was 16. Sixteen COPD subjects (males) were recruited from the outpatient COPD clinic, Faculty of Medicine at Ramathibodi Hospital, where they were screened by chest physicians. The inclusion criteria were as follows: moderate-to-severe COPD with stable clinical condition for the last 3 months; FEV1/FVC < 70% and FEV1 in post-bronchodilator 79%–30% of predicted [21] within the last 3 months; and no sign of infection or inflammation prior to the study. If the patients were found to have cardiac or neuromuscular problems, uncontrolled hypertension of > 140/90 mmHg, percutaneous oxyhaemoglobin saturation (SpO_2) of < 80% during daily activities, heart rate > 120 beats/min, or required oxygen supplementation at rest, they were excluded from the study. On the recruiting days, they were promptly trained to ensure correct breathing techniques. Prior to the first test, they were asked to avoid coffee, tea, and alcoholic drinks for at least 12 hours prior to each test. Routine medications that did not exert any effect on the study results were allowed by a physician. Informed consent was obtained from all the individuals included in this study.

Study design

This study used a randomised crossover design for the order of the breathing techniques (PLB and SB). Data were collected between January 2020 and February 2021 in the hospital during the first wave of the COVID-19 pandemic.

Breathing interventions

Pursed-lips breathing (*PLB*)

Subjects performed PLB by inspiring through the nostrils with the mouth closed, and then slowly breathing out through half-opened (puckered) lips. The correct manoeuvre must avoid forceful exhalation and cheek puffing [8, 22], such as while blowing out a candle. The expiratory phase must be performed slowly so that it is about two or more times longer than the inspiratory phase [22]. To attain the prolonged expiratory phase, the breathing cycle of PLB was governed by verbal commands from a well-practiced investigator, as suggested in previous studies [9, 22]. All participants were trained to confirm the use of the correct PLB technique before starting each experiment. They were asked to sit upright in a comfortable and relaxed position.

Spontaneous breathing (*SB*)

The subjects were asked to sit upright in a comfortable and relaxed position. They comfortably and spontaneously breathed in and out through the nose without using the muscles of the buccal cavity, neck, or abdomen.

Instrumentation

Assessment of cardiovascular function

Cardiovascular function, including the stroke volume (SV), heart rate (HR), and cardiac output (CO) were measured using a non-invasive cardiac impedance method (PhysioFlow®, Enduro™ technology, France). Based on the cardiac impedance principle, this method has been approved for reliable and valid outcomes with high correlations with the gold standard methods [23]. Signals from intrathoracic haemodynamic changes were transferred via six surface electrodes placed on specific chest wall skin areas: two on the left lateral aspect of the neck, one in the middle of the sternum, one in the mid-axillary line in the 5^{th} intercostal space, and two at the back at the same level of the xiphoid process. For accuracy and reproducibility of data, calibration was routinely performed using simultaneous inputs of blood pressure and ECG signals as the reference values. These variables were collected by a research assistant who was well-qualified to use this instrument.

Assessment of respiratory and metabolic functions

Respiratory and metabolic functions were determined using a telemetry gas analyser (Oxycon®, Jaeger, USA). The rate of oxygen consumption ($\dot{V}O_2$), carbon dioxide consumption ($\dot{V}CO_2$), tidal volume (V_T), minute ventilation ($\dot{V}_E$), and breathing frequency (BF) were continuously recorded. Starting from volume calibration using a 3-litre syringe, and automatic calibration for flows signals using the manufacturer's software at two points of flow, 0.2 l/s and 2 l/s, gas calibrations for CO_2 and O_2 were performed with ambient air (0% CO_2 and 20% O_2) and a standard gas cylinder (5% CO_2 and 16% O_2). Data were collected as the participants breathed via a face mask. The signal recording was set in a breath-by-breath pattern.

Procedure

Patients with COPD were recruited for this study in accordance with inclusion and exclusion criteria. The order of the breathing techniques (SB and PLB) was randomly assigned to each subject. For both types of breathing, the participants were asked to rest, relax, and breathe spontaneously for 5 min. Before these breathing techniques were correctly performed, cardiac, respiratory, and metabolic variables were collected at the baseline. The participants were then asked to perform PLB or SB for 10 cycles. Data were collected at the end of each breath throughout the 10 breathing cycles for cardiovascular, respiratory, and metabolic variables. The data in the recovery period were collected for each minute for a 5-minute period. They were then asked to rest for 30 minutes and all variables were returned to baseline levels. This procedure was repeated for crossover examination with the other breathing type.

Data analysis

Intention-to-treat analysis was performed in all participants. Cardiorespiratory and metabolic variables were analysed using two-way repeated measures ANOVA (SPSS software version 22) and Bonferroni correction to compare the within-group differences (time series from the baseline, 1^{st}–10^{th} cycles, and recovery at 1^{st}–5^{th} minutes), and differences between the two breathing types. Statistical significance was set at a *p*-value of less than 0.05 ($p < 0.05$)

Ethical approval

The research related to human use has complied with all the relevant national regulations and institutional policies, has followed the tenets of the Declaration of Helsinki, and has been approved by the Ethic Committee on Human Experiment of Mahidol University Central Institutional Review Board (approval No.: MU-CIRB 2019/076.0703).

Informed consent

Informed consent has been obtained from all individuals included in this study.

Results

Participants

Patients with COPD (n = 16) were enrolled in the study according to inclusion and exclusion criteria. All subjects completed the entire study with no cases of adverse events. Most of the participants were GOLD stage II (14 participants), and only two participants were GOLD stage III (Table 1). Moreover, all subjects had a history of smoking.

Table 1. General characteristics including anthropometric and COPD-related signs in mean ± *SD*

Subjects' characteristics	COPD group (n = 16)
Anthropometric variables	
Age (years)	68.69 ± 5.42
Weight (kg)	67.61 ± 12.55
Height (m)	1.65 ± 0.05
BMI (kg/m^2)	24.92 ± 5.05
Sex (n; male/female)	16/0
COPD-related variables	
GOLD stage of COPD (stage II /III)	(14/2)
History of smoking (Yes/No)	(16/0)

BMI – body mass index, GOLD – Global Initiative for Chronic Obstructive Lung Disease

Effect of repeated PLB on metabolic function

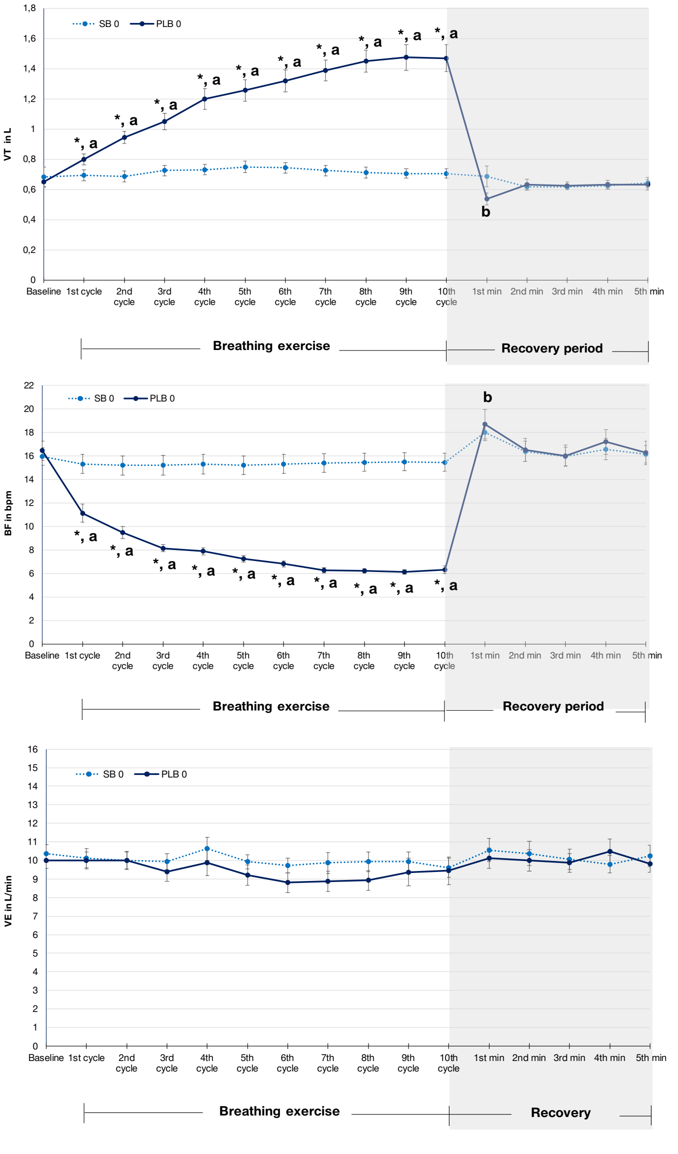
The absolute $\dot{V}O_2$ and $\dot{V}CO_2$ values at the baseline were not significantly different between the SB and PLB in the COPD patients ($\dot{V}O_2$: 0.26 ± 0.01 vs 0.24 ± 0.01 l/min, $\dot{V}CO_2$: 0.21 ± 0.01 vs 0.20 ± 0.01 l/min; $p > 0.05$). Compared to the initial values, $\dot{V}O_2$ and $\dot{V}CO_2$ showed no significant difference ($p > 0.05$) between PLB and SB throughout the 10 breathing cycles and recovery period. Between the two breathing types, both $\dot{V}O_2$ and $\dot{V}CO_2$ were not significantly different throughout the time series ($p > 0.05$).

Effect of repeated PLB on respiratory function

At the baseline, all parameters demonstrated no significant differences between SB and PLB (V_T: 0.68 ± 0.07 vs 0.65 ± 0.03 l, $\dot{V}_E$: 10.38 ± 0.47 vs 10.00 ± 0.43 l/min, BF: 15.94 ± 0.75 vs 16.44 ± 0.82 bpm, respectively; $p > 0.05$). During PLB, V_T significantly increased ($p < 0.05$) from the 1st to 10th cycle (0.80 ± 0.04 to 1.47 ± 0.09 l; $p < 0.05$) compared to the baseline, and then suddenly dropped to the baseline in the 1st minute (0.54 ± 0.04 l, $p < 0.05$) compared to the baseline (Figure 1). Interestingly, V_T increased gradually from the baseline to the 8th cycle and then plateaued until the 10th cycle of breathing. In contrast to V_T, the BF gradually and significantly decreased from the 1st to 10th cycle (11.13 ± 0.75 to 6.31 ± 0.31 bpm; $p < 0.05$) compared to the baseline, followed by recovery to the baseline after the 1st minute. During PLB, the BF decreased continuously from the baseline to the 7th cycle, and then plateaued to the 10th cycle. In addition, $\dot{V}_E$ during PLB in the COPD patients showed a tendency to decrease from the 3rd to the 10th cycle, although there was no significant difference throughout the 10 PLB cycles ($p > 0.05$). The comparison between the types of breathing (SB and PLB) showed significant differences at every time point from the 1st to 10th breathing cycle ($p < 0.05$) with regard to V_T and BF but did not show a significant difference in $\dot{V}_E$.

Effect of repeated PLB on cardiac function

There were no significant differences between SB and PLB at the baseline with regard to the absolute HR, SV, and CO ($p > 0.05$). HR during PLB in the COPD patients was significantly higher from the 3rd to 10th breathing cycles ($p < 0.05$) compared to SB, but not significantly different from the baseline within PLB ($p > 0.05$) (Table 2). In contrast, SV during PLB tended to decrease, but did not differ significantly between the breathing types and time series. The results indicated no significant effects of the breathing type and time series on SV and CO during PLB and SB.



a – significant difference within group from baseline ($p < 0.05$),
b – significant difference within group from previous time ($p < 0.05$)
* significant difference between SB and PLB

Figure 1. Comparisons between SB and PLB of VT, BF and $\dot{V}_E$ at baseline, 1st–10th cycle, post at 1st–5th min (means ± SEM)

Table 2. Cardiac function between SB and PLB at baseline, 1st–10th cycle post at 1st–5th min (means ± SEM)

Time	HR (bpm)		SV (ml)		CO (L/min)	
	SB	PLB	SB	PLB	SB	PLB
Baseline	79.20 ± 2.25	82.44 ± 3.22	72.98 ± 2.73	72.69 ± 2.95	5.90 ± 0.25	5.92 ± 0.24
1st cycle	81.13 ± 3.33	82.00 ± 3.19	74.11 ± 2.83	72.06 ± 3.35	5.92 ± 0.21	5.81 ± 0.21
2nd cycle	80.63 ± 3.15	82.56 ± 3.20	74.41 ± 2.99	72.23 ± 3.41	5.93 ± 0.24	5.84 ± 0.20
3rd cycle	80.00 ± 3.24	83.38 ± 3.29*	73.28 ± 2.64	71.61 ± 3.28	5.81 ± 0.23	5.86 ± 0.22
4th cycle	80.19 ± 3.24	83.69 ± 3.32*	71.95 ± 2.88	70.93 ± 2.93	5.71 ± 0.25	5.66 ± 0.12
5th cycle	80.44 ± 3.17	83.94 ± 3.33*	72.10 ± 2.83	70.88 ± 3.15	5.77 ± 0.28	5.84 ± 0.19
6th cycle	80.31 ± 3.28	84.38 ± 3.35*	72.69 ± 2.63	69.97 ± 3.10	5.83 ± 0.29	5.81 ± 0.18
7th cycle	80.25 ± 3.27	84.56 ± 3.41*	73.61 ± 2.55	70.37 ± 2.84	5.89 ± 0.27	5.73 ± 0.15
8th cycle	80.38 ± 3.16	84.56 ± 3.35*	74.24 ± 2.52	69.51 ± 2.63	5.94 ± 0.27	5.79 ± 0.19
9th cycle	80.56 ± 3.21	85.56 ± 3.54*	75.01 ± 2.48	70.41 ± 2.69	6.01 ± 0.27	5.92 ± 0.17
10th cycle	80.69 ± 3.17	85.69 ± 3.52*	75.48 ± 2.63	69.68 ± 2.93*	6.06 ± 0.27	5.86 ± 0.17
Post at 1st min	80.94 ± 3.56	80.38 ± 3.24	71.58 ± 2.43	73.96 ± 2.69	5.91 ± 0.29	5.89 ± 0.21
Post at 2nd min	81.44 ± 3.44	81.31 ± 3.01	75.89 ± 3.14	70.71 ± 2.49*	6.11 ± 0.25	5.69 ± 0.16*
Post at 3rd min	80.25 ± 3.40	80.69 ± 3.31	70.88 ± 2.13	74.01 ± 2.34	5.75 ± 0.23	5.75 ± 0.17
Post at 4th min	80.50 ± 3.26	82.31 ± 3.09	71.19 ± 2.56	75.49 ± 2.94	5.80 ± 0.25	6.03 ± 0.18
Post at 5th min	81.00 ± 3.39	81.50 ± 3.41	72.58 ± 32.72	77.28 ± 2.94	5.78 ± 0.24	6.22 ± 0.25*

* significant difference between SB and PLB ($p < 0.05$)

Discussion

Pulmonary rehabilitation is a part of COPD treatment that aims to relieve uncomfortable symptoms and complications. Understanding the effects of repeated PLB, which is a major component of this rehabilitation, will improve the usefulness of lung rehabilitation. Therefore, the efficacy of repeated PLB has to be clarified not only for therapists but also for nurses, caregivers, and patients themselves.

Effect of repeated PLB on respiratory function

Pulmonary ventilation is generally optimised by modifying the breathing frequency, tidal volume, or both. In our study, volitional PLB was repeatedly performed via deep inspiration and prolonged with slower expiration. This technique promoted an increase in V_T and reduction in BF compared to the baseline. This result was concurrent with previous studies showing that prolonged expiratory duration decreased the BF and increased the V_T, and had the benefits of relieving symptoms, such as reduced airway collapse, air trapping, and maintenance of alveolar ventilation [4, 18, 20, 24, 25]. In our study, the V_T gradually increased from the baseline to the 8th cycle and then plateaued to the 10th cycle of breathing. This implies that the change in V_T followed the PLB, which was stimulated through deeper breathing. These changes in V_T can help to improve dead space ventilation and improve gas exchange in the lungs [18, 20, 24, 26, 27].

On the other hand, the BF dropped steeply in the 1st cycle compared to the baseline, with a progressive decline until the 7th cycle, and then plateaued until the 10th cycle. This possibly implies that COPD patients have expiratory flow problems that have a higher resistance to expiration. In addition, the longer expiratory time in COPD helps to generate a small level of positive expiratory pressure (PEP) [24, 28]. This pressure in COPD prevents early airway closure and causes air trapping within the lung [4, 18]. Gandevia [29] found that slow expiration can increase the expired lung volume by 20% compared to forced expiration, which can reduce air trapping. Therefore, these changes promoted lung emptying and increased the inspiratory volume in the next breathing cycle, which supported the improvement in V_T in the above study. In comparison, our results showed a twofold increase in V_T in the 7th breathing cycle.

In the present study, the $\dot{V}_E$ did not change throughout the 10 breathing cycles in PLB and SB. These findings are similar to those of previous studies. $\dot{V}_E$ was calculated from the tidal volume and breathing frequency. During PLB, the pattern of $\dot{V}_E$ indicated that the increase in V_T was sufficient to maintain an unchanged $\dot{V}_E$, although there was a decrease in BF [27]. These changes seem to be related to the unchanged $\dot{V}O_2$ in COPD, which helped to diminish the WOB from a slower rate of breathing compared to healthy individuals [4, 26]. Tiep et al. [30] compared a relaxation technique and PLB in COPD and found no significant difference in $\dot{V}_E$ and $\dot{V}O_2$ between the techniques. They claimed that PLB did not change the WOB.

According to our results of respiratory function, the plateau in V_T lasted from the 8th to 10th cycle, which is nearly the same as the plateau in BF from the 7th to 10th cycle. Therefore, this study recommends the prescription of PLB for COPD patients for at least seven breathing cycles.

Effect of repeated PLB on metabolic function

The resting gas exchange showed the general characteristics of lower $\dot{V}CO_2$ production than $\dot{V}O_2$ consumption. These values have been generally found in human studies, which result in a respiratory exchange ratio of less than 1.00 [31]. During PLB, the $\dot{V}O_2$ and $\dot{V}CO_2$ patterns did not differ significantly between and within the two breathing types. It is possible that COPD subjects are used to using the accessory muscles to compensate for their routine breathing difficulties. Our results were similar to those reported by Mueller et al. [18]. PLB did not change the $\dot{V}O_2$, which means that the total body metabolic WOB was unchanged during the PLB manoeuvre [4, 18]. With consistently higher WOB seen in COPD, this will not affect the resting metabolic rate but rather improve the quality of life [32, 33]. In our study, it was possible that the COPD patients were unintentionally used to a higher $\dot{V}O_2$ and $\dot{V}CO_2$ as they used the accessory muscles to compensate for their routine daily breathing difficulties. Therefore, PLB did not significantly affect the metabolic function during the 10 breathing cycles in the patients with COPD.

Effect of repeated PLB on cardiac function

Regarding the haemodynamic status during repeated PLB and SB, this study focused on three simple cardiac indices: HR, SV, and CO. With regular evaluation of the cardiac indices, public health personnel will be able to better understand the potential abnormal signs and symptoms. This can help in making proper decisions and providing optimal care to each patient.

Our study revealed that the HR during repeated PLB was higher than that during SB (increase by 3–5 bpm from the 3rd to 10th cycle of repeated PLB). However, the HR in COPD patients dropped significantly to the baseline when the repeated PLB intervention was stopped. Therefore, a small change in the HR during PLB occurred due to repeated PLB. It is possible that (1) PLB may cause stress on the cardiac function and autonomic dysfunction in COPD patients by increasing the heart rate to maintain a steady cardiac output, and (2) it seems likely that there is a ventilation limitation that cannot increase the $\dot{V}_E$ in COPD patients, which is caused by dynamic hyperinflation during PLB that affects the decrease in SV (in this study, the trend was not significant) and HR to maintain the CO. A previous study reported fluctuations in the HR during PLB in both COPD patients and healthy individuals, which may be due to changes in the autonomic nervous system [34]. In our study, the stroke volume and CO remained unchanged (Table 2). However, the HR in the COPD group slightly increased from the 3rd to the 10th PLB cycles. Autonomic dysfunction in COPD patients has been reported to be affected by recurrent hypoxaemia, hypercapnia, and increased dynamic intrathoracic pressure fluctuations due to inconsistent airway obstruction [35]. Moreover, the respiratory rhythm and rate are not only affected by the respiratory system but also influenced by cardiac autonomic modulation. In previous studies, Sakhaei et al. [16] and Ramos et al. [19] studied the effect of continuously repeated PLB for 10 and 8 minute periods (long-term) on cardiac parameters and heart rate variability (HRV). They found a reduction in the HR and an increase in the parasympathetic activity while performing PLB. In contrast to the above study, we performed 10 acute repeated PLB cycles (total duration of approximately 2 minutes) in COPD patients and analysed every breathing cycle. Changes in the cardiac variables seem to be in response to the light-intensity exercise, and our study results showed an increase in the HR, not a reduction. These changes were possibly due to an autonomic adjustment in COPD patients due to which the higher HR may be enhanced during short-term repeated PLB. In summary, repeated PLB not only affects the respiratory system but also affects the cardiac system. Therefore, when practicing repeated PLB in COPD patients, attention should be paid to the cardiac response, especially the HR, when increasing the time of repetitions.

Further study

The changes in metabolic function from breathing exercises should be determined directly by arterial blood gas (ABG) test measuring the level of oxygen and carbon dioxide, and acid-base balance (pH) in the blood.

Limitations

This study did not determine the maximal voluntary ventilation (MVV) to assess the ventilatory reserve and ventilatory limitation in COPD, which may explain the dynamic alterations of the cardiac and respiratory variables. Further studies should examine this variable to explain the changes seen in these parameters. Moreover, all participants in this study were male, and this study did not investigate the effects of biological sex on breathing exercises. The next study should investigate all sexes.

Conclusions

The results of this study could be relevant to moderate-to-severe COPD patients. Repeated PLB in moderate-to-severe COPD may enhance the higher tidal volume and lower the breathing frequency. On the other hand, this technique may not change the minute ventilation, O_2 consumption, and CO_2 production in COPD patients. However, repeated PLB can cause possible adverse effects due to cardiac stress resulting from an increase in the heart rate, with no change in the cardiac output and stroke volume, and there should be awareness regarding these changes while prescribing PLB in COPD patients. Based on the above findings, this study recommends the use of PLB in COPD patients for seven breathing cycles.

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Disclosure statement

No author has any financial interest or received any financial benefit from this research.

Conflict of interest

The authors state no conflict of interest.

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