Efficacy of noninvasive respiratory techniques in the treatment of children with bronchial asthma: a randomized controlled trial

Ragab K. Elnaggar[a], Mohammed A. Shendy[b]

[a]Departments of Physical Therapy for Disturbances of Growth and Development in Children and its Surgery, [b]Physical Therapy for Cardiovascular, Respiratory Disorders and Geriatrics, Faculty of Physical Therapy, Cairo University, Cairo, Egypt

Correspondence to Ragab K. Elnaggar, PhD, Department of Physical Therapy for Disturbances of Growth and Development in Children and its Surgery, Faculty of Physical Therapy, Cairo University, Cairo, Giza 12613, Egypt Tel: + +20 109 351 2336
E-mail: rke_pt2001@yahoo.com

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Background and purpose
Although the effects of the respiratory techniques are appreciated, it is yet in need to be defined for the treatment of children with bronchial asthma. Thus, this study aimed to compare the effects of the active cycle of breathing technique (ACBT), Buteyko breathing technique (BBT), and thoracic lymphatic pump technique (TLPT) on the total serum immunoglobulin (Ig) E, ventilatory function, and asthma perception in children with bronchial asthma.
Materials and methods
In a randomized controlled trial, 54 children with bronchial asthma randomly allocated to three equal groups. The groups were then randomly assigned to the following interventions: the ACBT group, the BBT group, or the TLPT group. Total serum IgE, ventilatory function, and perception of asthma were evaluated before treatment and after 3 consecutive months of treatment.
Results
No significant differences were found between groups at entry ($P>0.05$). There were nonsignificant differences as regards all outcome measures within the ACBT group ($P>0.05$) and significant differences within the BBT group and the TLPT group ($P<0.05$). Significant difference in total serum IgE in favor of the BBT group was recorded when compared with ACBT group ($P=0.046$) and the TLPT group ($P=0.036$). Moreover, significant differences in ventilatory function measures favoring the BBT group in comparison with the ACBT group and the BBT group ($P<0.05$) were recorded. Finally, asthma control was significantly higher in the BBT group than ACBT group ($P=0.017$) but not BBT group ($P=0.081$).
Conclusion
The BBT and TLPT are more advantageous compared with the ACBT in the treatment of children with bronchial asthma, and Buteyko breathing is potentially more valuable.

Keywords:
asthma perception, bronchial asthma, respiratory techniques, total serum IgE, ventilatory function

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Introduction

Asthma is one of the most common chronic inflammatory and long-term disease of the airways in children [1]. It is characterized by reversible airflow obstruction, bronchospasm, breathlessness, and tightness of the chest [2]. The inside walls of an asthmatic patient's airway are swollen or inflamed, extremely sensitive to irritations, and susceptible to allergic reactions [3]. It is one of the diseases that account for hospital stay and school day loss. An average of one of every 10 school-aged children suffers from asthma worldwide [4]. However, the prevalence among Egyptian school-aged children is 7.7% [5].

Immunoglobulins (Igs) are a critical part of the immune response. It has many different isotypes. Thus, assessment of the isotypes can provide useful insight into immunological response [6]. IgE antibodies are found in the lungs and mucous membranes. IgE antibody levels are often high in patients with allergic conditions such as asthma. It is involved in allergic reactions by binding to allergens and triggering histamine release from mast cells and basophils [7].

The Buteyko breathing technique (BBT) is a drug-free asthma therapy. It is based on the premise that raising blood $PaCO_2$ through hypoventilation can treat asthma. The BBT may be effective in improving the quality of life and reducing the intake of inhaled reliever medication in patients with asthma [8,9]. The BBT is most often used by the asthmatic patient to reverse the chronic hyperventilation.

Several studies claimed the beneficial effects of Buteyko breathing in asthmatic patients [10,11], but these studies only reported the trends toward improvement or were being uncontrolled. Moreover, the favoring effects of the BBT were presented in two randomized controlled trials compared with other types of breathing and relaxation techniques [12,13]. Hassan *et al.* [14] concluded that the BBT significantly reduces the severity of symptoms (activity limitation, shortness of breathing, and wheezing) and significantly increases peak expiratory flow (PEF) rate. Conversely, a cross-sectional controlled trial by Cooper *et al.* [15] conducted on 51 individuals with symptomatic asthma showed no significant improvement when they used the BBT. In addition, Courtney and Cohen [16] recorded a negative correlation between breath-holding time and tidal carbon dioxide, contradictory to the claims of the BBT.

The active cycle of breathing technique (ACBT) is commonly used to promote airway clearance and prevent further deterioration of lung function [17]. The ACBT requires active participation of the patients and it can be adopted for patients with different diseases [18]. Previous studies by Savci *et al.* [19] and Wilson *et al.* [20] indicated that the ACBT is an effective treatment for improving pulmonary function airway clearance in patients with chronic obstructive lung diseases.

The pulmonary function is dependent on the distensibility of the airways and mobility of the chest [21]. In patients with asthma, the bronchospasm increases the workload on the respiratory muscles, reduces the mobility of the thoracic cage, and totally changes the thoracic compliance and limits the forced expiratory volume (FEV) of the lung. Therefore, any treatment regimen that helps in restoring the function and mobility of the thoracic cage should enhance ventilation and pulmonary function. The thoracic lymphatic pump technique (TLPT) is a combination of compressive force applied to the chest and respiration to create pressure differences between abdominal and thoracic cavities [22]. It can potentially improve lymphatic and venous return toward the heart and enhance deeper diaphragmatic breathing by limiting the upper chest movement and directly affects the volume of air that enters the lung [23,24].

Despite the benefits of the noninvasive respiratory techniques, the use of these exercise modes in the treatment of children with bronchial asthma is currently insufficient and its clinical effects not yet justified. Therefore, the present study aimed to compare the effects of ACBT, BBT, or TLPT on total serum IgE, ventilatory function, and asthma perception in children with bronchial asthma.

Materials and methods

Study design

A prospective, randomized controlled study was conducted in Abu El-Rish Pediatric Hospital, Faculty of Medicine, Cairo University. All children were conveniently selected from Abu El-Rish Pediatric Hospital and Al-Abasia Chest Hospital. The study procedures are in accordance with the local standards, and written informed consent was obtained from all children or their legal guardians.

Participants

Children were recruited from September 2014 to April 2015. All children were screened before inclusion by measuring the predicted value of the ratio of forced expiratory volume in the first second to the forced vital capacity (FEV_1/FVC) [25]. The children were referred to the study if the value of FEV_1/FVC was more than 60 and less than 80. Furthermore, children were included if they were between 8 and 14 years of age and were diagnosed as having mild or moderate asthma based on the predicted value of PEF (PEF >60 and <80). Exclusion criteria included chronic sinusitis, chronic chest problem that affects ventilatory functions, besides asthma, congenital heart diseases, costovertebral fractures, spinal deformities, medications, or other significant health problems that may affect the results of the study and/or have an impact on their safe participation in the study and/or significantly impairs their cognitive function.

Children were randomly assigned to three equal groups (ACBT, BBT, and TLPT) of equal numbers; 18 children were allocated to each group using an independent person who was asked to pick up one of the sealed envelopes that contained numbers created by random number generator. Permuted block randomization with a fixed block size was used to ensure allocation of equal numbers in each group; each block had a sequence of six consecutively numbered nonpellucid closed envelopes. When each child was enrolled in the study, the next envelope in sequence was then opened.

Procedures

The primary outcome measure of this study was the ventilatory function in terms of percentage of predicted values of FVC, FEV_1, PEF, forced expiratory flow

from 25 to 75% of vital capacity ($FEF_{25–75\%}$), and the ratio of FEV_1/FVC. The ventilatory function was measured using the Master Screen IOS spirometer, 1999 (Jaeger, Würzburg, Germany). Each child was instructed to adopt a comfortable sitting. With lips closed firmly on the spirometer disposable mouth piece, initially, the child was asked to breathe normally. After a few breaths, each child was asked to breathe in maximally and then breathe out forcefully. Three trials were allowed, and the largest value obtained from the three executions was used for final analysis.

The secondary outcome measures included total serum IgE levels and childhood asthma control test (C-ACT). Total serum IgE levels were measured using a fully automated immunoassay enzyme-linked immunosorbent assay analyzer, 2000 (TKA, Lacchiarella (Milan), Italy). A blood sample was drawn from the antecubital or dorsal metacarpal veins. The analysis was repeated twice, before and after intervention, to determine the IgE levels. Values of total serum IgE were reported in international units per milliliters (IU/ml).

Asthma control was measured using the C-ACT. It is a seven-item scale that was used to address the last 4 weeks. It consists of two parts [26]. One part is completed by the child and includes four questions as regards the child's perception of asthma, activity limitation, coughing, and night awakening. Each question had four response choices, of which the child had to choose one response. Each response is assigned a specific score. However, the second part comprises three questions as regards daytime complaints, daytime wheezing, and night-time awakening completed by the parents or caregivers and included six response choices. The total scores were calculated from the sum scores of the seven items (0 is the least asthma control score and 27 is the optimal asthma control score with a cutoff point of less than or equal to 19 that indicates poor asthma control) [27].

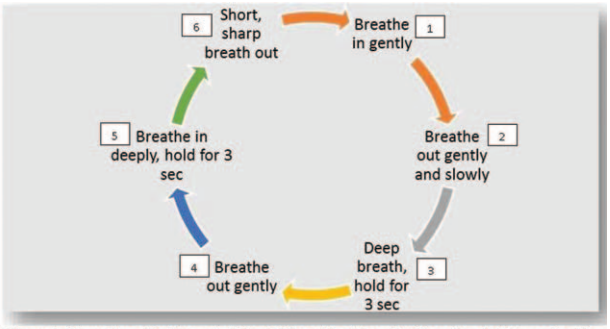
All outcome measures were assessed for the three groups at entry (before treatment) and after 3 consecutive months (post-treatment).

Treatment

Children in the ACBT group were treated with the ACBT. Treatment was conducted by three well-trained physical therapists throughout the treatment period. The treatment consisted of three phases: (a) the relaxed breathing control phase (four to six breaths); (b) the thoracic expansion phase (three to four expansion exercises); and (c) the forced expiration phase (four to six breaths combined with two or three huffs). Once the therapist ensured that there were no signs of exhaustion and the children were breathing comfortably, each child was positioned in a comfortable sitting position and was instructed to actively participate in each phase of treatment [28]. In phase 1, children were instructed to place their hands on their abdomen, breathe in gently feeling their hands rise and breathe out gently and slowly. In phase 2, they were asked to breathe in deeply with relaxed shoulders and upright sitting to expand their chest as far as possible, hold the breath for 3 s, and then finally let the breath out gently. In phase 3, short, sharp breathe out through an open mouth was allowed (Fig. 1). The treatment was applied once/day under supervision, and the duration of each session was determined according to the patient's tolerance, but was kept for 30 min with intervals of rest [18].

Children in the BBT group were treated with the BBT. Children were instructed to adopt a comfortable sitting position with relaxed shoulders and supported back. The BBT was taught to children in three steps. (a) The breathing pause control test: in this test, they were asked to take in a small breath for 2 s, followed by 3 s breathe out. Thereafter, with empty lungs, each child was asked to close the nose and count how long they can comfortably hold breath before they need to breathe in again. Finally, the children released the nose and took a small breath for 2 s as they did before the control pause, especially in the first breath intake after pausing their breath. (b) The shallow breathing technique: in a comfortable sitting position, children learned to monitor their breathing by slightly breathing in just to fill the tip of the nostrils and breath very gently such that a piece of paper in front of the nose could not move. They learned to monitor their breath by feeling the warmth of air

Figure 1



Phase 1: Steps 1 and 2. Repeated for 4-6 breaths, **Phase2:** Steps 3and 4. Repeated for 4-6 breaths, **Phase 3:** Steps 5 and 6. Repeated for 4-6 breaths

Active cycle of breathing technique.

during exhalation with a finger horizontally placed on the upper lip, a little away from the nostrils, to avoid blocking of breathing. They were asked to concentrate to calm down breath to decrease the amount of warm air so that they can feel the need for air. The need for air should be maintained for about 2–3 min. (c) The children were asked to perform breathing pause control followed by shallow reduced breathing for 2–3 min, and then 2 min of relaxed, normal breathing was allowed (Fig. 2). This breathing cycle was repeated three times per session [14,29].

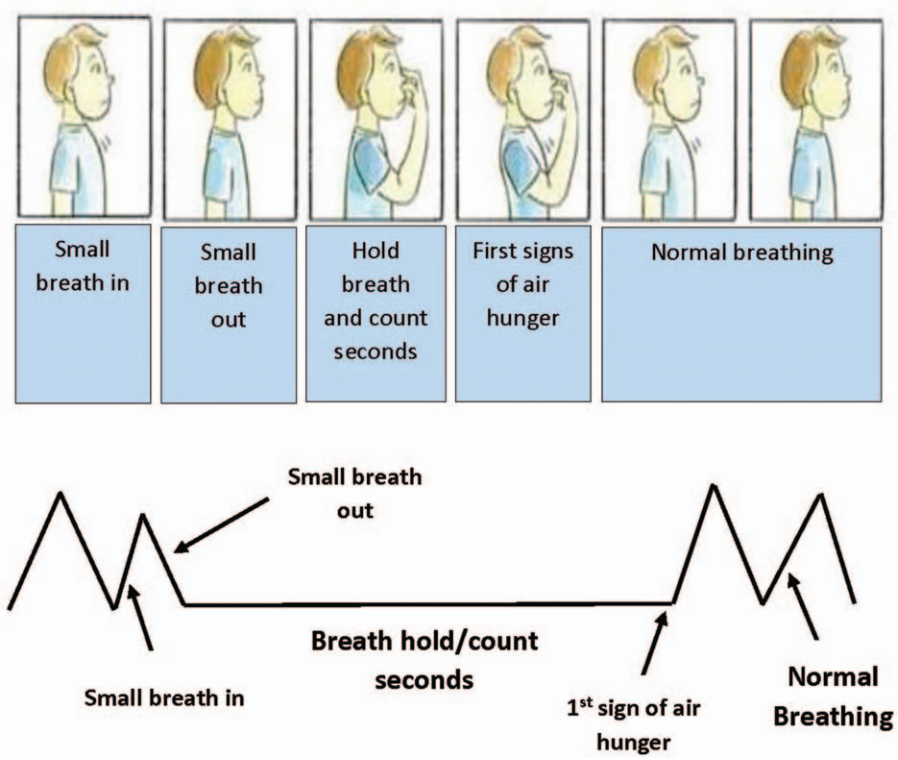
Children in the TLPT group were treated with the TLPT. Children were made to lie in the supine position, with the therapist standing at the head of the table facing children. The therapist's hands were placed bilaterally on the patient's chest, with the thenar eminence on the upper rib infraclavicular and the other fingers fanned on the upper chest and the pectoral region. A posterior and caudal compression was applied to the chest. Thereafter, the children were asked to breathe in deeply while the therapist maintained the compressive force equal to the force applied by the thoracic cage, to allow full inspiration and to avoid unnecessary discomfort. Once the expiration was begun, the therapist applied a rapid and rhythmic vibratory force to the chest. When expiration ended and inspiration started again, the compressive force was maintained. The technique was repeated for a total of five maximal inspirations and five oscillatory chest compressions. In the sixth breath, the chest compression force was released gradually to allow full inspiration [23].

For the three groups, treatment duration was determined according to patient's tolerance, but maintained for about 30 min with intervals of rest. The treatment was conducted three times per week for 3 consecutive months. Children and parents were knowledgeable about the administered treatment before they started after allocation to the groups.

Sample size calculation

The sample size was initially calculated using G*power (version 3.0.10, Neu-Isenburg, Germany) to determine the number of children in each group. Estimates of means of the predicted value of FVC were collected from a pilot study conducted on 12 asthmatic children who received the same interventions in three groups. One-way analysis of variance, α level 0.05, power desired was 95%. These assumptions created a total sample size of 39 children. The sample size increased to 54 to account for dropout rates.

Figure 2



Buteyko breathing technique [29].

Statistical analysis

Descriptive statistics (mean and SD) were computed for all data. The Kolmogorov–Smirnov test of normality was conducted to test how likely the pretreatment outcome measures were normally distributed. The variables of interest were the total serum IgE, PEF, and perception of asthma. Consequently, one-way analysis of variance (ANOVA) test was used to compare the pre and post treatment levels of total serum IgE between groups, and the post-hoc Bonferroni test was used for pairwise comparison of the post-treatment outcomes that revealed significant differences. Moreover, paired sample *t*-test was used to compare the pretreatment and post-treatment mean values of IgE level within each group. Regarding the ventilatory function measures (FVC, FEV_1, PEF, $FEF_{25–75\%}$, and FEV_1/FVC) and the outcomes of C-ACT. The Kruskal–Wallis *H*-test was conducted to compare the pretreatment and post-treatment mean values between groups, and pairwise comparison between groups was assessed using the Mann–Whitney *U*-test. However, comparison within each group was computed using the Wilcoxon signed-rank test. The effect size within group was calculated on the basis of the mean differences using Cohen's *d* formula: $\left(d = \overline{X} - \frac{\overline{X}}{S_{\text{pooled}}}\right)$, where $\overline{X_1} - \overline{X_2}$ represents the mean difference of the pretreatment and post-treatment outcome measures and S_{pooled} refers to the pooled SD; effect size of 0.2–0.3 was considered a small effect, around 0.5 a medium effect, and effect size of 0.8 or more a large effect. The effect size between groups based on variance was calculated using η^2 equation $\left(\eta^2 = \frac{\text{SS}_{\text{treatment}}}{\text{SS}_{\text{total}}}\right)$, where SS refers to the sum of squares, the percentage of the effect size due to treatment calculated by (η^2×100). The level of significance for all statistical tests was set at *P*-value less than 0.05. All statistical measures were performed using the statistical package for social sciences, version 20 for windows.

Results

A total of 71 children were assessed for eligibility. Of them 54 children were conveniently selected to participate in the study. They were randomized to three equal groups (Fig. 3).

There were no statistically significant differences at entry as regards age, weight, height, and BMI (Table 1).

Test of normality

We hypothesized that all pretreatment outcome measures of total serum IgE, PEF, and perception of asthma were not normally distributed. Data analysis indicated that the pretreatment values of total serum IgE and PEF were likely to be normally distributed and the null hypothesis was rejected (*P*=0.173 and 0.419, respectively). However, perception of asthma was unlikely to be normally distributed (*P*=0.003).

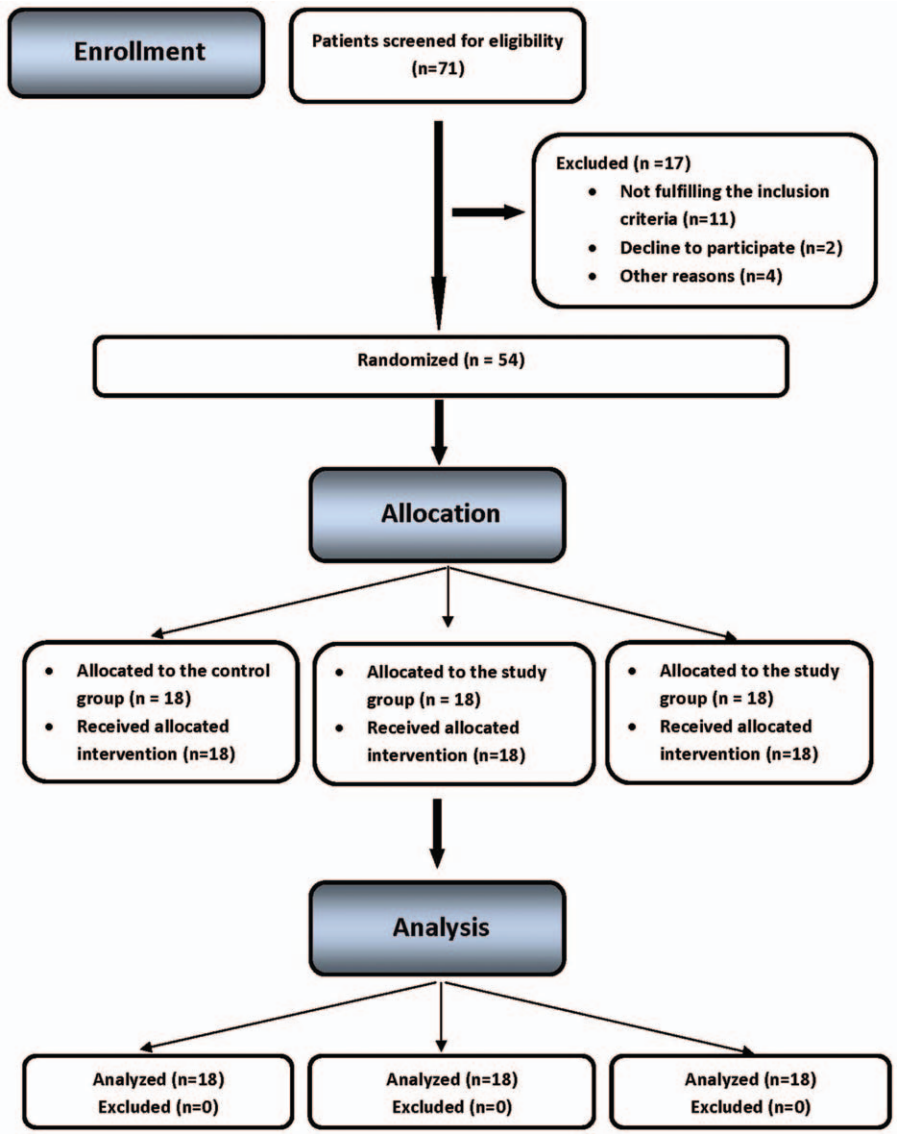
Total serum immunoglobulin E

There were no significant differences between all groups at the entry level. Comparison within groups revealed no significant differences between the pretreatment and post-treatment mean values of total serum IgE level within the ACBT group and the TLPT group, whereas there was a significant difference within the BBT group (Table 2). Significant differences were indicated between groups after treatment. The recorded post-treatment difference was in favor of the BBT group compared with the ACBT group (*P*=0.046) and the TLPT group (*P*=0.036).

Ventilatory functions

There were no statistically significant differences in the mean values of the percentage of predicted values of FVC, FEV_1, PEF, $FEF_{25–75\%}$, and FEV_1/FVC at baseline (Table 3). The post-treatment mean values of FVC, FEV_1, PEF, $FEF_{25–75\%}$, and FEV_1/FVC are presented in Table 4. The data indicated significant differences between the three groups as regards all outcome measures. The post-treatment difference in FVC between groups was noted on comparing the ACBT group with the BBT group favoring the BBT group (*P*=0.001), with no differences between the ACBT group and the TLPT group (*P*=0.051) or between the BBT group and the TLPT group (*P*=0.074). As regards post-treatment differences in FEV_1, there were significant differences in favor of the BBT group when compared with the ACBT group (*P*=0.001) and the TLPT group (*P*=0.010). Pairwise comparison of the mean values of PEF after treatment indicated significant differences favoring the BBT group when compared with the ACBT group (*P*=0.029) or the TLPT group (*P*=0.030), with no significant differences between the ACBT group and the TLPT group (*P*=0.815). Post-treatment differences in $FEF_{25–75\%}$ were found between the ACBT group and the BBT group (*P*=0.007) in favor of the BBT group, and between the ACBT group and the TLPT group, favoring the TLPT group (*P*=0.008). However, there were no significant differences between the BBT group and the TLPT group (*P*=0.863). Finally, pairwise comparison of the post-treatment mean values of FEV_1/FVC indicated a statistically significant

Figure 3



Flow chart of the participants.

Table 1 Demographic data of all participants

	ACBT group	BBT group	TLPT group	*P*-value	*F*-value	Significance
Age (years)	10.61±2.03	11.06±2.04	11.56±1.82	0.362	1.037	NS
Weight (kg)	37.55±4.22	38.22±3.50	37.89±6.97	0.927	0.076	NS
Height (cm)	138.22±6.30	136.94±3.96	140.11±5.09	0.196	1.684	NS
BMI	19.61±1.46	20.40±1.73	19.24±2.74	0.232	1.506	NS

ACBT, active cycle of breathing technique; BBT, Buteyko breathing technique; NS, nonsignificant; TLPT, thoracic lymphatic pump technique.

difference between the ACBT group and the BBT group (P=0.011) in favor of the BBT group. However, no differences were found between the ACBT group and the TLPT group (P=0.078) or between the BBT group and the TLPT group (P=0.0161).

Comparison of the pretreatment and post-treatment mean values of the outcome measures of the ventilatory functions (FVC, FEV_1, PEF, $FEF_{25–75\%}$, and FEV_1/FVC) revealed no statistically significant differences within the ACBT group, except for FVC outcomes that indicated a significant difference. Moreover, statistically significant differences of all outcome measures of the ventilatory function were reported within the BBT group. In addition, pretreatment and post-treatment outcome measures were

Table 2 Total serum IgE level (IU/ml) for all groups

	ACBT group [(95% CI)]	BBT group [$\overline{X}$±SD (95% CI)])	TLPT group [$\overline{X}$±SD (95% CI)]	*P*-value	Effect size [% (η^2)]	Significance
Pretreatment	278.67±64.36 (246.66–310.67)	301.39±48.69 (277.17–325.60)	270.72±63.66 (239.06–302.38)	0.283		NS
Post-treatment	256.17±67.13 (222.78–289.55)	204.89±39.41 (185.29–224.48)	258.11±72.43 (222.09–294.13)	0.018	14.6 (0.146)	S
t-value	1.633	8.018	1.103			
P-value	0.121	<0.0001	0.285			
Effect size (*d*)		1.89				
Significance	NS	S	NS			

ACBT, active cycle of breathing technique; BBT, Buteyko breathing technique; CI, confidence interval; *d*, Cohen's effect size for paired sample; Ig, immunoglobulin; NS, nonsignificant; S, significant; TLPT, thoracic lymphatic pump technique.

Table 3 Pretreatment mean values of ventilatory function (% of predicted values) for the three groups

	ACBT group [$\overline{X}$±SD (95% CI)]	BBT group [$\overline{X}$±SD (95% CI)]	TLPT group [$\overline{X}$±SD (95% CI)]	*P*-value	Significance
FVC%	69.83±6.57 (66.56–73.10)	72.06±5.29 (69.42–74.69)	73.500±4.05 (71.48–75.51)	0.109	NS
FEV_1%	51.06±6.08 (48.03–54.8)	52.17±6.96 (48.70–55.63)	52.44±6.68 (49.12–55.77)	0.785	NS
PEF%	66.44±4.78 (64.07–68.82)	64.61±7.63 (60.81–68.41)	61.44±7.37 (57.78–65.11)	0.463	NS
$FEF_{25–75\%}$	63.78±7.78 (59.91–67.65)	65.61±4.74 (63.25–67.97)	66.94±6.72 (63.60–70.28)	0.456	NS
FEV_1/FVC	70.11±8.09 (66.09–74.14)	72.50±8.77 (68.14–76.86)	71.22±6.79 (67.75–74.69)	0.797	NS

ACBT, active cycle of breathing technique; BBT, Buteyko breathing technique; CI, confidence interval; FEF, forced expiratory flow; FEV_1, forced expiratory volume in the first second; FVC, forced vital capacity; NS, nonsignificant; PEF, peak expiratory flow; TLPT, thoracic lymphatic pump technique.

Table 4 Post-treatment mean values of ventilatory function (% of predicted values) for the three groups

	ACBT group [$\overline{X}$±SD (95% CI)]	BBT group [$\overline{X}$±SD (95% CI)]	TLPT group [$\overline{X}$±SD (95% CI)]	*P*-value	Effect size [% (η^2)]	Significance
FVC%	72.67±4.24 (70.56–74.77)	78.67±3.60 (76.88–80.46)	75.89±4.56 (73.62–78.16)	0.001	26.9 (0.269)	S
FEV_1%	52.33±6.70 (49.00–55.66)	62.06±4.71 (59.41–64.70)	57.39±4.62 (55.09–59.68)	0.001	34.6 (0.346)	S
PEF%	68.28±5.33 (65.62–73.93)	71.44±8.86 (67.04–75.85)	65.44±5.97 (62.47–68.41)	0.042	18.4 (0.184)	S
$FEF_{25–75\%}$	66.28±8.47 (62.06–70.49)	73.11±6.67 (69.79–76.43)	72.11±7.01 (68.62–75.60)	0.010	14.8 (0.148)	S
FEV_1/FVC	71.50±9.52 (66.76–76.23)	78.83±5.60 (76.05–81.62)	75.500±5.16 (72.93–87.06)	0.010	16.1 (0.161)	S

ACBT, active cycle of breathing technique; BBT, Buteyko breathing technique; CI, confidence interval; FEF, forced expiratory flow; η^2, effect size; FEV_1, forced expiratory volume in the first second; FVC, forced vital capacity; PEF, peak expiratory flow; S, significant; TLPT, thoracic lymphatic pump technique.

significantly different within the TLPT group with the exception of $FEF_{25–75\%}$ (Table 5).

Childhood asthma control test

No significant differences were identified between all groups at baseline. On comparing the pretreatment and post-treatment mean values of C-ACT scores within groups, there was no statistically significant difference within the ACBT group, whereas there were significant differences within the BBT group and the TLPT group (Table 6). Significant differences were indicated between groups after treatment. The recorded post-treatment differences were found between the ACBT group and the BBT group in favor of the BBT group (P=0.017). However, no statistically significant differences were indicated between the ACBT group and the TLPT group or between the BBT group and the TLPT group (P>0.05).

Discussion

This study demonstrated that the BBT and the TLPT can effectively improve the total serum IgE, the ventilatory function in terms of FVC, FEV_1, PEF,

Table 5 The mean values of ventilatory function (% of predicted values) within the three groups

	FVC%	FEV_1%	PEF%	$FEF_{25–75\%}$	FEV_1/FVC
ACBT group					
Pre	69.83±6.57	51.06±6.08	66.44±4.78	63.78±7.78	70.11±8.09
Post	72.67±4.24	52.33±6.70	64.67±6.03	68.28±5.33	71.50±9.52
P-value	0.021	0.462	0.154	0.176	0.932
Z-value	–2.315	–0.736	–1.426	–1.353	<0.0001
Significance	NS	NS	NS	NS	NS
BBT group					
Pre	72.06±5.29	52.17±6.96	64.61±7.63	65.61±4.74	72.50±8.77
Post	78.67±3.60	62.06±4.71	71.44±8.86	73.11±6.67	78.83±5.60
P-value	0.001	0.001	0.014	0.001	0.034
Z-value	–3.340	–3.196	–2.462	–3.182	–2.115
d (95% CI)	1.28 (0.70–2.16)	1.15 (0.81–2.31)	0.84 (0.19–1.56)	1.04 (0.55–1.98)	0.72 (0.16–1.52)
Significance	S	S	S	S	S
TLPT group					
Pre	73.50±4.05	52.44±6.68	61.44±7.37	66.94±6.72	71.22±6.79
Post	75.89±4.56	57.39±4.62	65.44±5.97	72.11±7.01	75.500±5.16
P-value	0.013	0.004	0.033	0.081	0.029
Z-value	–2.471	–2.858	–2.133	–1.748	–2.179
d (95% CI)	0.59 (0.12–1.21)	0.87 (0.16–1.52)	0.63 (0.01–1.35)	0.51 (0.06–1.41)	0.58 (0.01–1.35)
Significance	S	S	S	S	S

ACBT, active cycle of breathing technique; BBT, Buteyko breathing technique; CI, confidence interval; *d*, (Cohen's *d*) effect size; FEF, forced expiratory flow; FEV_1, forced expiratory volume in the first second; FVC, forced vital capacity; NS, nonsignificant; PEF, peak expiratory flow; S, significant; TLPT, thoracic lymphatic pump technique.

Table 6 Pretreatment and post-treatment mean values of the childhood asthma control test for the three groups

	ACBT group	BBT group	TLPT group	*P*-value	Significance
Pretreatment	13.67±3.31	14.67±2.66	12.78±3.29	0.156	NS
Post-treatment	15.06±4.11	18.44±4.08	16.11±3.89	0.017	S
Z-value	–1.382	–2.908	–2.709		
P-value	0.167	0.004	0.007		
Significance	NS	S	S		

ACBT, active cycle of breathing technique; BBT, Buteyko breathing technique; NS, nonsignificant; S, significant; TLPT, thoracic lymphatic pump technique.

$FEF_{25–75\%}$ and FEV_1/FVC, and C-ACT scores in children with bronchial asthma. However, Buteyko breathing was more significantly effective compared with the TLPT. Furthermore, the ACBT failed to elicit improvement in the total serum IgE, the ventilatory function, or the C-ACT scores in children with mild-to-moderate bronchial asthma.

Even though no previous studies exactly reported why the Buteyko breathing is so effective in the treatment of asthma, it is believed that chronic hyperventilation results in loss of CO_2 from the lung and the blood and the CO_2 deficits disturb the acid–base balance, causing bronchoconstriction, vasoconstriction, and poor oxygenation. The breath hold technique in Buteyko breathing raises the CO_2 levels and reverses the bronchoconstriction [30]. There are other possible multidimensional mechanisms for Buteyko breathing. Biochemically, breathing through the nose carries a large amount of the nitric oxide formed at the paranasal sinuses to the lungs. It plays significant physiological roles, such as bronchodilation, vasodilatation, immune response, and oxygen transport [31]. Composition of the surfactants that are known to be a smooth muscle relaxant have beneficial effects on lung inflammation and immunity can be changed by the pattern of Buteyko breathing [32]. Biomechanically, patients with asthma are unable to breathe in deeply because of lung hyperinflation that flattens the diaphragm and shortens and reduces its ability to widen and lift the lower rib cage [33]. Thus, the reduction of hyperinflation by means of Buteyko breathing helps the diaphragm to work efficiently, decreases the symptom of breathlessness, and allows the patient to breathe deeply [34]. Moreover, asthmatic patients treated with Buteyko breathing have shown significant improvement because they learned to reduce breathing volume by increasing the

abdominal muscle tone and relaxing other breathing muscles, particularly chest and shoulder muscles. Such reduction in the breathing volume helps to reduce the breathing effort, relaxing the respiratory muscles, and improving the diaphragmatic function. Thus, it can reduce the hyperventilation and air trapping in lungs [35,36].

The results of this study are supported by those of Hassan *et al.* [14], who concluded that Buteyko breathing produces a significant improvement in the daily symptoms and the PEF rate for patients with bronchial asthma. A randomized controlled study by Cowie *et al.* [37] in Canada indicated that the Buteyko group achieved a good asthma control, which increased from 40% at entry level to 79% at 6 months. Bowler *et al.* [10] observed improvements in the expiratory flow rates among the participants who were taught Buteyko breathing exercises. Moreover, the results of a study by Prasanna *et al.* [38] supported the effectiveness of Buteyko breathing exercises for 2 months in terms of expiratory flow rates and asthma control over the traditional treatment methods in newly diagnosed asthmatic patients. Conversely, a study by McHugh *et al.* [13] recorded no changes in the FEV. Another study claimed that the benefits were not related to changes in ventilation when the BBT was used [39].

In contrast, increased respiratory muscle work and decreased thoracic cage distensibility in asthmatic patients change the total thoracic compliance and decreases the FEV of the lungs [40]. On this basis, the improvement of asthmatic children in the TLPT group could be attributed to the improvement in chest expansion and blood flow throughout the lung when they were treated with the TLPT. The TLPT helps to flatten the diaphragm during inspiration and drops the intrathoracic pressure, enhancing the lymphatic flow, which is important for optimal lung function [23,41]. However, very few research studies have demonstrated the effects of TLPT in the treatment of children with bronchial asthma. Therefore, further investigations into the benefits of this technique incorporating the long-term effects in the treatment of children with mild, moderate, or severe asthma and larger sample sizes would be advisable to support the outcomes of this study.

However, our study has some potential limitations, each of which should be considered in the future research studies. Because of the nature of the exercises, it was difficult to blind the physiotherapist who conducted the treatment, and lack of blind investigation of the ventilatory function was the primary limitation. In addition, the sample size was convenient instead of being a representative for the whole population and was availability dependent. Furthermore, lack of follow-up to study the long-term effect of the treatment methods is another limitation. Although this study was a randomized controlled trial, the results should be interpreted cautiously because the external validity or the extent to which the results could be generalized might be limited because of the permuted randomization with fixed blocks. Hence, further randomized controlled trials comprising breathing retraining approaches with diverse methodology are needed for clear, thoughtful, and meaningful interpretation of the outcomes and draw a more reasonable, judgmental conclusion about the effects of these respiratory techniques. Despite these limitations, the study has several strengths, including the objective functional assessment of ventilatory function in addition to patient perception to their problem. Moreover, the study tried to associate the functional recovery to the physiological changes by assessing both ventilatory function and total serum IgE. Likewise, treatment of the three groups was provided by an experienced, well-trained physical therapist.

Conclusion

The results of this study indicate that the BBT and the TLPT are more helpful than the active cycle of breathing in the treatment of children with bronchial asthma and Buteyko breathing is potentially more valuable.

Authors' contribution: Ragab K. Elnaggar had full access to all of the data in the study and takes the responsibility for the integrity and accuracy of the data, was involved in all stages of this study (concept and design, study supervision, analysis and interpretation of data, drafting the manuscript and revision); Mohammed A. Shendy: study conduction and supervision, acquisition, analysis and interpretation of data, drafting the manuscript, editing and revision.

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Conflicts of interest

There are no conflicts of interest.

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