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A randomized placebo-controlled study investigating the efficacy of inspiratory muscle training in the treatment of children with bronchial asthma

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ABSTRACT

Objective: To investigate the efficacy of inspiratory muscle training (IMT) on respiratory functions, respiratory muscle strength, and asthma symptoms in asthmatic children.

Methods: In a randomized placebo-controlled assessor-blinded study, 34 children with asthma were randomized to receive either the IMT at 40% of the maximal inspiratory pressure (IP_{max}) for 20 min/session, thrice/week, over 12 consecutive weeks (IMT group; *n* = 17) or placebo IMT at 5% of IP_{max} (placebo group; *n* = 17). Additionally, both groups received the conventional respiratory rehabilitation (CRR) program. Outcome measurements performed pre- and post-treatment, included respiratory functions [forced expiratory volume at the first second (FEV₁), forced vital capacity (FVC), and FEV₁/FVC], respiratory muscle strength [represented by IP_{max} and maximal expiratory pressure (EP_{max}), and asthma control test (ACT).

Results: At a significance level adjusted to *P* < .008, there were significant post-treatment differences between the IMT and placebo groups in FEV₁ (*P* = .003), FVC (*P* = .001), FEV₁/FVC (*P* = .004), IP_{max} (*P* = .002), EP_{max} (*P* = .004), and ACT (*P* = .001) adjusted to the pretreatment values, in favor of the IMT group.

Conclusion: Incorporation of IMT in the CRR program for children with asthma can improve respiratory function, enhance respiratory muscle strength, and improve children's perception of asthma symptoms.

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Introduction

Asthma has recently been described as the most common inflammatory disease of airways, in children. It is a multifaceted condition featuring bronchial hyper-responsiveness and recurrent episodes of airflow obstruction (1,2). Children with bronchial asthma (CwBA) suffer from increased airway resistance, air trapping, and increased end-expiratory lung volume (i.e. lung hyperinflation) (3), which lead to deformation of the diaphragm, causing it to pull the ribs transversely, limit the expansion of the rib cage, and thus reducing the capacity to breathe in (4). Lung hyperinflation can also increase the breathing effort and place further stresses on respiratory muscles (5,6). Importantly, the resultant maladaptation in thoracic-abdominal mechanics and respiratory muscle fatigue can reduce dynamic lung volumes such as forced

expiratory volume at one second and forced vital capacity (7).

The key objectives of asthma management as per Global Initiative for Asthma (GINA) guidelines are; controlling asthma symptoms, preventing exacerbations, keeping the lung function as near-to-normal as possible, scaling down drug-induced side effects, and allowing children to participate in all daily living activities (8). Although asthma symptoms can be controlled by drug-therapy, the biomechanical alterations induced by asthma (9) may justify the use of inspiratory muscle training (IMT) and respiratory exercises as complements to medications to reduce respiratory difficulties and maximize the outcomes (10,11).

Inspiratory muscle training consists of a series of breathing exercises that aim to strengthen respiratory muscles, making it easier to breathe (12). IMT resembles peripheral skeletal muscle training, where

resistance is placed on respiratory muscles to create structural adaptations to these muscles (13). Muscle loading protocols are diverse but typically fall into three separate categories: normocapnic hyperpnea, pressure threshold loading, and flow-resistive loading (14). Prior studies on healthy individuals and chronic obstructive lung diseases have shown that IMT can promote diaphragmatic hypertrophy (12,15). Also, studies on adults with asthma have found positive impacts of IMT on asthma symptoms, exercise capacity, inspiratory-muscle strength, and quality of life (14,16–18). However, there is still insufficient evidence on the efficacy of IMT in children with asthma (12,19).

So far, there is only one published report on the use of IMT in CwBA (20). The report demonstrated that IMT besides respiratory exercises can improve respiratory-muscle efficiency and asthma symptoms. Still, the findings of that report, are non-conclusive, and further investigations are warranted. A recent systematic review recommended that to develop standard protocols of IMT, they should be tested against placebo-training in representative samples, to develop concrete suggestions concerning the supporting role of IMT for traditional treatment strategies (14). This study was therefore conceived to investigate the effects of IMT on respiratory functions, respiratory muscle strength, and asthma symptoms in CwBA. We hypothesized that incorporating IMT into conventional respiratory rehabilitation (CRR) would be particularly more effective in improving respiratory functions, enhancing respiratory muscle strength, and controlling asthma symptoms.

Materials and methods

Study design

This study was designed as a randomized, placebo-controlled, assessor-blinded clinical trial. It was conducted between January and November 2019 at the Physical Therapy Outpatient Clinic of Prince Sattam bin Abdulaziz University. The study approved by the Physical Therapy Research Ethics Committee (Protocol No: RHPT/18/0052) and performed in accordance with the Declaration of Helsinki code of ethics. Parents/guardians signed a consent form to authorize their children's participation.

Subjects

Thirty-four children with asthma were recruited from the outpatient clinic of the Department of Pulmonary Medicine at King Khalid Hospital, Al-Kharj, Saudi

Arabia. In preparation for the study, the study protocol was discussed thoroughly with the pulmonologists, who identified the potential subjects. A confirmed diagnosis of asthma was the key criterion. A separate recruitment protocol was followed to establish a database of potential subjects. Subjects provided consent to be contacted in advance. Researchers contacted subjects based on the signed consent for participation. Then, recruited subjects were comprehensively reassessed for eligibility, against the inclusion criteria in cooperation with the referring pulmonologist. They were included if aged from 12 to 16 years, diagnosed with asthma according to the current GINA guidelines (8) (i.e. if children had a history of more than one of asthma symptoms, which often occur or are worse at night or in the early morning, and triggered by exercise, allergens or cold air, and if they had significant bronchodilator responsiveness, meaning that the forced expiratory volume at one second increased by $> 12\%$ of the predicted value or the peak expiratory flow rate (PEFR) increased by $> 13\%$ of the predicted values after inhaling a bronchodilator), had a baseline PEFR $60 - 80\%$ (21), had a body mass index (BMI) $< 25 \text{ kg.m}^{-1}$, had stable doses of asthma medication in the past month, identified as being a clinically-stable condition by the attending physician (implying that children did not experience daytime symptoms $< \text{t-wice/week}$, did not wake up at night due to asthma, did not need short-acting beta agonists $< \text{two times a week}$, and did not experience activity restrictions because of asthma) (22), and if they did not need to change medications during the study. Children with; exacerbated asthma symptoms that required the use of systemic corticosteroids, unstable asthma, chronic sinusitis, other respiratory problems causing additional morbidities, history of thoracic surgery, and cognitive or behavioral problems were excluded.

A *priori* power analysis was conducted to estimate the required sample size and nullify the effect of type II error using PASS software version 15.0.5 (NCSS, Kaysville, UT, USA). In a two-sided independent *t*-test with equal-variance, a group-sample of 14 children (i.e. an overall sample-size of 28 children) was required to achieve power $(1 - \beta)$ of 92.1% to reject the null-hypothesis of equal means when the population mean-difference ($\text{MD} = 5.24$) with a pooled standard deviation for both groups ($\text{SD}_{\text{pooled}} = 3.96$) based on estimates of the MD and $\text{SD}_{\text{pooled}}$ of the predicted percentage of forced vital capacity, which were obtained from a preliminary study, with a significance level ($\alpha = 0.05$). Assuming that 20% of the

children could be lost at random through the study phases, the sample was increased to 34 children.

Eligible children were allocated randomly to either the IMT group ($n=17$) who received IMT program with a training load representing 40% of the inspiratory pressure threshold besides the CRR program, or the Placebo group ($n=17$) who received placebo IMT with a fixed workload of 5% of the pressure threshold. A simple randomization procedure was implemented. Thirty-four black nontransparent envelopes were created for the entire sample, each envelope contained a code for either of the study groups (IMT or Placebo). When each child has formally joined the study, envelopes were mixed in a container, then an independent person (a chest physical therapy student) drew an envelope representing treatment allocation for this child.

Intervention protocols

Respiratory rehabilitation

The IMT and placebo groups received a CRR program lasting for a total of 30 min each session, three times/week over 12 weeks. The focus of the CRR was to reduce hyperventilation, improve pulmonary ventilation, and promote adaptation to the increasing physical exertion. The CRR was conducted on a case-by-case basis under the supervision of the same physical therapist. In general, the program included the following exercises: diaphragmatic breathing, pursed-lip breathing, breathing-hold and breathing control, manual expiratory passive therapy techniques, postural orientation techniques, relaxation techniques, and aerobic training on a treadmill or bicycle according to the preference of each child. Each of the foregoing exercises was repeated 5 times and aerobic training lasted for 10 – 15 min (2,3,23).

Inspiratory muscle training

A pressure threshold-loading device (Respironics, Cedar Grove, NJ, USA) was used for the training. This device offers an adjustable inspiratory resistance through a spring-loaded valve. All children attended a familiarization session to learn adequately about breathing with the device. The IMT was applied immediately after the CRR session ended. The training load for the IMT group was 40% of the IP_{max} . The training load was adjusted every week after the IP_{max} was re-assessed at the beginning of the first session they attended each week. The training load for the placebo group was fixed at 5% of IP_{max} throughout the study. The training load that children in the IMT group were able to perform without discomfort has been determined from a preliminary study on six

CwBA. We applied 40%, and 50% of IP_{max} . Children reported that training with 40% of IP_{max} was perceived more comfortably. The IMT was performed in two phases as follow: phase I; children were trained to keep diaphragmatic breathing through the device for 15 breaths with 10-s rest intervals, and continue this paradigm for 15 min, Phase II; children were asked to breathe through the device continuously for additional 5 min to develop muscle endurance. The IMT and placebo groups exercised for 20 min/session in total, three sessions per week over 12 weeks in succession.

Measurement protocols

Baseline measurements

For all subjects, body weight (Kg) was measured using a weight scale (TANITA; BC-418; Tanita, Tokyo, Japan), height was assessed through a wall-mounted stadiometer (Charder HM200P; Quick Medical®, WA, USA), and the body mass index (BMI, kg/m^2) was calculated employing the prevailing algorithm: $BMI = \text{weight/square of height}$. In addition, data regarding the age of onset, asthma duration, and medication usage were either collected from patients record or reported by patients or pulmonologists.

Dependent outcome measures

Children were assessed for respiratory functions, respiratory muscle strength, and asthma control, pre- and post-treatment by an independent investigator, who was not an author. Measurements were conducted at the University Laboratories, specifically at Cardiopulmonary Testing Laboratory, in the Department of Health and Rehabilitation Sciences. Measurements were performed in the day-morning by the same investigator.

Spirometric measurements

A well-trained technician assessed the forced expiratory volume at the first second (FEV_1), forced vital capacity (FVC), and FEV_1/FVC ratio using a spirometry analyzer (Autospiro-507; Minato Medical Science; Osaka, Japan). From standing position, each child was instructed to close lips tightly on the mouthpiece and to breathe as usual for a few cycles while a soft nose caliper was applied to prevent air leakage. Thereafter, he/she was required to take in a breath slowly as deeply as possible, then breathe out vigorously. Three trials were permitted for each child and the average values were used for the analysis (3). Reference values

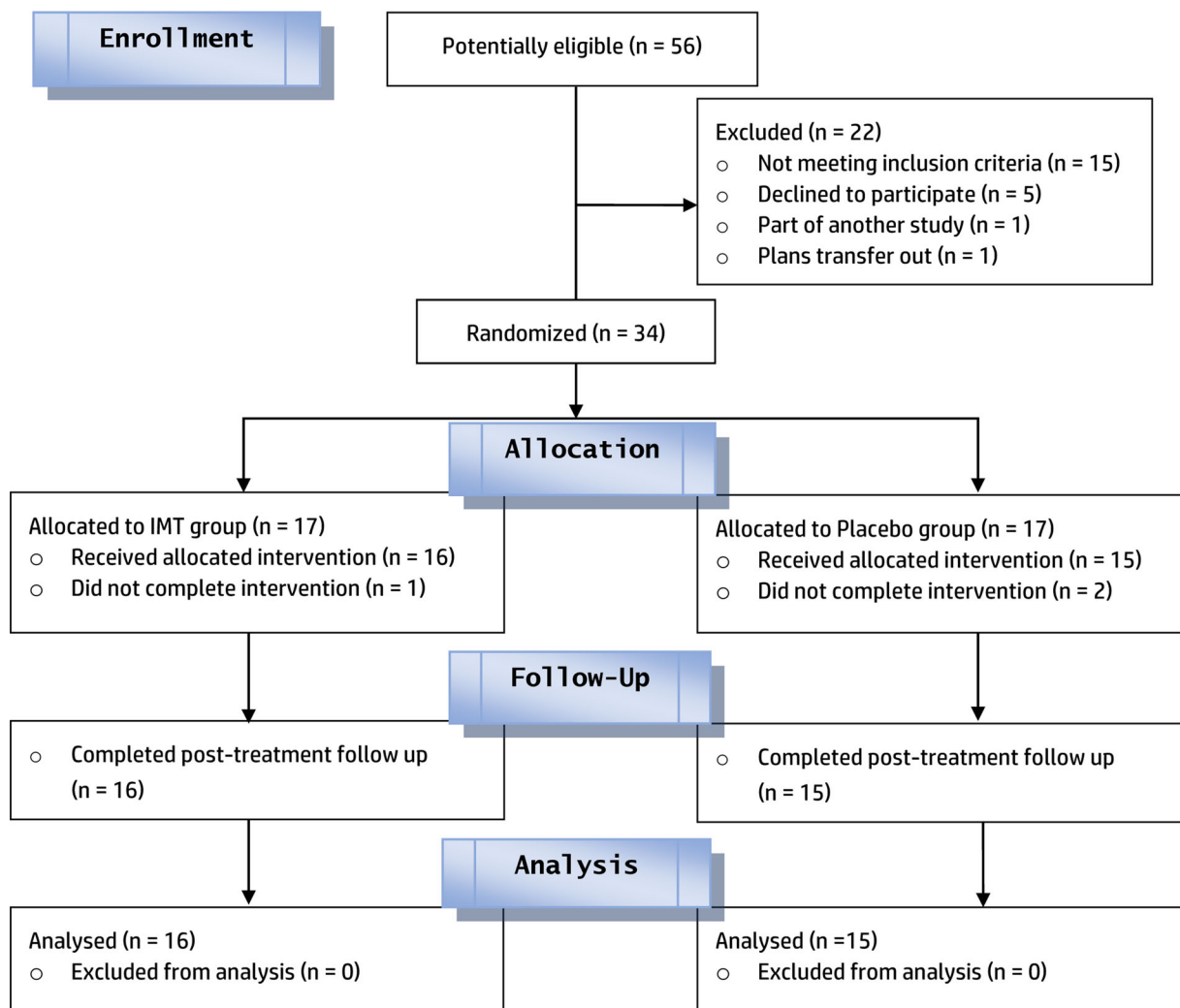


Figure 1. A flowchart illustrating children's recruitment and retention.

for healthy children and adolescents in the region were used to drive percent predicted values (24).

Respiratory muscle strength

The strength of respiratory muscles was assessed through the maximal inspiratory pressure (IP_{max}) and maximal expiratory pressure (EP_{max}) during the maximal respiratory effort. An electronic respiratory pressure meter with a rigid mouthpiece (Micro RPM[®], Micro Medical, UK) was used for assessment according to the standards set by the American Thoracic Society and European Respiratory Society (25). To measure the IP_{max} , children were asked to perform maximal inspiration, starting from residual lung volume to total lung capacity, following maximal expiration. To measure the EP_{max} , children were asked to make a maximal expiratory effort starting from total lung capacity to residual volume. The pressure thresholds sustained at least for 1-s were recorded. Each

child performed 5–8 maneuvers to measure IP_{max} and EP_{max} . Then, three acceptable maneuvers including at least two reproducible maneuvers (i.e. the difference between values $< 5\%$) were selected. The highest-pressure value of these maneuvers, expressed in cmH_2O , was recorded (25,26). The percentage of the predicted value of IP_{max} and EP_{max} was calculated by an equation suggested earlier (27).

Asthma control

The control of asthma symptoms was assessed using the asthma control test (ACT), as participating children were 12 years old or more. ACT is a validated self-report 5-items scale evaluating the activity limitations, breathing difficulties, night awakening, medication usage, and asthma control in CwBA whose age ranging from 12–19 years (28). Each item has five response options (resulting in a score of 1–5). The total ACT score is estimated as the sum of all items'

Table 1. Participants' demographic profile and baseline clinical characteristics.

	IMT group (n = 16)	Placebo group (n = 15)	P-value
Age, year	14.56 ± 1.36	13.87 ± 1.13	.13 [‡]
Gender (boy/girl), n (%)	9 (56.3) / 7 (43.7)	11 (73.3) / 4 (26.7)	.46 [§]
Weight, Kg	49.13 ± 6.86	47.26 ± 4.76	.39 [‡]
Height, m	1.49 ± 0.08	1.46 ± 0.07	.22 [‡]
BMI, Kg/m ²	21.96 ± 1.82	22.25 ± 1.95	.67 [‡]
Age at onset, year	6.25 ± 1.06	6.07 ± 1.58	.71 [‡]
Duration of asthma, year	8.31 ± 1.74	7.80 ± 1.57	.4 [‡]
Children who have been hospitalized last year, n (%)	3 (18.8) / 13 (81.2)	4 (26.7) / 11 (73.3)	.69 [§]
Montelukast sodium use (yes/no), n (%)	10 (62.5) / 6 (37.5)	8 (53.3) / 7 (46.7)	.72 [§]
Inhaled steroids (Budesonide, mg/day)	0.76 ± 0.14	0.81 ± 0.11	.38 [‡]
Short β_2 agonist dose, μ g/day	465.25 ± 78.79	433.67 ± 65.83	.24 [‡]
Baseline PEFR, % of predictive values	71.19 ± 3.17	69.73 ± 3.15	.21 [‡]

All data expressed as mean ± standard deviation except gender distribution and montelukast sodium use among the study groups are expressed as frequency (percentages).

Abbreviations: IMT: inspiratory muscle training, BMI: body mass index, PEFR: peak expiratory flow rate.

P values: [‡] student's two-sample t-test, [§] Fishers' exact test.

scores. The minimum ACT score is 5; indicating poorer asthma control and the maximum score is 25; representing the optimal asthma control. ACT score ≥ 20 indicates that asthma is controlled (28).

Statistical analysis

The Minitab statistical software, version 19.2 (Minitab Inc., State College PA, USA) was used to analyze the data. The Anderson-darling test of normality showed that the data of all measured variables were symmetrically distributed. The baseline homogeneity of the study groups was verified using the students' two-sample *t*-test for continuous variables and Fisher's exact test for categorical variables. The difference in children's compliance-with-training between study groups was calculated using the students' two-sample *t*-test. The post-treatment differences concerning dependent variables (FEV₁, FVC, FEV₁/FVC, IP_{max}, EP_{max}, and ACT) between groups were computed using the 1-way analysis of co-variance (ANCOVA) test. The baseline values of these variables were used as co-variables to calculate the post-treatment differences. To correct for multiple comparisons, a targeted alpha of 0.05 was corrected using the Holm-Bonferroni's method. In total, we performed six ANCOVAs, thus, the significance level was adjusted to $P < .008$. The effect-size of the differences was computed through partial eta-squared (η^2_{partial}) formula when ANCOVA analyses were approaching statistical significance.

Results

Participants' flow and retention

A total of 56 children were screened for eligibility. Of whom, 34 children satisfied the inclusion criteria and proceeded to the random-allocation phase. However,

only 31 children (91.2%) completed the assigned intervention and follow-up measurements; 16 of 17 in the IMT group (94.1%) and 15 of 17 in the placebo group (88.2%). Three children (8.82%) lost during the study; one child lost from the IMT group for unknown causes, and two children lost from the placebo group as one child's asthma symptoms exacerbated and required taking prednisone while the other child moved away from the working area. A flowchart illustrating children's recruitment and retention is shown in Figure 1.

Baseline characteristics

The baseline demographic and clinical features of both groups are demonstrated in Table 1. The IMT and placebo groups were similar with respect to age, gender distribution, and anthropometry (weight, height, and BMI) (all *p* values < 0.05). Additionally, asthma-related characteristics in terms of the age of onset ($P = 0.71$), asthma duration ($P = 0.4$), medications [montelukast sodium use ($P = 0.72$), Budesonide ($P = 0.38$), and short β_2 agonist dose ($P = 0.24$)], and baseline BEFR ($P = 0.21$) were analogous in both groups at the baseline.

Compliance with training

The analysis of children's compliance-with-training (i.e. the percentage of sessions that each child attended, out of 36 sessions, planned to complete over 3 months) in the IMT and placebo groups demonstrated a non-significant difference between both groups ($P = 0.09$). The median and interquartile ranges (IQR) of compliance-with-training were 94.44% (IQR; 91.67% and 97.22%) in the IMT group and 91.67% (IQR; 91.67% and 94.44%) in the placebo group.

Table 2. Summary of the findings of ANCOVA analysis.

Dependent variables	Pretreatment		Post-treatment		Post-treatment difference	
	IMT	Placebo	IMT	Placebo	P-value	η^2_{partial}
Spirometric measurements						
FEV ₁ , % predicted	67.56 ± 4.18	65.47 ± 3.85	79.56 ± 6.73	71.13 ± 5.62	.003*	0.28
FVC, % predicted	73.44 ± 3.88	71.87 ± 3.68	85.94 ± 3.68	79.73 ± 5.39	.001*	0.31
FEV ₁ /FVC	75.43 ± 3.50	73.93 ± 4.30	86.88 ± 5.65	80.33 ± 4.92	.004*	0.26
Respiratory muscle strength						
IP _{max} , cmH ₂ O	69.81 ± 9.29	67.53 ± 6.94	87.25 ± 8.14	78.47 ± 7.13	.002*	0.27
EP _{max} , cmH ₂ O	72.75 ± 7.80	71.67 ± 5.97	91.56 ± 7.29	82.40 ± 9.65	.004*	0.26
Asthma perception						
ACT	17.19 ± 2.48	16.40 ± 2.26	21.75 ± 1.29	19.47 ± 1.98	.001*	0.33

Abbreviations: IMT: inspiratory muscle training, FEV₁: forced expiratory volume at the first second, FVC: forced vital capacity, FEV₁/FVC: proportion of actual FEV₁ (liters) to the full FVC (liters), IP_{max}: maximal inspiratory pressure, EP_{max}: maximal expiratory pressure.

*Significant at $P < 0.05$, η^2_{partial} : the effect size for significant ANCOVA test [$\eta^2_{\text{partial}} = 0.01$ (small), $\eta^2_{\text{partial}} = 0.09$ (medium) and $\eta^2_{\text{partial}} = 0.25$ (large)].

Between-groups analysis

The differences between study groups at the post-treatment occasion are depicted in Table 2. All variables are expressed as mean ± standard deviations. The ANCOVA analysis revealed statistically significant differences between IMT and placebo groups in all spirometric measures, adjusted to the pretreatment values, in favor of the IMT group; FEV₁ ($F_{(1, 28)} = 10.96$, $P = 0.003$), FVC ($F_{(1, 28)} = 12.74$, $P = 0.001$), and FEV₁/FVC ($F_{(1, 28)} = 9.84$, $P = 0.004$). Also, a statistically significant between-groups differences in the respiratory muscle strength adjusted to the pretreatment values were observed, favoring the IMT group; IP_{max} ($F_{(1, 28)} = 11.76$, $P = 0.002$) and EP_{max} ($F_{(1, 28)} = 9.58$, $P = 0.004$). Eventually, a statistically significant between-groups difference in the ACT scores adjusted to the pretreatment value was proven, where the IMT group showed greater control of asthma ($F_{(1, 28)} = 13.88$, $P = 0.001$).

Discussion

This study proved that IMT along with CRR is more effective than the CRR alone in improving the ventilatory function, respiratory muscle strength, and asthma control in CwBA. Although the effects of IMT have been tested in several studies, including adult patients with asthma or chronic obstructive pulmonary diseases (12,14–17), there is still a great deal of interest regarding the impacts of such a therapeutic method in CwBA. Therefore, the findings herein may extend the evidence on the effectiveness of IMT in CwBA.

Applying IMT using 40% of IP_{max} (moderate intensity) beside CRR produced large improvements in pulmonary functions, specifically the FEV₁, FVC, and FEV₁/FVC. Evidence that IMT is an effective asthma treatment has been controversial. Some studies showed that static and dynamic lung volumes have improved in patients with asthma (12,29,30) and other

patient populations (15,31,32), as FEV₁ and FVC increased significantly following IMT application. Contrarily, other studies noted no changes in either the FEV₁ or FVC (33–35). These discrepancies can be explained by methodological variations and sample heterogeneity, which may confound any conclusion concerning the efficacy of IMT for asthma. Some methodological disparities have been studied previously and included study designs, purposes, distinct characteristics of control, IMT techniques, and treatment parameters (12). It is possible that, due to IMT, the diaphragm and respiratory muscles, have been able to generate more work that led to an improvement in the respiratory capacity and an increase in the thoracic expansion, thus played a role in increasing static and dynamic lung volumes (14,36).

The IMT group exhibited greater increases in the IP_{max} and EP_{max}, denoting a higher acquisition of respiratory muscle strength. These results were consistent with those of previous studies including pediatric patients (20) and adult patients (7,14,16,17,29,33–35) suffering from bronchial asthma, where uniform improvements of respiratory muscles strength have been demonstrated. On the contrary, we found only one randomized clinical trial including 18 subjects with stable mild/moderate asthma pointed out there was no difference between the IMT group and the age- and gender-matched control group for the EP_{max} and asthma symptoms (37). The improvement in respiratory muscle strength herein might be attributed to an improved neuromuscular recruitment pattern of respiratory musculature, and increased diaphragm cross-sectional area, and increased type II muscle fibers in the external intercostal muscles, permitting them to generate higher forces in response to a given level of respiratory muscle drive (38,39). Also, reduced energy costs of respiratory muscles may represent another plausible explanation for improvements in respiratory muscle strength and endurance (40).

The findings of this study have further established that adding IMT to CRR can improve control of asthma symptoms. These findings corroborate those of previous studies involving patients with mild-to-moderate asthma who have been treated with IMT (14,33,35). In these studies, an improvement in asthma control has been demonstrated. Although did not evaluate explicitly, improvement in asthma control could be linked to the increase in inspiratory muscle strength, FEV₁, and FVC, which may partially alleviate the increased breathing effort resulting from hyperinflated lung, therefore enhancing control of asthma symptoms (14).

The placebo IMT was established to match the true placebo criteria outlined by Ojanen (41), meaning that placebo treatment should be meaningful for participants, inert, and create expectations, engagement, and subjective utility. For this study, we used the minimal training load (5% of IP_{max}) that has been used in previously implemented for children (42) and subjected children to the same training protocol. Hence, it is conceivable that our procedure justified the foregoing placebo criteria. The findings of the placebo group have also indicated significant post-treatment improvement of respiratory functions, respiratory muscle strength, and asthma symptoms. Resulting changes may be attributed to the effect of respiratory exercises, which may have promoted a more controlled breathing pattern, improved thoracic mobility, enhanced diaphragmatic strength, and increased respiratory efficiency (2,3,23). Another possible explanation is the psychological effect of placebo IMT. Conditioning and expectations may have played a significant role in improving outcomes, especially as participating children have been engaged in regular placebo training for three months (41).

This study implemented a randomized placebo-controlled design and had a convenient sample size and a statistical power (92.1%) sufficient to underpin the study hypothesis. Also, the children's compliance-with-training was reasonable and none of the children reported any adverse effects. However, certain limitations are worthy to be mentioned. This study focused on children with clinically stable asthma. There could be potential sampling bias, as clinical stability may reflect provider practice more than the child's experience with asthma. Therefore, it may limit the generalizability of findings to all CwBA. Further investigation should include children with mild-to-severe asthma, considering the criteria stated earlier. The follow-up measurements were done immediately post-treatment. So, the long-term effects of IMT remain uncertain.

Future studies should plan to follow up on the IMT effects at six and 12 months after the end of the program to find out how far the treatment effects will last.

Conclusion

These findings suggest that inspiratory muscle training may be an effective modality to improve respiratory functions, respiratory muscle strength, and asthma symptoms in children with bronchial asthma. Thus, it is possibly used as an adjunctive therapy alongside conventional respiratory rehabilitation to provide concrete effects.

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Declaration of interest

The author of this work has no conflicts of interest.

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References

1. Noutsios GT, Floros J. Childhood asthma: causes, risks, and protective factors; a role of innate immunity. *Swiss Med Wkly* 2014;144:w14036. doi:10.4414/smw.2014.14036.
2. Elnaggar RK, Shendy MA. Efficacy of noninvasive respiratory techniques in the treatment of children with bronchial asthma: a randomized controlled trial. *Bull Fac Phys Ther* 2016;21(1):1–10. doi:10.4103/1110-6611.188025.
3. Elnaggar RK, Shendy MA, Mahmoud MZ. Prospective effects of manual diaphragmatic release and thoracic lymphatic pumping in childhood asthma. *Respir Care* 2019;64(11):1422–1432. doi:10.4187/respcare.06716.
4. Reid WD, Dechman G. Considerations when testing and training the respiratory muscles. *Phys Ther* 1995; 75(11):971–982. doi:10.1093/ptj/75.11.971.
5. Loughheed MD, Fisher T, O'Donnell DE. Dynamic hyperinflation during bronchoconstriction in asthma:

- implications for symptom perception. *Chest* 2006; 130(4):1072–1081. doi:10.1378/chest.130.4.1072.
6. Laghi F, Tobin MJ. Disorders of the respiratory muscles. *Am J Respir Crit Care Med* 2003;168(1): 10–48. doi:10.1164/rccm.2206020.
7. López-de-Uralde-Villanueva I, Candelas-Fernández P, de-Diego-Cano B, Mínguez-Calzada O, Del Corral TJCr. The effectiveness of combining inspiratory muscle training with manual therapy and a therapeutic exercise program on maximum inspiratory pressure in adults with asthma: a randomized clinical trial. *Clin Rehabil* 2018; 32(6):752–765. doi:10.1177/0269215517751587.
8. Global Initiative for Asthma: global strategy for asthma management and prevention. 2017. Available from: <https://ginasthma.org/2017-gina-report-global-strategy-for-asthma-management-andprevention/> [last accessed 24 December 2019].
9. Gorini M, Iandelli I, Misuri G, Bertoli F, Filippelli M, Mancini M, Duranti R, Gigliotti F, Scano G. Chest wall hyperinflation during acute bronchoconstriction in asthma. *Am J Respir Crit Care Med* 1999;160(3): 808–816. doi:10.1164/ajrccm.160.3.9712088.
10. Ochmann U, Kotschy-Lang N, Raab W, Kellberger J, Nowak D, Jörres RAJR. Long-term efficacy of pulmonary rehabilitation in patients with occupational respiratory diseases. *Respiration* 2012;84(5):396–405. doi:10.1159/000337271.
11. Bateman ED, Bousquet J, Busse WW, Clark TJH, Gul N, Gibbs M, Pedersen S, on behalf of the GOAL Steering Committee and Investigators. Stability of asthma control with regular treatment: an analysis of the Gaining Optimal Asthma control (GOAL) study. *Allergy* 2008;63(7):932–938. doi:10.1111/j.1398-9995.2008.01724.x.
12. Silva IS, Fregonezi GA, Dias FA, Ribeiro CT, Guerra RO, Ferreira G. Inspiratory muscle training for asthma. *Cochrane Database Syst Rev* 2013;2013(9):1–29.
13. Romer LM, McConnell AKJM, sports Si, exercise. Specificity and reversibility of inspiratory muscle training. *Med Sci Sports Exerc* 2003;35(2):237–244.
14. Shei R-J, Paris HL, Wilhite DP, Chapman RF, Mickleborough T. The role of inspiratory muscle training in the management of asthma and exercise-induced bronchoconstriction. *Phys Sportsmed* 2016; 44(4):327–334. doi:10.1080/00913847.2016.1176546.
15. Petrovic M, Reiter M, Zipko H, Pohl W, Wanke T. Effects of inspiratory muscle training on dynamic hyperinflation in patients with COPD. *Int J Chron Obstruct Pulmon Dis* 2012;7:797–805.
16. Weiner P, Berar-Yanay N, Davidovich A, Magadle R, Weiner MJC. Specific inspiratory muscle training in patients with mild asthma with high consumption of inhaled β_2 -agonists. *Chest* 2000;117(3):722–727. doi: 10.1378/chest.117.3.722.
17. Duruturk N, Acar M, Doğrul M. Effect of inspiratory muscle training in the management of patients with asthma. *J Cardiopulm Rehabil Prev* 2018;38(3): 198–203. doi:10.1097/HCR.0000000000000318.
18. Lage S, Pereira D, Hoffman M, Andrade A, Fregonezi G, Parreira V. Inspiratory muscle training (IMT) in patients with asthma: a pilot study. *Eur Res J* 2016;48: PA1371. doi:10.1183/13993003.congress-2016.PA1371.
19. Zhang W, Wang Q, Liu L, Yang W, Liu HJPR. Effects of physical therapy on lung function in children with asthma: a systematic review and meta-analysis. *Pediatr Res* 2020;1–10. doi:10.1038/s41390-020-0874-x
20. Lima E, Lima WL, Nobre A, Dos Santos A, Brito L, Costa MR. Inspiratory muscle training and respiratory exercises in children with asthma. *J Bras Pneumol* 2008; 34(8):552–558. doi:10.1590/S1806-37132008000800003.
21. Lemanske RF, Jr. A review of the current guidelines for allergic rhinitis and asthma. *J Allergy Clin Immunol* 1998;101(2):392–396.
22. Global Initiative for Asthma: global strategy for asthma management and prevention. 2020. Available from: https://ginasthma.org/wpcontent/uploads/2020/04/Main-pocket-guide_2020_04_03-final-wms.pdf [last accessed 13 July 2020].
23. David MMC, Gomes ELFD, Mello MC, Costa D. Noninvasive ventilation and respiratory physical therapy reduce exercise-induced bronchospasm and pulmonary inflammation in children with asthma: randomized clinical trial. *Ther Adv Respir Dis* 2018; 12:1753466618777723doi:10.1177/1753466618777723.
24. Alfrayh A, Khoja T, Alhusain K, Alshehri S, Gad A, Madani M. FEV1 and FVC pulmonary function reference values among 6-18-year-old children: a multi-centre study in Saudi Arabia. *East Mediterr Health J* 2014;20(7):424–430. doi:10.26719/2014.20.7.424.
25. American Thoracic Society/European Respiratory Society. ATS/ERS statement on respiratory muscle testing. *Am J Respir Crit Care Med* 2002;166:518–624.
26. Domènech-Clar R, López-Andreu J, Compte-Torrero L, De Diego-Damia A, Macian-Gisbert V, Perpina-Tordera M, Roqués-Serradilla JM. Maximal static respiratory pressures in children and adolescents. *Pediatr Pulmonol* 2003;35(2):126–132.
27. Wilson SH, Cooke NT, Edwards RH, Spiro SG. Predicted normal values for maximal respiratory pressures in caucasian adults and children. *Thorax* 1984; 39(7):535–538. doi:10.1136/thx.39.7.535.
28. Schatz M, Sorkness CA, Li JT, Marcus P, Murray JJ, Nathan RA, Kosinski M, Pendergraft TB, Jhingran P. Asthma Control Test: reliability, validity, and responsiveness in patients not previously followed by asthma specialists. *J Allergy Clin Immunol* 2006;117(3): 549–556. doi:10.1016/j.jaci.2006.01.011.
29. Weiner P, Azgad Y, Ganam R, Weiner MJC. Inspiratory muscle training in patients with bronchial asthma. *Chest* 1992;102(5):1357–1361. doi:10.1378/chest.102.5.1357.
30. Shaw BS, Shaw IJL. Pulmonary function and abdominal and thoracic kinematic changes following aerobic and inspiratory resistive diaphragmatic breathing training in asthmatics. *Lung* 2011;189(2):131–139. doi: 10.1007/s00408-011-9281-8.
31. McConnell A. Respiratory muscle training e-book: theory and practice. Churchill Livingstone, Edinburgh: Elsevier Health Sciences; 2013.
32. Houston BW, Mills N, Solis-Moya A. Inspiratory muscle training for cystic fibrosis. *Cochrane Database Syst Rev* 2013;(11):Cd006112 doi:10.1002/14651858.CD006112.pub3.

33. Turner LA, Mickleborough TD, McConnell AK, Stager JM, Tecklenburg-Lund S, Lindley MR. Effect of inspiratory muscle training on exercise tolerance in asthmatic individuals. *Med Sci Sports Exerc* 2011; 43(11):2031–2038.
34. Weiner P, Magadle R, Beckerman M, Berar-Yanay N. The relationship among the inspiratory muscle strength, the perception of dyspnea and inhaled beta2-agonists in patients with asthma. *Can Respir J* 2002;9(5):307–312. doi:[10.1155/2002/746808](https://doi.org/10.1155/2002/746808).
35. Weiner P, Magadle R, Massarwa F, Beckerman M, Berar-Yanay NJC. Influence of gender and inspiratory muscle training on the perception of dyspnea in patients with asthma. *Chest* 2002;122(1):197–201. doi: [10.1378/chest.122.1.197](https://doi.org/10.1378/chest.122.1.197).
36. Hoffman M, Augusto VM, Eduardo DS, Silveira BM, Lemos MD, Parreira VF. Inspiratory muscle training reduces dyspnea during activities of daily living and improves inspiratory muscle function and quality of life in patients with advanced lung disease. *Physiother Theory Pract* 2019;1–11. doi:[10.1080/09593985.2019.1656314](https://doi.org/10.1080/09593985.2019.1656314).
37. McConnell AK, Caine MP, Donovan KJ, Toogood AK, Miller MJ. Inspiratory muscle training improves lung function and reduces exertional dyspnoea in mild/moderate asthmatics. *Clin Sci* 1998;95(s39). doi: [10.1042/cs095004pb](https://doi.org/10.1042/cs095004pb).
38. Enright SJ, Unnithan VB, Heward C, Withnall L, Davies D. Effect of high-intensity inspiratory muscle training on lung volumes, diaphragm thickness, and exercise capacity in subjects who are healthy. *Phys Ther* 2006;86(3):345–354.
39. Ramírez-Sarmiento A, Orozco-Levi M, Güell R, Barreiro E, Hernandez N, Mota S, Sangenis M, Broquetas JM, Casan P, Gea J. Inspiratory muscle training in patients with chronic obstructive pulmonary disease: structural adaptation and physiologic outcomes. *Am J Respir Crit Care Med* 2002;166(11): 1491–1497. doi:[10.1164/rccm.200202-075OC](https://doi.org/10.1164/rccm.200202-075OC).
40. Turner LA, Tecklenburg-Lund SL, Chapman RF, Stager JM, Wilhite DP, Mickleborough T. Inspiratory muscle training lowers the oxygen cost of voluntary hyperpnea. *J Appl Physiol* 2012;112(1):127–134. doi: [10.1152/jappphysiol.00954.2011](https://doi.org/10.1152/jappphysiol.00954.2011).
41. Ojanen M. Can the true effects of exercise on psychological variables be separated from placebo effects?. *Int J Sport Psychol* 1994;25(1):63–80.
42. Keles MN, Elbasan B, Apaydin U, Aribas Z, Bakirtas A, Kokturk N. Effects of inspiratory muscle training in children with cerebral palsy: a randomized controlled trial. *Braz J Phys Ther* 2018;22(6):493–501. doi:[10.1016/j.bjpt.2018.03.010](https://doi.org/10.1016/j.bjpt.2018.03.010).