Effects of a balloon inflation exercise program on sleep apnea severity and respiratory muscle strength in school-aged children with obstructive sleep apnea

Efectos del ejercicio de inflado de globos sobre la apnea obstructiva del sueño y fuerza respiratoria en niños

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Abstract

Introduction: Obstructive sleep apnea (OSA) is a common sleep-related breathing disorder in children that may impair physical health, cognitive function, and quality of life. Respiratory muscle training may improve airway function and reduce OSA symptoms.
Objective: To investigate the effects of a balloon-blowing exercise program on sleep apnea severity and respiratory muscle strength in school-age children with OSA.
Methodology: A randomized controlled trial included 30 children with OSA randomly assigned to a balloon-blowing exercise group (BBG; n = 15) or a control group (CG; n = 15). The BBG completed a five-week exercise program, whereas the CG received routine care. Sleep apnea severity and respiratory muscle strength were assessed using a sleep apnea severity scale and maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP). Data were analyzed using paired and independent t-tests.
Results: The BBG showed a significant reduction in sleep apnea severity compared with baseline and the CG (t = -2.45, p-value < .05, 95% CI [-0.33, -0.03]). Respiratory muscle strength improved significantly, with greater gains in the BBG (t = 3.46, p-value < .05, 95% CI [7.07, 27.59]). MEP increased significantly, whereas no significant between-group difference was observed for MIP.
Discussion: Balloon-blowing exercises improved respiratory muscle performance and reduced OSA severity, supporting their use as a non-invasive intervention for pediatric OSA.
Conclusions: A five-week balloon-blowing exercise program effectively reduced sleep apnea severity and improved respiratory muscle strength in school-age children with OSA.

Keywords

Balloon-blowing exercise; obstructive sleep apnea; respiratory muscle strength; school-age children.

Resumen

Introducción: La apnea obstructiva del sueño (AOS) es un trastorno respiratorio frecuente en niños que afecta la salud física, la función cognitiva y la calidad de vida. El entrenamiento de los músculos respiratorios puede mejorar la función de la vía aérea y reducir los síntomas de la AOS.
Objetivo: Evaluar los efectos de un programa de ejercicios de inflado de globos sobre la gravedad de la apnea del sueño y la fuerza de los músculos respiratorios en niños en edad escolar con AOS.
Metodología: Se realizó un ensayo controlado aleatorizado con 30 niños con AOS asignados a un grupo de ejercicios de inflado de globos (BBG; n = 15) o a un grupo control (CG; n = 15). El BBG realizó un programa de cinco semanas y el CG recibió la atención habitual. La gravedad de la apnea del sueño, la presión inspiratoria máxima (PIM) y la presión espiratoria máxima (PEM) fueron evaluadas. Los datos se analizaron mediante pruebas t pareadas e independientes.
Resultados: El BBG mostró una reducción significativa de la gravedad de la apnea del sueño en comparación con la evaluación basal y el CG (t = -2.45, valor p < .05, IC del 95% [-0.33, -0.03], d de Cohen = -0.90). La fuerza de los músculos respiratorios mejoró significativamente, con mayores incrementos en el BBG (t = 3.46, valor p < .05, IC del 95% [7.07, 27.59], d de Cohen = 1.26). La PEM aumentó significativamente, mientras que la PIM no mostró diferencias entre los grupos.
Discusión: Los ejercicios de inflado de globos mejoraron la función de los músculos respiratorios y redujeron la gravedad de la AOS.
Conclusiones: Un programa de ejercicios de inflado de globos de cinco semanas redujo la gravedad de la apnea del sueño y mejoró la fuerza de los músculos respiratorios en niños en edad escolar con AOS.

Palabras clave

Apnea obstructiva del sueño; ejercicio de inflado de globos; fuerza de los músculos respiratorios; niños en edad escolar.

Introduction

Obstructive sleep apnea (OSA) is one of the most common sleep-related breathing disorders in children, characterized by recurrent episodes of partial or complete upper airway obstruction during sleep. Globally, a substantial number of new cases are reported among school-age children, highlighting the growing burden of this condition (Ng et al., 2024). The primary cause of pediatric OSA is adenotonsillar hypertrophy, which narrows the upper airway and impairs normal breathing during sleep. Repeated episodes of nocturnal hypoxia and sleep fragmentation adversely affect multiple physiological systems, including cardiovascular, neurological, cognitive, and behavioral functions. Children with OSA frequently exhibit hyperactivity, aggression, emotional instability, attention deficits, impaired memory, and poor academic performance. Furthermore, disrupted sleep patterns can interfere with growth hormone secretion, resulting in delayed physical growth and development. Common clinical manifestations include loud snoring, labored breathing, unusual sleeping postures, and excessive daytime sleepiness, all of which contribute to reduced quality of life (Ma, Xie, & Wu, 2024).

Management of pediatric OSA commonly includes pharmacological treatment, environmental modifications, and behavioral strategies. Children with mild to moderate OSA are often prescribed intranasal corticosteroids and leukotriene antagonists (Ergenekon, Gokdemir, & Ersu, 2023). However, these medications may be associated with adverse behavioral effects, including aggression, hyperactivity, and nightmares (Ersu et al., 2023). In addition, children with OSA often have increased energy expenditure due to the greater respiratory effort required during sleep (Chuang et al., 2023). Therefore, adjunctive non-pharmacological interventions that improve respiratory function and airway stability may provide additional benefits. Failure to adequately manage respiratory symptoms can contribute to worsening airway obstruction and increased OSA severity, particularly in the presence of adenotonsillar hypertrophy (Iwasaki et al., 2020).

Recent evidence has highlighted the potential role of respiratory muscle training as a complementary intervention for pediatric OSA. Exercises targeting the respiratory and upper airway muscles may improve airway patency, reduce airway collapsibility, and enhance breathing efficiency during sleep (Cavalcante-Leão et al., 2022; Giuca et al., 2021; Pratanaphon et al., 2022; Saba et al., 2024). Respiratory training is also recommended as part of comprehensive management strategies that include allergen avoidance, prevention of respiratory infections, and promotion of respiratory health (Levrini et al., 2014). Among the various respiratory training approaches, balloon-blowing exercises have emerged as a simple, low-cost, and child-friendly method for strengthening respiratory muscles and promoting active participation in treatment. Previous studies have demonstrated that structured breathing exercises, including balloon inflation, can improve airway function, increase respiratory muscle performance, and reduce the severity of sleep-related breathing disorders compared with standard treatment alone (Bunlam et al., 2024; Dwi Ningsih, 2023; L. Lata, 2024; Sumartini et al., 2020).

Despite growing evidence supporting respiratory muscle training, adherence to non-pharmacological interventions and respiratory exercises remains inconsistent among children with OSA. Challenges related to treatment compliance, medication adherence, and inadequate respiratory training may limit therapeutic effectiveness (Piotto et al., 2023; Tao et al., 2024; Xiao et al., 2022). Consequently, identifying engaging and developmentally appropriate exercise interventions is important for improving respiratory outcomes in this population. Balloon-blowing exercises represent a practical and accessible approach that can be easily incorporated into daily routines while targeting respiratory muscle function.

Although previous studies have reported the benefits of breathing exercises in children with respiratory disorders, evidence regarding the effects of balloon-blowing exercise programs on sleep apnea severity and respiratory muscle strength in school-age children with OSA remains limited. Therefore, this study aimed to investigate the effects of a balloon-blowing exercise program on sleep apnea severity and respiratory muscle strength among school-age children with obstructive sleep apnea.

Method

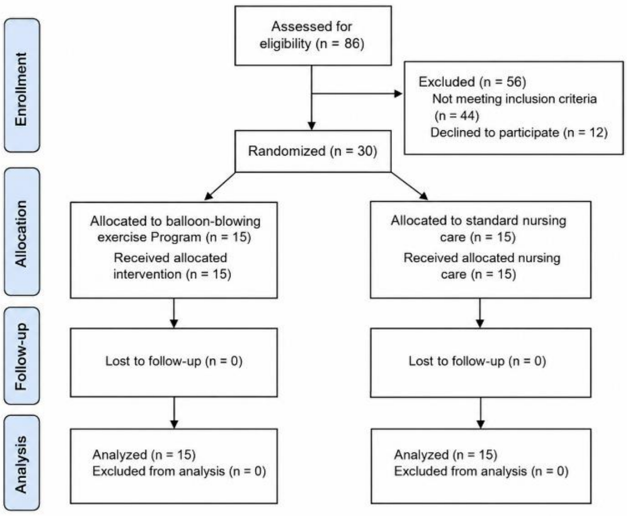
This randomized controlled trial (RCT) followed a pretest–posttest design with a comparison group. It was registered on ClinicalTrials.gov (NCT06780982) and approved by the Research Ethics Committee of the Faculty of Medicine, Siriraj Hospital, Mahidol University, Bangkok, Thailand (COA No. Si 829/2023).

Participants

The study included school-aged children (6–12 years) with mild-to-moderate OSA (apnea-hypopnea index [AHI], 1–9 events/hour). Eligible participants were on stable medication with no planned adjustments, fully conscious, without hearing impairments, and fluent in Thai. They were required to have parental consent, access to a smartphone or tablet with the LINE application, and willingness to communicate via LINE or telephone. Recruitment was conducted at the department of Otolaryngology outpatient clinic. Exclusion criteria included severe comorbidities requiring continuous treatment, previous continuous positive airway pressure (CPAP) therapy, or participation in regular intensive exercise (≥20 minutes per session, ≥3 times per week) within the previous six months.

The sample size was calculated using G*Power software based on a previous study (Bunlam et al., 2024). An effect size of 1.24, a significance level of .05, a one-tailed test, and a statistical power of 80% were used, resulting in a required sample size of 24 participants. To compensate for a potential 20% attrition rate (Gray, 2017), the sample size was increased to 30 participants. Participants were then randomly assigned to either the balloon-blowing exercise group (BBG, n = 15) or the control group (CG, n = 15). Written informed consent was obtained from all participants and their parents prior to data collection. As shown in Figure 1, eligible participants were equally allocated to the two groups, and no participants withdrew from the study.

Figure 1. CONSORT 2010 flow diagram of participant allocation, follow-up and analysis.



Procedure

Balloon-blowing exercise program

The balloon-blowing exercise program was implemented over 35 days and consisted of two phases. Phase 1 (Day 1) was conducted at the Otolaryngology outpatient clinic and included participant orientation, goal setting, and instruction in the balloon-blowing exercise protocol. Children and their parents received education regarding OSA management, including adherence to prescribed treatment, healthy dietary practices, avoidance of respiratory irritants and allergens, and the creation of a sleep-supportive environment. Participants were then trained to perform the balloon-blowing exercise correctly under researcher supervision. Instructions for communication and monitoring through the LINE application were also provided.

Phase 2 (Days 2-35) consisted of home-based practice and follow-up. Participants performed the balloon-blowing exercise daily at home according to the prescribed protocol. Weekly monitoring was conducted through LINE-based communication, and parents recorded daily exercise completion through the application or by submitting video recordings. Regular follow-up was performed to encourage adherence and ensure correct exercise performance throughout the intervention period.

Evaluation of sleep apnea severity

Sleep apnea severity was assessed using the Thai version of the 22-item Sleep-Related Breathing Disorder Scale of the Pediatric Sleep Questionnaire (SRBD–PSQ) (Longlalerng et al., 2019) The questionnaire evaluates symptoms associated with pediatric OSA, including snoring frequency, loud snoring, witnessed apneas, breathing difficulties during sleep, daytime sleepiness, hyperactivity, and related behavioral symptoms. Responses were scored as 1 (yes), 0 (no). The final score was calculated by dividing the total number of positive responses by the number of completed items, resulting in a score ranging from 0 to 1, with higher scores indicating greater OSA severity. The Thai version of the SRBD–PSQ demonstrated good internal consistency, with a Cronbach's alpha coefficient of 0.83.

Evaluation of respiratory muscle strength

Respiratory muscle strength was assessed using a Respiratory Pressure Meter (MicroRPM®, Micromedical, United Kingdom), which measures maximal inspiratory pressure (MIP) and maximal expiratory pressure (MEP) in cmH_2O. Participants performed three maximal inspiratory and expiratory maneuvers, each sustained for approximately two seconds. The mean value of the three attempts was used for analysis, with higher values indicating greater respiratory muscle strength. All measurements were conducted by the same researcher according to the recommendations of the American Thoracic Society (ATS) and the European Respiratory Society (ERS) (Dimitriadis et al., 2011; Kuo et al., 2020; Leelarungrayub et al., 2017). To minimize detection bias, the research assistant who conducted the MicroRPM measurements and administered the SRBD-PSQ was blinded to the participants' group allocation.

Data analysis

All statistical analyses were conducted using a significance level of .05. Descriptive statistics were used to summarize participant characteristics. Paired-sample t-tests were used to compare pre- and post-intervention outcomes within groups, whereas independent-sample t-tests were used to compare outcomes between the BBG and CG. Assumptions for parametric testing were examined before analysis. Specifically, normality was verified using the Shapiro-Wilk test (p-value > .05) and homogeneity of variances was confirmed using Levene's test (p-value > .05) for all outcomes, justifying the application of parametric t-tests.

Results

The demographic characteristics of participants are presented in Table 1. No significant differences were observed between the BBG and CG at baseline (p-value > .05), indicating group homogeneity. Baseline comparisons of age, sex, and nutritional status (BMI) showed no significant differences between the BBG and CG (p-value > .05), confirming that these potential covariates were balanced and did not act as confounders. Most participants were male, with a mean age of 8.53 years (SD = 1.71) in the BBG and 8.32 years (SD = 2.11) in the CG. The majority were first-grade students (33.33%) and had above-average nutritional status (56.67%). More than half of the participants (53.3%) were receiving montelukast (Singulair) for an average of 2.33 years (SD = 1.27), while 70% used fluticasone furoate nasal spray (Avamys) for an average of 2.37 years (SD = 1.42). The mean duration of OSA treatment was 1.57 years (SD = 0.86), and 73.33% of participants had mild OSA. Most caregivers were mothers (83.34%), and 53.33% were employed in private companies.

Table 1. Demographic characteristics of participants in the control group and balloon-blowing exercise group (N = 30)

Demographic data	CG (n=15)		BBG (n=15)		Total (N=30)		df	p-value
	n	%	n	%	n	%		
	Gender							
Male	12	80.00	12	80.00	24	80.00	1	1.00[b]
Female	3	20.00	3	20.00	6	20.00		
Age (years)	x̄ = 8.32 SD =2.11		x̄ =8.53 SD =1.71		x̄ = 8.42 SD =1.90		28	0.76[a]
	Current grade level						5	0.76[b]
Grade 1	5	33.33	5	33.33	10	33.33		
Grade 2	5	33.33	2	13.33	7	23.33		

Grade 3	1	6.67	3	20.00	4	13.33		
Grade 4	2	13.33	2	13.33	4	13.33		
Grade 5	1	6.67	1	6.67	2	6.67		
Grade 6	1	6.67	2	13.33	3	10.00		
Nutritional status*								
Underweight	2	13.33	1	6.67	3	10.00		
Normal weight	5	33.33	5	33.33	10	33.33		
Overweight	1	6.67	1	6.67	2	6.67	4	0.97[b]
Pre-obese	2	13.33	3	20.00	5	16.67		
Obese	5	33.33	5	33.33	10	33.33		
Medication use								
Singulair	11	73.33	5	33.33	16	53.33	3	0.10[b]
Antihistamine	3	20.00	6	40.00	9	30.00		
Singulair & Antihistamine	0	0.00	3	20.00	3	10.00		
No medication	1	6.67	1	6.67	2	6.67		
Years of medication use	$\bar{x}$ = 2.27 SD= 1.22		$\bar{x}$ = 2.40 SD= 1.35		$\bar{x}$ = 2.33 SD=1.27		28	0.78[a]
Current nasal spray use								
Avamys	11	73.33	10	66.67	21	70.00		
Nasonex	3	20.00	2	13.33	5	16.67	3	0.52[b]
Dymista	0	0.00	2	13.33	2	6.67		
No	1	6.67	1	6.67	2	6.67		
Years of nasal spray use	$\bar{x}$ = 2.47 SD = 1.60		$\bar{x}$ = 2.27 SD = 1.28		$\bar{x}$ = 2.37 SD = 1.42		28	0.71[a]
Years of OSA treatment	$\bar{x}$ = 1.33 SD = 0.49		$\bar{x}$ = 1.80 SD = 1.08		$\bar{x}$ = 1.57 SD = 0.86		28	0.14[a]
OSA severity							1	
Mild	11	73.33	11	73.33	22	73.33		1.00[b]
Moderate	4	26.67	4	26.67	8	26.67		
Caregiver–child relationship								
Father	2	13.33	2	13.33	4	13.33		
Mother	12	80.00	13	86.67	25	83.34	2	0.59[b]
Grandmother	1	6.67	0	0.00	1	3.33		
Caregiver occupation								
Government officer	0	0.00	1	6.67	1	3.33		
Private company employee	11	73.33	5	33.33	16	53.33		
University employee	3	20.00	5	33.33	8	26.67	4	0.15[b]
Business/self-employed	1	6.67	1	6.67	2	6.67		
Unemployed	0	0.00	3	20.00	3	10.00		

Note. CG = control group; BBG = balloon-blowing exercise group; OSA = obstructive sleep apnea. Values are presented as number (n) and percentage (%); a—T-test ; b—Chi-square test ; * World Health Organization. WHO child growth standards: length/height-for-age, weight-for-age, weight-for-length, weight-for-height and body mass index-for-age: methods and development. Geneva: WHO; 2006.

Sleep Apnea Severity

Independent-samples t tests were used to compare baseline characteristics between the groups. No significant between-group differences were observed in OSA severity or respiratory muscle strength at baseline (Table 2).

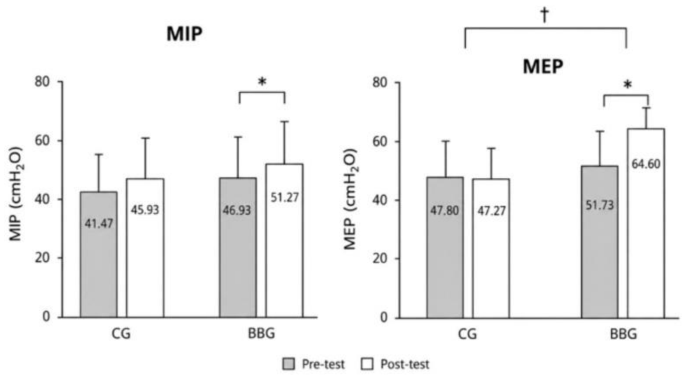
Table 2. Baseline comparison of sleep apnea severity and respiratory muscle strength between the CG and BBG before the intervention

Variables		Pre-test				df	t	p-value
		CG		BBG				
		$\bar{X}$	SD	$\bar{X}$	SD			
Sleep apnea severity		0.43	0.18	0.41	0.18	28	-0.35	0.83
Respiratory Muscle Strength	MIP (cmH2O)	41.47	15.58	46.93	12.39	28	1.06	0.38
	MEP (cmH2O)	47.80	12.09	51.73	14.54	28	0.81	0.78

Note. CG = control group; BBG = balloon-blowing exercise group; MIP = maximal inspiratory pressure; MEP = maximal expiratory pressure. Values are presented as mean ($\bar{X}$) and standard deviation (SD).

Following the five-week balloon-blowing exercise program, sleep apnea severity significantly decreased in the BBG compared with baseline values (t = -6.453, p-value < .05, 95% CI [-0.173, -0.087], Cohen's d = -1.67). Post-intervention comparisons also demonstrated significantly lower sleep apnea severity scores in the BBG than in the CG (t = -2.45, p-value < .05, 95% CI [-0.330, -0.030], Cohen's d = -0.90), indicating the effectiveness of the balloon-blowing exercise program in reducing OSA severity (Figure 2).

Figure 2. The comparison of the respiratory muscle strength variables between the CG and BBG. Data are presented as mean ± SD. *p-value < .05 vs. pre-test; †p-value <.05



Respiratory Muscle Strength

After the five-week balloon-blowing exercise program, sleep apnea severity significantly decreased and respiratory muscle strength significantly improved in the BBG (Table 3).

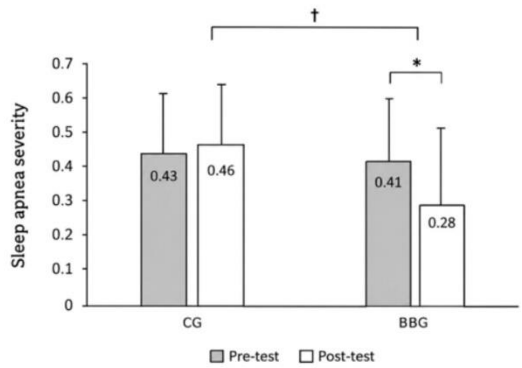
Table 3. Changes in sleep apnea severity and respiratory muscle strength in the BBG before and after the intervention

Variables		Pre-program		Post-program		df	t	p-value
		X̅	SD	X̅	SD			
Sleep apnea severity		0.46	0.18	0.28	0.22	14	-6.453	<0.001*
Respiratory Muscle Strength	MIP (cmH_2O)	46.93	12.39	51.27	13.63	14	1.757	0.05*
	MEP (cmH_2O)	51.73	14.54	64.6	16.03	14	5.148	<0.001*

Note. MIP = maximal inspiratory pressure; MEP = maximal expiratory pressure. Values are presented as mean (X̅) and standard deviation (SD); *p-value < .05

Respiratory muscle strength improved following participation in the balloon-blowing exercise program. Within the BBG, both MIP (t = 1.757, p-value < .05, 95% CI [-0.96, 9.64], Cohen's d = 0.45) and MEP (t = 5.148, p-value < .05, 95% CI [7.51, 18.23], Cohen's d = 1.33) increased significantly from baseline. Between-group comparisons revealed significantly greater improvements in MEP in the BBG than in the CG after the intervention (t = 3.46, p-value < .05, 95% CI [7.07, 27.59], Cohen's d = 1.26). However, no significant between-group difference was observed for MIP following the intervention (p-value > .05). These findings suggest that the balloon-blowing exercise program was particularly effective in improving expiratory muscle strength in school-age children with OSA (Figure 3).

Figure 3. The comparison of the sleep apnea severity between the CG and BBG. Data are presented as mean ± SD. *p-value < .05 vs. pre-test; †p-value <.05



Post-intervention comparisons demonstrated significantly lower sleep apnea severity and higher MEP values in the BBG than in the CG (Table 4).

Table 4. Post-intervention comparison of sleep apnea severity and respiratory muscle strength between the CG and BBG

Variables		Post-program				t	df	p-value
		CG		BBG				
		X̄	SD	X̄	SD			
Sleep apnea severity		0.46	0.18	0.28	0.22	-2.45	28	0.02*
Respiratory Muscle Strength	MIP (cmH_2O)	45.93	14.93	51.27	13.63	1.02	28	0.32
	MEP (cmH_2O)	47.27	10.91	64.60	16.03	3.46	28	<0.01*

Note. CG = control group; BBG = balloon-blowing exercise group; MIP = maximal inspiratory pressure; MEP = maximal expiratory pressure. Values are presented as mean (X̄) and standard deviation (SD); *p-value < .05

Discussion

Sleep Apnea Severity

The findings support the study hypothesis, demonstrating that participation in the balloon-blowing exercise program significantly reduced sleep apnea severity among school-age children with OSA (p-value < .05). This result is consistent with the pathophysiology of OSA, in which upper airway narrowing, commonly caused by adenotonsillar hypertrophy, increases airway resistance, impairs airflow, promotes carbon dioxide retention, disrupts sleep architecture, and contributes to daytime sleepiness and functional impairment (Giuca et al., 2021).

The reduction in sleep apnea severity observed in this study may be attributed to the combined effects of respiratory muscle training and supportive OSA management strategies delivered throughout the intervention period. Participants received guidance regarding adherence to prescribed medical treatment, healthy dietary habits, respiratory muscle exercises, hygiene and allergen avoidance, and optimization of the sleep environment. Adherence to pharmacological treatment and nasal care may contribute to symptom improvement and reductions in the AHI (Yu & Afolabi-Brown, 2019). Maintaining appropriate nutrition may help prevent excessive weight gain, which is associated with increased upper airway obstruction and OSA severity (Chuang et al., 2023). Furthermore, reducing exposure to allergens and respiratory irritants may decrease upper airway inflammation and improve respiratory function (Aljaid, 2024; Sanford & Lam, 2024). Improvements in sleep hygiene and sleeping conditions have also been associated with better sleep quality and reduced OSA-related symptoms (Ersu et al., 2023; Hady & Okorie, 2021; Mussi et al., 2023; Faúndez-Casanova et al., 2023). A key component of the intervention was the balloon-blowing exercise program, which provided repeated respiratory muscle training through controlled inhalation and exhalation against resistance. Balloon-blowing exercises may enhance upper airway stability, improve breathing control, and reduce airway collapsibility during sleep. Previous studies have reported that respiratory exercises can improve airway function and reduce symptoms associated with OSA and other respiratory disorders (Weiss et al., 2021). Additionally, the short-term (5-week) practice of breathing training has been shown to significantly enhance respiratory capacity in school-age populations (Costa et al., 2021), indicating its feasibility and efficacy as a child-friendly training modality. The significant reduction in sleep apnea severity observed in the present study suggests that balloon-blowing exercises may represent a practical and accessible adjunctive intervention for children with OSA.

Respiratory muscle strength

The balloon-blowing exercise program significantly improved respiratory muscle strength, particularly expiratory muscle performance. The exercise required participants to repeatedly inflate a 10-inch natural rubber balloon, creating resistance during both inhalation and exhalation. This repetitive respiratory loading may have enhanced respiratory muscle function by increasing muscle recruitment and endurance during breathing tasks.

Children with OSA often experience increased respiratory workload because of upper airway obstruction. Repeated breathing against resistance during balloon inflation may strengthen respiratory muscles and improve ventilatory efficiency. Following the five-week intervention, significant improvements were observed in both MIP and MEP within the BBG. These findings are consistent with previous studies demonstrating the benefits of respiratory muscle training for improving respiratory performance and supporting OSA management (Giuca et al., 2021; Jadhav et al., 2025). Similarly, balloon-blowing exercises have been reported as a simple and effective non-pharmacological strategy for enhancing respiratory muscle function in children (Bunlam et al., 2024; Zhang, 2025). Clinical implications of this study suggest that balloon-blowing is an easily accessible, cost-effective, and highly engaging non-pharmacological approach suitable for pediatric settings. While other therapies, such as orofacial myofunctional therapy, have shown positive results in reducing OSA severity (Saba et al., 2024), they often require specialized clinical therapists and high compliance. In contrast, the balloon-blowing program can be performed at home under parental supervision, making it a highly practical alternative for children.

Although significant within-group improvements were observed for both MIP and MEP, only MEP demonstrated a significant advantage over the CG after the intervention. Several factors may explain the absence of a significant between-group difference in MIP. Respiratory muscle strength is influenced by age, sex, body composition, and pulmonary mechanics. Male children generally demonstrate higher respiratory pressures, whereas respiratory muscle performance changes with growth and development (Di Cicco et al., 2021; LoMauro & Aliverti, 2021). In addition, the relatively high prevalence of overweight participants in both groups may have contributed to upper airway narrowing and altered respiratory mechanics, thereby limiting improvements in inspiratory muscle function (di Palmo et al., 2021; Satapathy et al., 2022).

The balloon-blowing exercise primarily emphasizes forceful exhalation against resistance, which may explain the greater improvement observed in MEP than in MIP. Because the intervention provides a stronger training stimulus for expiratory muscles, gains in inspiratory muscle strength may require longer intervention periods or exercises specifically designed to target inspiratory muscle function. Therefore, while balloon-blowing exercises appear effective for enhancing expiratory muscle strength, additional inspiratory muscle training strategies may be necessary to maximize improvements in MIP.

Limitations and future directions

Several limitations should be considered when interpreting the findings. First, monitoring adherence to the balloon-blowing exercise program required considerable time for data recording and verification. Future studies may benefit from automated digital monitoring systems or video-based verification through mobile applications. Second, the relatively high proportion of overweight participants suggests that future interventions should incorporate nutritional management and weight-control strategies, given the established relationship between obesity and OSA severity. Third, environmental factors such as air pollution, cigarette smoke exposure, and household allergens were not controlled and may have influenced respiratory outcomes. Finally, future studies should consider incorporating objective physiological monitoring tools, such as wearable devices for oxygen saturation and heart rate assessment, to provide more comprehensive evaluations of OSA severity and treatment effectiveness.

Conclusions

The balloon-blowing exercise program significantly reduced sleep apnea severity and improved respiratory muscle strength in school-age children with OSA. Greater improvements were observed in expiratory muscle strength than inspiratory muscle strength, indicating that the intervention primarily enhances expiratory muscle performance. Balloon-blowing exercises may serve as an effective, practical, and low-cost complementary intervention for pediatric OSA management.

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