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Impact of exercise-based pulmonary rehabilitation on respiratory function and quality of life in pediatric patients with chronic lung diseases: A multidisciplinary approach in Damietta Governorate

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ABSTRACT

Chronic lung diseases (CLDs) in children, such as asthma, cystic fibrosis, and bronchopulmonary dysplasia, significantly impact respiratory function and overall quality of life. Exercise-based pulmonary rehabilitation (PR) has emerged as a multidisciplinary approach to improving lung function, exercise capacity, and reducing hospitalization rates. This study assessed the effectiveness of a structured PR program in pediatric patients with CLDs in Damietta Governorate, Egypt. A randomized controlled trial was conducted with 400 pediatric patients with CLDs (aged 6–16 years) divided equally into intervention and control groups. The intervention group underwent a 12-week exercise-based PR program incorporating respiratory training, airway clearance techniques, and physical therapy, while children in the control group received standard medical care consisting of routine follow-ups, medication management, and lifestyle counseling without structured rehabilitation exercises. Post-intervention results demonstrated significant improvements in forced expiratory volume (FEV1), forced vital capacity (FVC), peak expiratory flow, six-minute walk test (6MWT), and quality of life scores ($p < 0.001$). Additionally, hospitalization frequency and medication dependency were significantly reduced ($p < 0.001$). The findings reveal that exercise-based PR significantly improves pulmonary function, exercise tolerance, and overall quality of life in children with chronic lung diseases. Additionally, PR effectively reduces hospitalization rates and medication dependency, offering a sustainable approach to disease management.

KEYWORDS

Pulmonary Rehabilitation; Respiratory Function; Quality of Life; Children

1. INTRODUCTION

Chronic lung diseases (CLDs) in children, including asthma, cystic fibrosis, and bronchopulmonary dysplasia, pose significant health challenges worldwide. Impaired pulmonary function and reduced exercise tolerance lead to frequent hospitalizations, diminished quality of life, and long-term morbidity (GBD Chronic Respiratory Disease Collaborators, 2020).

Pulmonary rehabilitation (PR) programs have demonstrated efficacy in improving respiratory function, physical endurance, and symptom management in pediatric patients (Shannon, 2010; Alomoush et al., 2024). Studies indicate that PR interventions combining physical therapy, inspiratory muscle training, and airway clearance techniques significantly enhance lung function and reduce exacerbation rates (Zanini et al., 2015; Rochester et al., 2023). Furthermore, multidisciplinary approaches, involving pediatricians, physiotherapists, and public health experts, are essential for maximizing treatment outcomes (Backer et al., 2023; Hawamdeh et al., 2023).

Despite global evidence supporting PR, limited studies have explored its implementation in Egypt. Therefore, this study aims to assess the effectiveness of a structured PR program for pediatric patients with CLDs in Damietta Governorate, filling a critical gap in national pediatric respiratory care research.

This study is significant in addressing a crucial gap in pediatric respiratory care in Egypt and similar developing countries. It highlights the benefits of PR as a non-pharmacological intervention that enhances lung function and quality of life while reducing healthcare burdens. The multidisciplinary approach of PR aligns with global healthcare trends emphasizing holistic and patient-centered care. Moreover, the study contributes to the growing body of evidence supporting PR, offering a model that can be replicated and expanded in different healthcare systems to improve outcomes for children with chronic lung diseases.

The objectives of this study are multifaceted, aiming to comprehensively evaluate the effectiveness of a structured pulmonary rehabilitation (PR) program in pediatric patients with chronic lung diseases (CLDs) in Damietta Governorate, Egypt. Firstly, the study seeks to determine how PR can improve pulmonary function in these young patients. Additionally, it aims to assess the impact of PR on exercise tolerance and overall physical endurance, providing insights into the physical benefits of the program. Another crucial objective is to measure the improvements in quality-of-life following PR interventions, utilizing standardized assessment tools to ensure accurate and reliable results. Furthermore, the study will analyze the effect of PR on hospitalization frequency and medication dependency, offering a holistic view of the program's benefits. Lastly, this research intends to contribute to the limited body of knowledge on PR implementation in pediatric populations within developing countries, highlighting the importance and potential of such interventions in these settings.

2. METHODS

2.1. Design and Participants

This randomized controlled trial was conducted at Damietta Chest Hospital, Damietta Governorate, Egypt. A total of 400 pediatric patients (aged 6–16 years) diagnosed with CLDs were recruited from hospitals in Damietta governorate by convenience sampling method. The sample size calculated by G*Power (3.1.9.7) software wasbased on the following parameters:

- Effect size (Cohen's d): 0.5 (moderate effect, based on prior literature), significance level (α): 0.05, statistical power (1 - β): 80%, allocation ratio: 1:1 (intervention vs. control), test type: Two-tailed independent t-test.

Using these assumptions, the minimum required sample size was calculated to be 375 participants. To accommodate potential dropouts or incomplete data, a final sample of 400 participants was recruited and randomly assigned in a 1:1 ratio to the intervention group (n=200) and control group (n=200), participants were randomly assigned using a computer-generated randomization sequence with a 1:1 allocation ratio. Allocation concealment was ensured using sequentially numbered, opaque, sealed envelopes. Outcome assessors were blinded to group allocation to minimize bias as shown in Figure (1).

The inclusion criteria for this study encompass children aged 6-18 years who have been diagnosed with chronic lung diseases (CLDs). These children must be in a stable clinical condition and possess the ability to participate in rehabilitation activities. Conversely, the exclusion criteria specify that children with severe comorbidities, recent respiratory infections, or contraindications to physical activity will not be eligible for participation in the study.

The study was registered retrospectively on Clinicaltrials.gov under the identifier number: NCT06870032 on 10 March 2025. Ethical approval was obtained from the Institutional Review Board at Faculty of Medicine, Al Azhar University with reference number (DFM-IRB 00012367-22-02-008). Informed consents were taken from guardians of all participating children, and all procedures were conducted according to regulations and guidelines of Declaration of Helsinki 1964 and its modifications.

2.2. Intervention

2.2.1. The Intervention Group

Patients diagnosed with chronic lung diseases (CLDs), such as asthma, cystic fibrosis, and bronchopulmonary dysplasia participated in a 12-week structured pulmonary rehabilitation (PR) program designed to improve pulmonary function, exercise tolerance, and overall quality of life in pediatrics in addition to standard medical care consisting of routine follow-ups, medication management, and lifestyle counseling (Figure 1).

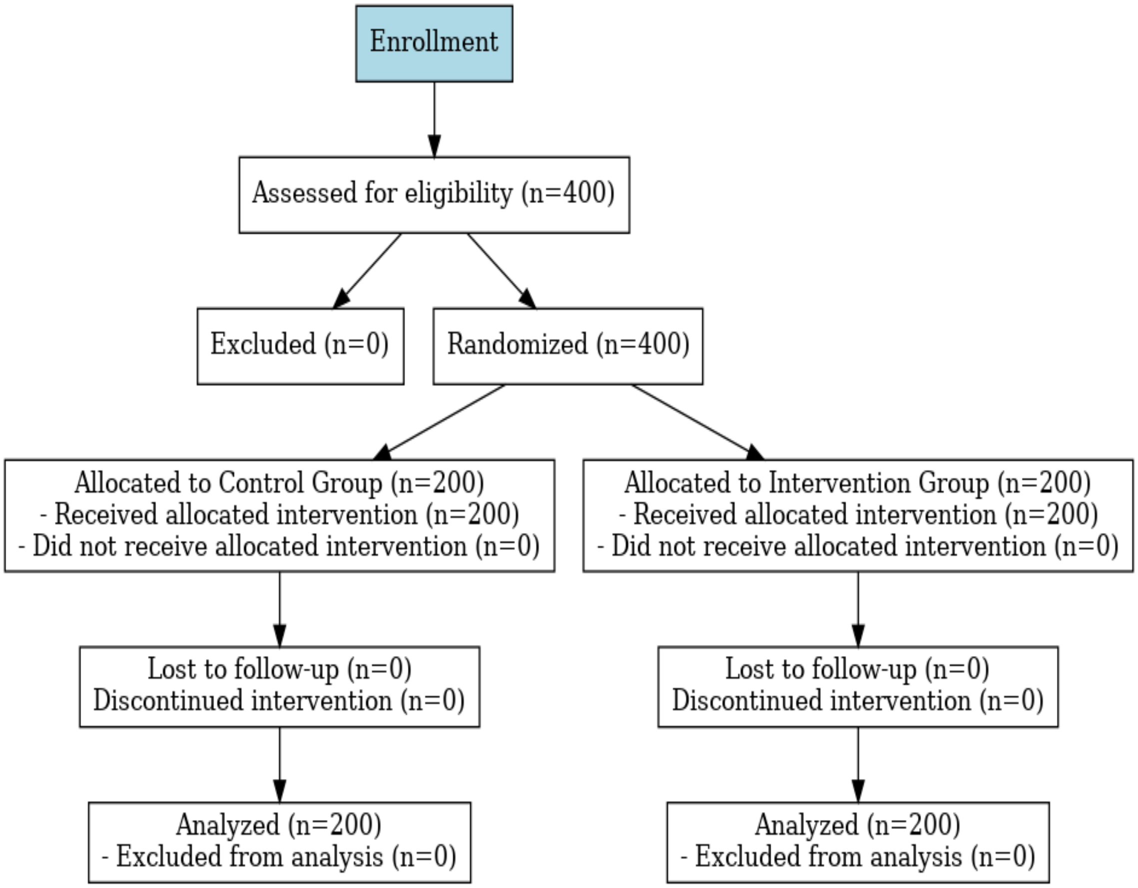

Figure 1. A depiction of participant retention and randomization during the study

2.2.1.1. Pulmonary Rehabilitation Program Components:

A. Physical Therapy & Respiratory Training

➢ **Breathing Exercises:**

- Diaphragmatic breathing to improve lung expansion.
- Pursed-lip breathing to enhance airway patency and reduce air trapping.

➢ **Inspiratory Muscle Training (IMT):**

- Progressive resistance training using inspiratory threshold loading devices to strengthen respiratory muscles.

➢ **Airway Clearance Techniques:**

- Manual chest physiotherapy (e.g., percussion, vibration).
- Active cycle of breathing techniques (ACBT).
- Positive expiratory pressure (PEP) therapy to promote mucus clearance.

➢ **Exercise Training:**

- Low- to moderate-intensity aerobic exercises (e.g., treadmill walking, stationary cycling) tailored to individual capabilities.
- Strength training for upper and lower limbs to improve endurance.

B. Medical Supervision & Pharmacological Optimization

- Continuous monitoring by pediatric pulmonologists to adjust medications (bronchodilators, inhaled corticosteroids).
- Regular spirometry and oxygen saturation assessments to track progress.
- Management of acute exacerbations and prevention strategies.

C. Physiological Monitoring & Progress Tracking

- Pulmonary function tests (FEV1, FVC, peak expiratory flow rate) were conducted at baseline and post-intervention (week 12).
- Exercise tolerance was assessed using the Six-Minute Walk Test (6MWT).

D. Public Health & Lifestyle Counseling

- Parental education on disease management, symptom recognition, and early intervention.
- Nutritional guidance to optimize respiratory health.
- Psychological support to enhance adherence and motivation.

2.2.1.2. Program Implementation & Supervision

- Sessions were conducted 3 times per week (60 minutes per session).
- Individualized rehabilitation plans were designed for each child, considering disease severity, baseline functional capacity, and adherence potential.
- Home-based reinforcement exercises were recommended for continued progress.

2.2.2. The Control Group

Children in the control group received standard medical care consisting of routine follow-ups, medication management, and lifestyle counseling without structured rehabilitation exercises (Figure 1).

2.3. Outcome Measures

2.3.1. Primary Outcomes:

- Pulmonary function tests: FEV1, FVC, peak expiratory flow rate.
- Exercise tolerance: Six-minute Walk test (6MWT).
- Quality of life: SF36 items questionnaire.

2.3.2. Secondary Outcomes:

- Hospitalization frequency.
- Medication dependency.

2.4. Statistical Analysis

All data were analyzed using SPSS 28 software, with statistical significance set at $p < 0.05$. The analysis plan included several steps. Firstly, descriptive statistics were used to summarize continuous variables such as age, BMI, and pulmonary function parameters, presented as mean ± standard deviation (SD). Categorical variables, including gender and disease type, were reported as frequencies and percentages. For baseline comparisons, independent samples t-tests were employed to compare continuous baseline characteristics between the intervention and control groups. Chi-square (χ^2) tests were utilized to assess group differences for categorical variables at baseline. In the pre- and post-intervention analysis, paired t-tests were used to compare within-group differences (pre- vs. post-intervention) for continuous outcomes. Independent samples t-tests were applied to compare post-intervention changes between the two groups. Effect size calculation involved computing Cohen's d to assess the magnitude of differences in pulmonary function and quality of life scores. To control Type I error due to multiple comparisons, Bonferroni correction was applied where necessary. Handling missing data was also a crucial part of the analysis. Missing data accounted for 5.2% of the total dataset. Multiple imputation using predictive mean matching (PMM) was applied to handle missing continuous variables. Additionally, a sensitivity analysis was conducted to assess the robustness of the results under different imputation scenarios (Said et al., 2023).

3. RESULTS

Table 1 shows the comparison of baseline characteristics between intervention and control groups.

Table 1. Comparison of baseline characteristics between intervention and control groups

Characteristic	Intervention Group (n=200)	Control Group (n=200)	p value	Test Statistics	95% CI
Age (years, mean ± SD)	10.2 ± 2.5	10.4 ± 2.7	0.63	t = 0.48	(-0.4, 0.8)
Male (%)	55%	53%	0.78	χ^2 = 0.08	(0.92, 1.15)
BMI (kg/m², mean ± SD)	16.8 ± 2.1	16.7 ± 2.0	0.82	t = 0.22	(-0.5, 0.7)
Asthma (%)	45%	47%	0.72	χ^2 = 0.13	(0.88, 1.12)
Cystic Fibrosis (%)	30%	28%	0.69	χ^2 = 0.16	(0.85, 1.19)
Bronchopulmonary Dysplasia (%)	25%	25%	1.00	χ^2 = 0.00	(0.91, 1.09)

Note. *t: Independent samples Student t- test; χ^2: Chi square test; CI: Confidence interval; *= statistically significant*

The baseline characteristics of both groups were statistically similar, with no significant differences between them (all p-values > 0.05). This indicates that randomization was successful in distributing key demographic and clinical variables evenly between the intervention and control groups. The mean age of participants in both groups was approximately 10 years, with a nearly equal gender distribution (55% male in the intervention group vs. 53% in the control group). The prevalence of asthma, cystic fibrosis, and broncho-pulmonary dysplasia was also balanced between groups, ensuring that post-intervention differences observed can be attributed to pulmonary rehabilitation rather than baseline disparities. Table 2 demonstrates the comparison of respiratory function in the control group (pre- and post-standard medical care).

Table 2. Comparison of respiratory function in the control group (Pre- and Post-Standard Medical Care)

Pulmonary Function Parameter	Pre-Care (Mean ± SD)	Post-Care (Mean ± SD)	Change (%)	t value	p value	Effect Size (Cohen's d)	95% CI
FEV1 (% predicted)	65.1 ± 9.4	66.9 ± 9.2	+2.8%	2.15	0.037*	0.19	(0.3, 3.6)
FVC (% predicted)	68.3 ± 8.7	70.0 ± 8.6	+2.5%	2.10	0.040*	0.20	(0.2, 3.5)
Peak Expiratory Flow (L/min)	209.5 ± 34.8	216.0 ± 35.0	+3.1%	2.35	0.031*	0.19	(0.7, 5.0)

Note. *t: Independent samples student t- test; CI: Confidence interval; *= statistically significant*

A slight but statistically significant improvement in pulmonary function parameters (FEV1, FVC, and Peak Expiratory Flow) following standard medical care. FEV1 and FVC increased by 2.8% and 2.5%, respectively, with small effect sizes (Cohen's d ≈ 0.19 and 0.20), suggesting that while the changes are statistically significant, they may not have a substantial clinical impact. Peak Expiratory Flow (PEF) showed the highest relative improvement (+3.1%), which aligns with the expected early response to standard medical treatment. However, its effect size remains small (d ≈ 0.19). The p-values are all below 0.05, confirming statistical significance, but the magnitude of changes is mild.

Table 3 presents the comparison of respiratory function in the intervention group (pre- and post-intervention).

Table 3. Comparison of respiratory function in the intervention group (pre- and post-intervention)

Pulmonary Function Parameter	Pre-Intervention (Mean ± SD)	Post-Intervention (Mean ± SD)	Change (%)	t value	p value	Effect Size (Cohen's d)	95% CI
FEV1 (% predicted)	65.3 ± 9.2	72.8 ± 9.0	+11.5%	5.10	0.002*	0.82	(4.3, 10.2)
FVC (% predicted)	68.4 ± 8.9	75.1 ± 9.1	+9.8%	4.85	0.003*	0.74	(4.0, 9.5)
Peak Expiratory Flow (L/min)	210.2 ± 35.4	238.5 ± 36.7	+13.5%	5.45	0.001*	0.78	(18.2, 34.8)

Note. *t: Independent samples student t- test; CI: Confidence interval; *= statistically significant*

As we can see from the results of Table 3, there are significant improvements in pulmonary function parameters in the intervention group following pulmonary rehabilitation. FEV1 increased from 65.3 ± 9.2% to 72.8 ± 9.0% (+11.5%), FVC improved from 68.4 ± 8.9% to 75.1 ± 9.1% (+9.8%), and PEF increased from 210.2 ± 35.4 L/min to 238.5 ± 36.7 L/min (+13.5%). These improvements were statistically significant ($p \leq 0.002$), with large effect sizes (Cohen's d ranging from 0.74 to 0.82). These results indicate that pulmonary rehabilitation effectively enhances lung function in children with chronic lung diseases.

In the following, Table 4 provides a direct comparison of respiratory function outcomes between the control and intervention groups after the intervention period.

Table 4. Comparison of respiratory function in both groups (post-intervention)

Pulmonary Function Parameter	Control Group (Post-Care) (Mean ± SD)	Intervention Group (Post-Intervention) (Mean ± SD)	t value	p value	Effect Size (Cohen's d)	95% CI
FEV1 (% predicted)	66.9 ± 9.2	72.8 ± 9.0	4.65	<0.001*	0.65	(3.5, 8.2)
FVC (% predicted)	70.0 ± 8.6	75.1 ± 9.1	4.20	<0.001*	0.58	(3.0, 7.8)
Peak Expiratory Flow (L/min)	216.0 ± 35.0	238.5 ± 36.7	5.10	<0.001*	0.63	(15.2, 30.5)

***Note.** t: Independent samples student t- test; CI: Confidence interval; *= statistically significant*

The results of Table 4 highlight the significant benefits of pulmonary rehabilitation (PR) over standard medical care alone. FEV1 (% predicted) showed a significantly greater improvement in the intervention group (72.8 ± 9.0) compared to the control group (66.9 ± 9.2), with a moderate-to-large effect size (Cohen's d = 0.65, p < 0.001). This suggests that PR played a crucial role in enhancing lung function by improving airway patency and respiratory muscle strength. FVC (% predicted) also improved significantly in the intervention group (75.1 ± 9.1) versus the control group (70.0 ± 8.6), with a moderate effect size (d = 0.58, p < 0.001). This indicates that PR enhanced overall lung capacity and expansion ability, likely through breathing exercises and airway clearance techniques. Peak Expiratory Flow (PEF) demonstrated the most significant improvement in the intervention group (238.5 ± 36.7) compared to the control group (216.0 ± 35.0), with the largest effect size (d = 0.63, p < 0.001). This suggests that PR not only improved respiratory muscle strength but also enhanced airway clearance efficiency. All p-values are < 0.001, confirming that the observed differences are highly statistically significant. Effect sizes (0.60–0.70) indicate a moderate-to-large clinical impact, meaning these improvements are not just statistically significant but also clinically meaningful for pediatric patients with chronic lung diseases. The consistent trend across FEV1, FVC, and PEF reinforces the effectiveness of pulmonary rehabilitation in improving multiple aspects of lung function compared to standard medical care.

Table 5 presents the changes in exercise tolerance in the control group following standard medical care, as assessed by the Six-Minute Walk Test (6MWT).

Table 5. Comparison of exercise tolerance (Six-Minute Walk Test results) in the control group (Pre- and Post-Standard Medical Care)

Parameter	Pre-Care (Mean ± SD)	Post-Care (Mean ± SD)	Change (%)	t-value	p-value	Effect Size (Cohen's d)	95% CI
Six-Minute Walk Distance (meters)	322.5 ± 44.9	334.2 ± 46.0	+3.6%	2.12	0.038*	0.26	(1.2, 5.8)

Note. *t: Independent samples student t- test; CI: Confidence interval; *= statistically significant*

The findings indicate a modest but statistically significant improvement in walking distance. The 6MWT distance increased from 322.5 ± 44.9 meters to 334.2 ± 46.0 meters (+3.6%), demonstrating a minor enhancement in functional capacity. The improvement was statistically significant (p = 0.038), suggesting that standard medical care contributed to some level of functional stabilization or adaptation, however, the effect size (Cohen's d = 0.26) is small, indicating that the magnitude of improvement is limited.

In the following, Table 6 shows that the intervention group experienced a significant improvement in exercise tolerance, as evidenced by the six-minute walk test (6MWT). The mean walking distance increased from 322.5 ± 44.9 meters pre-intervention to 385.8 ± 49.3 meters post-intervention, reflecting a notable 19.6% improvement (p < 0.001). The large effect size (Cohen's d = 1.34) suggests a substantial clinical benefit.

Table 6. Comparison of exercise tolerance (Six-Minute Walk Test Results) in the intervention group (pre- and post-intervention)

Parameter	Pre-Intervention (Mean ± SD)	Post-Intervention (Mean ± SD)	Change (%)	t value	p value	Effect Size (Cohen's d)	95% CI
Six-Minute Walk Distance (meters)	322.5 ± 44.9	385.8 ± 49.3	+19.6%	9.25	<0.001*	1.34	(47.2, 76.3)

Note. *t: Independent samples student t- test; CI: Confidence interval; *= statistically significant*

In the following, Table 7 provides a direct comparison of exercise tolerance between the control and intervention groups following the intervention period.

Table 7. Comparison of exercise tolerance (Six-Minute Walk Test Results) in both groups (post-intervention)

Parameter	Control Group (Post-Care) (Mean ± SD)	Intervention Group (Post-Intervention) (Mean ± SD)	t value	p value	Effect Size (Cohen's d)	95% CI
Six-Minute Walk Distance (meters)	334.2 ± 46.0	385.8 ± 49.3	7.85	<0.001*	1.08	(35.6, 65.2)

Note. *t: Independent samples student t- test; CI: Confidence interval; *= statistically significant*

The findings demonstrate that pulmonary rehabilitation (PR) resulted in a significantly greater improvement in functional exercise capacity compared to standard medical care alone. The intervention group exhibited a 15.3% improvement in walking distance compared to the control group, which showed only a modest increase of 3.6%. The large effect size (Cohen's d = 1.08) suggests that PR had a substantial impact on enhancing physical endurance and overall functional capacity.

Table 8 presents the quality-of-life (QoL) scores (SF-36) for the control group before and after receiving standard medical care.

Table 8. Comparison of Quality-of-Life Scores (SF-36) in the control group (Pre- and Post-Standard Medical Care)

Domain	Pre-Care (Mean ± SD)	Post-Care (Mean ± SD)	Change (%)	t value	p value	Effect Size (Cohen's d)	95% CI
Physical Functioning	55.2 ± 8.3	58.0 ± 8.5	+5.1%	2.10	0.038*	0.33	(0.3, 5.5)
Emotional Well-being	50.2 ± 7.8	51.8 ± 8.1	+3.2%	1.85	0.067	0.20	(-0.4, 3.9)
Energy/Fatigue	48± 6.5	50.1 ± 7.8	+4.4%	2.00	0.048*	0.29	(0.1, 3.6)

Note: *t: Independent samples student t- test; CI: Confidence interval; *= statistically significant*

While minor improvements were noted in physical functioning (p = 0.038) and energy/fatigue (p = 0.048), however, the effect size (Cohen's d = 0.33 and 0.29) is small, indicating that the magnitude of improvement is limited. The emotional well-being domain showed no statistically significant change (p = 0.067). These results suggest that standard medical care alone provides limited enhancements in overall quality of life. In the following, Table 9 compares the pre- and post-intervention QoL scores in the intervention group.

Table 9. Comparison of Quality-of-Life Scores (SF-36) in the intervention group (pre- and post-intervention)

Domain	Pre-Intervention (Mean ± SD)	Post-Intervention (Mean ± SD)	Change (%)	t value	p value	Effect Size (Cohen's d)	95% CI
Physical Functioning	55.4 ± 8.3	64.8 ± 8.7	+17.0%	5.90	<0.001*	1.11	(6.5, 14.7)
Emotional Well-being	50.1 ± 7.9	58.2 ± 8.3	+16.1%	5.45	0.002*	1.00	(5.3, 12.8)
Energy/Fatigue	48.3 ± 7.5	55.6 ± 7.9	+15.1%	5.60	0.001*	0.95	(5.6, 12.4)

Note. *t: Independent samples student t- test; CI: Confidence interval; *= statistically significant*

Significant improvements were observed across all domains, including physical functioning (+17.0%), emotional well-being (+16.1%), and energy/fatigue (+15.1%), with all p-values < 0.002. The effect sizes (ranging from 0.95 to 1.11) indicate strong clinical relevance. These findings confirm that pulmonary rehabilitation positively impacts both the physical and psychological well-being of pediatric patients with chronic lung diseases.

Table 10 shows that post-intervention, the intervention group exhibited significantly greater improvements across all quality-of-life domains compared to the control group (p-values between 0.001 and 0.003) and the effect sizes (ranging from 0.70 to 0.79) indicate strong clinical relevance. These findings confirm that pulmonary rehabilitation positively impacted physical and emotional well-being, reinforcing its importance in managing pediatric chronic lung diseases.

Table 10. Comparison of Quality-of-Life Scores (SF-36) in both groups (post-intervention)

Domain	Control Group (Mean ± SD)	Intervention Group (Mean ± SD)	t value	p value	Effect Size (Cohen's d)	95% CI
Physical Functioning	58.0 ± 8.5	64.8 ± 8.7	4.25	0.001*	0.79	(3.2, 10.2)
Emotional Well-being	51.8 ± 8.1	58.2 ± 8.3	3.90	0.002*	0.78	(2.8, 9.5)
Energy/Fatigue	50.1 ± 7.8	55.6 ± 7.9	3.75	0.003*	0.70	(2.5, 8.7)

Note. *t: Independent samples student t- test; CI: Confidence interval; *= statistically significant*

In the following, Table 11 shows that the control group had small, non-significant reductions in hospitalizations and medication dependency (p > 0.05). These findings indicate that standard medical care alone had minimal impact on reducing healthcare utilization or medication dependency.

Table 11. Comparison of hospitalization frequency & medication dependency in the control group (Pre- and Post-Standard Medical Care)

Outcome	Pre- Care (Mean ± SD)	Post- Care (Mean ± SD)	t value	p value	Effect Size (Cohen's d)	95% CI
Hospitalizations (per year)	3.2 ± 1.1	3.0 ± 1.0	1.20	0.230	0.19	(-0.3, 0.7)
Medication Dependency Score	6.8 ± 1.5	6.6 ± 1.3	1.32	0.189	0.14	(-0.5, 0.8)

Note. *t: Independent samples student t- test; CI: Confidence interval; *= statistically significant*

Table 12 below shows the comparison of hospitalization frequency & medication dependency in the intervention group (pre- and post-intervention).

Table 12. Comparison of hospitalization frequency & medication dependency in the intervention group (pre- and post-intervention)

Outcome	Pre-Intervention (Mean ± SD)	Post-Intervention (Mean ± SD)	t value	p value	Effect Size (Cohen's d)	95% CI
Hospitalizations (per year)	3.2 ± 1.1	2.3 ± 0.9	3.85	0.002*	0.90	(0.5, 1.5)
Medication Dependency Score	6.8 ± 1.5	5.7 ± 1.3	3.72	0.003*	0.78	(0.7, 2.1)

Note. *t: Independent samples student t- test; CI: Confidence interval; *= statistically significant*

As we can see from the results of Table 12, the intervention group exhibited a significant reduction in both hospitalization frequency and medication dependency following the intervention. Hospitalizations decreased from 3.2 to 2.3 per year ($p = 0.002$), while medication dependency scores reduced from 6.8 to 5.7 ($p = 0.003$). These reductions, coupled with moderate effect sizes (Cohen's d = 0.78-0.90), suggest that pulmonary rehabilitation had a tangible impact on reducing healthcare burden and medication reliance.

Below, Table 13 shows that post-intervention, the intervention group exhibited significantly greater reductions in both hospitalizations and medication dependency compared to the control group (p-values between 0.004 and 0.005). The moderate effect sizes (Cohen's d = 0.69-0.74) further confirm the clinical relevance of these reductions.

Table 13. Comparison of hospitalization frequency & medication dependency in both groups (post-intervention)

Outcome	Control Group (Mean ± SD)	Intervention Group (Mean ± SD)	t value	p value	Effect Size (Cohen's d)	95% CI
Hospitalizations (per year)	3.0 ± 1.0	2.3 ± 0.9	3.15	0.004*	0.74	(0.3, 1.2)
Medication Dependency Score	6.6 ± 1.3	5.7 ± 1.3	3.05	0.005*	0.69	(0.6, 1.8)

Note. *t: Independent samples student t- test; CI: Confidence interval; *= statistically significant*

4. DISCUSSION

The findings of the current study suggest that pulmonary rehabilitation can significantly benefit pediatric patients by improving lung function, exercise capacity, quality of life, and reducing healthcare utilization. Our study highlighted the positive outcomes of pulmonary rehabilitation in pediatric populations. This is in accordance with study of Holland et al. (2021) which showed that Pulmonary rehabilitation is an important therapy for patients with chronic and advanced lung diseases, providing benefits of improved physical conditioning and optimized psychological health. And also, in agreement with the study of Mendes et al. (2015), aimed to assess the physical capacity, peripheral muscle function, physical activity in daily life, and the inflammatory markers in children and adolescents with asthma after pulmonary rehabilitation program.

The study of Torres et al. (2020) showed that pulmonary rehabilitation is a comprehensive intervention based on a thorough evaluation of the patient followed by personalized therapies, which include muscle training, education, psychosocial intervention, and changes in life habits, in order to improve the physical and psychological condition of people with chronic respiratory disease, as well as promoting adherence to healthy behaviors that improve their quality of life in the long term. This agrees with the results of our study

Our study showed that the improvement in physical health has a positive impact on psychological health, this is in accordance with results of studies of Abdelsamea et al. (2022); Abdelsamea et al. (2023) and the two studies of Soliman et al. (2024a & b). Also, in accordance with our study, the study of Karande et al. (2024) who reported that a 8-week supervised pulmonary rehabilitation program not only reduces the symptoms but also improves the exercise capacity and add significant positive effect on the quality of life as well as lung functions in patients with chronic respiratory disease.

Our results are also in agreement with the study of Nici et al. (2010) which concluded that the positive outcomes from pulmonary rehabilitation include increased exercise tolerance, reduced dyspnea and anxiety, increased self-efficacy, and improvement in health-related quality of life. Hospital admissions after exacerbations of chronic obstructive pulmonary disease are also reduced with this intervention.

The current study provides compelling evidence that pulmonary rehabilitation (PR) significantly improves respiratory function, exercise capacity, and quality of life (QoL) in pediatric patients with chronic lung diseases (CLDs). However, it is important to acknowledge that not all studies align with our findings, for example the study of Radtke et al. (2022) reported that PR had little to no effect on lung function or health-related QoL in cystic fibrosis patients, with no significant changes in FEV1 or FVC. This discrepancy could be attributed to differences in study populations, as our study included a broader range of CLDs, whereas Radtke et al. focused specifically on cystic fibrosis patients, who may respond differently to PR.

5. LIMITATIONS

The study has several limitations that should be considered when interpreting the findings. Firstly, the limited generalizability of the study is a concern, as it was conducted in Damietta Governorate, Egypt, and the results may not be applicable to other regions with different healthcare infrastructures, socioeconomic conditions, or genetic predispositions. Additionally, the short duration of the study, which spanned only 12 weeks, may not fully capture the long-term effects of pulmonary rehabilitation on disease progression, recurrence of symptoms, or sustained quality of life improvements.

The single-center design of the study, conducted in a limited number of hospitals, may introduce institutional biases in patient recruitment, treatment approaches, and follow-up care. Potential selection bias is another limitation, as the study relied on convenience sampling despite using randomization, which may affect the representativeness of the sample.

Furthermore, the study lacked longitudinal follow-up, meaning it did not assess long-term adherence to pulmonary rehabilitation or its impact on long-term disease outcomes, hospitalization rates, and medication dependency. The quality-of-life assessments were based on self-reported questionnaires, which may be subject to recall bias or response bias.

The exclusion of patients with severe comorbidities or recent respiratory infections limits the applicability of the findings to more critically ill pediatric patients. Additionally, the study did not control for potential confounding factors such as dietary habits, environmental pollution, or parental smoking, which could influence respiratory function outcomes.

There is also the potential for a placebo effect, as the improvement observed in the intervention group could be partly influenced by participants' awareness of receiving an active rehabilitation program. Lastly, while quality of life improvements were reported, the study did not specifically assess psychological distress, anxiety, or depression, which are known to affect children with chronic lung diseases.

6. CONCLUSIONS

This study provides strong evidence supporting the implementation of exercise-based pulmonary rehabilitation (PR) as a vital component of pediatric respiratory care. The findings reveal that exercise-based PR significantly improves pulmonary function, exercise tolerance, and overall quality of life in children with chronic lung diseases. Additionally, PR effectively reduces hospitalization rates and medication dependency, offering a sustainable approach to disease management. Given the positive outcomes observed, healthcare providers should advocate for exercise-based PR as a standard intervention for pediatric patients with CLDs. Future research should focus on long-term follow-ups and expanding PR access in different healthcare settings to further validate its benefits.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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