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ORIGINAL RESEARCH

Optimizing pulmonary rehabilitation: The role of structured exercise interventions in enhancing functional and physiological outcomes in chronic obstructive pulmonary disease

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ABSTRACT

Background: Chronic obstructive pulmonary disease (COPD) is a progressive respiratory condition characterized by airflow limitation and exercise intolerance. Pulmonary rehabilitation, including structured exercise programs, is a key intervention to improve functional capacity and quality of life. However, the efficacy of exercise interventions in COPD patients requires further investigation.**Objectives:** To evaluate the impact of structured exercise interventions on exercise tolerance, dyspnea severity, and overall quality of life in COPD patients.**Methods:** A randomized controlled trial (RCT) was conducted with 100 COPD patients (GOLD stages II-IV). Participants were assigned to either a structured exercise intervention group (aerobic and resistance training) or a control group (standard care) for 12 weeks. Outcome measures included pulmonary function (FEV1, FVC), six-minute walk distance (6MWD), quadriceps strength, dyspnea severity (mMRC scale), and St. George's Respiratory Questionnaire (SGRQ) scores. Adherence rates and adverse events were also monitored.**Results:** This study showed significant improvements in exercise capacity, with a 15.6% increase in six-minute walk distance ($p < 0.001$). Quadriceps strength increased by 21.1% ($p < 0.001$), demonstrating the benefits of resistance training. Dyspnea severity decreased by 30% ($p < 0.001$), indicating improved breathing efficiency. Pulmonary function (FEV1) remained unchanged ($p = 0.12$), consistent with prior studies. Quality of life improved significantly, with a 22.6% reduction in St. George's Respiratory Questionnaire scores ($p < 0.001$). Adherence was high at 82%, with mild adverse events (15%) and minimal severe exacerbations (2%), confirming the safety and feasibility of structured exercise programs for COPD patients.**Conclusion:** Structured exercise interventions significantly enhance exercise capacity, dyspnea severity, and quality of life in COPD patients. While pulmonary function remains stable, functional improvements reinforce the necessity of pulmonary rehabilitation in COPD management. Future research should explore strategies to enhance adherence and optimize long-term rehabilitation programs.

Key words:COPD, exercise training, pulmonary rehabilitation, dyspnea, functional capacity, quality of life

1. INTRODUCTION

1.1 BACKGROUND AND EPIDEMIOLOGY

Chronic obstructive pulmonary disease (COPD) is a leading cause of morbidity and mortality worldwide, with an increasing prevalence due to environmental pollutants, cigarette smoking, and aging populations (Jeyachandran & Hurst, 2022; Mei *et al*., 2022). COPD is characterized by persistent respiratory symptoms and airflow limitation caused by airway and alveolar abnormalities, primarily due to exposure to noxious particles or gases (Nielsen *et al*., 2025; Zhang *et al*., 2022). The disease imposes a significant burden on healthcare systems due to frequent hospitalization, disease progression, and the need for long-term management strategies(X. Wang *et al*., 2025).

Globally, COPD affects more than 300 million individuals and is projected to become the third leading cause of death by 2030 (WHO 2020). The economic burden associated with COPD is substantial, with direct healthcare costs and productivity losses contributing to financial strain on

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patients and healthcare systems (Quan *et al*., 2021). The primary risk factors include tobacco smoke exposure, occupational dust and chemical exposure, biomass fuel use, genetic predisposition, and respiratory infections during childhood (S. Chen *et al*., 2023; Ortiz-Quintero *et al*., 2023).

1.2 PATHOPHYSIOLOGY AND CLINICAL MANIFESTATIONS

COPD is a progressive disease with an irreversible decline in lung function, primarily due to chronic inflammation, oxidative stress, and structural changes in the airways (Albano *et al*., 2022; Scaramuzzo *et al*., 2022). Pathophysiological changes include narrowing of the small airways, destruction of lung parenchyma, mucus hypersecretion, and increased airway resistance, leading to chronic respiratory symptoms such as dyspnea, cough, and sputum production (Celli *et al*., 2021; Russell *et al*., 2022).

Exacerbations of COPD, defined as acute worsening of respiratory symptoms, contribute to disease progression and increased mortality risk (MacLeod *et al*., 2021). The decline in pulmonary function results in systemic effects such as skeletal muscle dysfunction, cardiovascular disease, metabolic alterations, and osteoporosis, further impairing functional status and quality of life (Vaes *et al*., 2024).

1.3 IMPACT OF EXERCISE ON COPD PATHOPHYSIOLOGY

Patients with COPD often experience reduced physical activity due to dyspnea and exercise intolerance, leading to deconditioning and muscle waste. Deconditioning results in increased ventilatory demand during exertion, contributing to a downward spiral of reduced activity and worsening health outcomes (Vaes *et al*., 2024). Exercise training is a cornerstone of pulmonary rehabilitation programs and has been shown to improve exercise tolerance, reduce dyspnea, and enhance overall well-being (Tonga & Oliver, 2023).

Exercise-induced adaptations in COPD patients include improved skeletal muscle function, increased oxidative enzyme activity, enhanced oxygen utilization, and reduced ventilatory inefficiency (Nymand *et al*., 2022). Resistance training specifically targets muscle atrophy and improves muscle strength, while aerobic exercise enhances cardiovascular fitness and reduces the sensation of breathlessness (Y. Wang *et al*., 2023).

1.4 PULMONARY REHABILITATION: AN ESSENTIAL STRATEGY

Pulmonary rehabilitation, which incorporates exercise training, education, and behavioral modifications, is a well-established intervention for COPD management (Coll *et al*., 2021; Lee *et al*., 2020). Pulmonary rehabilitation programs typically include (Sharma *et al*., 2023):

- Aerobic exercise training (e.g., treadmill walking, cycling).
- Resistance training (e.g., weight training, elastic band exercises).
- Breathing exercises and inspiratory muscle training.
- Nutritional counseling and psychological support.
- Education on disease management and self-care.

Evidence suggests that pulmonary rehabilitation reduces hospitalization, improves dyspnea scores, enhances exercise tolerance, and positively impacts mental health (Almdabgy *et al*., 2023; Xiong *et al*., 2023). However, adherence to rehabilitation programs remains a challenge due to factors such as disease severity, transportation barriers, and psychological comorbidities (Martins *et al*., 2024; Schultz *et al*., 2022).

1.5 EXERCISE MODALITIES AND THEIR BENEFITS IN COPD

Several exercise modalities are beneficial in COPD rehabilitation, including:

1. **AEROBIC TRAINING:** Improves cardiovascular fitness, reduces dyspnea, and enhances exercise capacity. Common exercises include treadmill walking, cycling, and swimming (H. Chen *et al*., 2021; Shen *et al*., 2023; Xiong *et al*., 2023).
2. **RESISTANCE TRAINING:** Enhances muscle strength and counteracts muscle wasting, particularly in lower extremities (Henrot *et al*., 2023).
3. **HIGH-INTENSITY INTERVAL TRAINING (HIIT):** Alternating periods of high- and low-intensity exercise helps COPD patients exercise with lower dyspnea perception while gaining fitness benefits (Zeng *et al*., 2018).
4. **INSPIRATORY MUSCLE TRAINING (IMT):** Strengthens respiratory muscles, reducing breathlessness and improving endurance (Hill *et al*., 2022).
5. **YOGA AND TAI CHI:**Improve flexibility, breathing efficiency, and mental well-being in COPD patients (Reychler *et al*., 2019; Sujie *et al*., 2024).

1.6 GAPS IN RESEARCH AND FUTURE DIRECTIONS

Despite the established benefits of exercise in COPD, several gaps remain in research and clinical practice. Long-term adherence to pulmonary rehabilitation remains a challenge, requiring innovative strategies such as home-based exercise programs and telerehabilitation (Canepa *et al*., 2019; Tabyshova *et al*., 2021). Additionally, the role of personalized exercise interventions tailored to disease severity, comorbidities, and genetic factors warrants further investigation.

Future research should explore:

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- The impact of early exercise interventions on disease progression
- The role of biomarkers in predicting exercise response
- Telehealth and mobile applications for remote pulmonary rehabilitation
- Exercise interventions in different COPD phenotypes (e.g., emphysema-dominant vs. chronic bronchitis-dominant patients) (Cazzola *et al*., 2024).

2. METHODS

A total of 100 COPD patients (GOLD stages II-IV) were recruited from a tertiary care center, HITECH Medical College, Bhubaneswar, Odisha, India. The study utilized a randomized controlled trial (RCT) design to ensure methodological rigor. Participants were assigned to either the intervention group, which received a 12-week supervised exercise program, or the control group, which continued with standard care (Burkow *et al*., 2018). The exercise regimen included structured aerobic training (treadmill walking, cycling) and resistance training (targeting major muscle groups). Sessions were conducted three times per week, with each session lasting 45-60 minutes (Cui *et al*., 2024; Tounsi *et al*., 2021).

Baseline and post-intervention assessments included pulmonary function tests (FEV1, FVC), six-minute walk distance (6MWD), quadriceps strength measurement, and quality-of-life evaluation using the St. George's Respiratory Questionnaire (SGRQ) (Oliveira *et al*., 2021). Additionally, inflammatory biomarkers such as C-reactive protein (CRP) and interleukin-6 (IL-6) were measured to assess systemic inflammation. Compliance with the exercise program was monitored, and adverse events were documented. Data were analyzed using statistical methods to compare pre-and post-intervention changes within and between groups (Shahriary *et al*., 2017).

3. RESULTS

3.1 BASELINE CHARACTERISTICS

Table 1 presents the baseline characteristics of the study participants. There were no significant differences between the intervention and control groups in terms of age, gender distribution, BMI, smoking history, or baseline pulmonary function tests (FEV1, FVC) (Alsubheen *et al*., 2022). Both groups demonstrated similar six-minute walk distances before the intervention, ensuring comparability (Marques *et al*., 2021; Wu *et al*., 2018) (Table 1).

Table 1: Baseline Characteristics of Study Participants

Variable	Intervention Group (n=50)	Control Group (n=50)	p-value
Age (years)	65.3 ± 7.8	66.1 ± 8.2	0.56
Male (%)	60%	58%	0.78
BMI (kg/m²)	25.2 ± 3.4	24.8 ± 3.7	0.65
Smoking History (%)	80%	78%	0.72
FEV1 (% predicted)	52.1 ± 12.5	51.8 ± 13.0	0.89
Six-Minute Walk Distance (m)	320 ± 45	315 ± 48	0.78

Table 2: Exercise Intervention Program

Exercise Type	Frequency	Duration per session	Intensity
Aerobic Training	3x/week	30-45 min	Moderate (60-80% HRmax)
Resistance Training	3x/week	2-3 sets of 8-12 reps	Moderate-to-high intensity
Inspiratory Muscle Training	Daily	15-20 min	30-50% of Maximal Inspiratory Pressure
Flexibility Exercises	3x/week	10-15 min	Mild-to-moderate intensity

3.2 IMPROVEMENTS IN FUNCTIONAL CAPACITY AND PULMONARY OUTCOMES

After the 12-week exercise intervention, the intervention group showed significant improvements in exercise capacity, as evidenced by an increase in six-minute walk distance (6MWD) from 320 ± 45 meters to 370 ± 50 meters ($p < 0.001$). Similarly, quadriceps strength improved by 21.1% ($p < 0.001$), indicating enhanced muscular endurance and strength (Gephine *et al*., 2022; Nymand *et al*., 2022).

Pulmonary function, as measured by FEV1, showed a slight but non-significant improvement ($p = 0.12$). However, there was a substantial decrease in dyspnea severity, as measured by the modified Medical Research Council (mMRC) scale, with a 30% reduction ($p < 0.001$) (Braz *et al*., 2015; Lee *et al*., 2020).

Table 3

Table 3: Outcome Measures Pre-and Post-Intervention

Outcome Measure	Pre-Intervention	Post-Intervention	% Improvement	p-value
Six-Minute Walk Distance (m)	320 ± 45	370 ± 50	15.6%	<0.001
Quadriceps Strength (kg)	18.5 ± 3.2	22.4 ± 3.5	21.1%	<0.001

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Dyspnea Score (mMRC scale)	3.0 ± 0.6	2.1 ± 0.5	-30%	<0.001
FEV1 (% predicted)	52.1 ± 12.5	53.3 ± 11.9	2.3%	0.12
St. George's Respiratory Questionnaire (SGRQ) Score	62 ± 14	48 ± 13	-22.6%	<0.001

3.3 ADHERENCE AND SAFETY PROFILE

Adherence to the exercise program was recorded at 82% in the intervention group, demonstrating the high feasibility of supervised exercise programs in COPD management. The dropout rate was 12%, primarily due to logistical reasons rather than exacerbation-related issues (Houchen-Wolloff *et al.*, 2021).

In terms of safety, mild adverse events such as transient muscle soreness and fatigue were reported in 15% of participants, while severe adverse events requiring hospitalization occurred in only 2% of cases, which was lower than the 4% reported in the control group (Deng *et al.*, 2021).

Table 4: Adherence and Adverse Events (Insert Table 4 here)

Table 4: Adherence and Adverse Events

Parameter	Intervention Group (%)	Control Group (%)
Adherence to Exercise Program (>80%)	82%	Not Applicable
Dropout Rate	12%	10%
Mild Adverse Events (Muscle Soreness, Fatigue)	15%	5%
Severe Adverse Events (Exacerbation requiring hospitalization)	2%	4%

3.4 SUBJECTIVE QUALITY-OF-LIFE IMPROVEMENTS

Participants in the intervention group reported improved quality of life, as reflected in a 22.6% reduction in St. George's Respiratory Questionnaire (SGRQ) scores ($p < 0.001$). Participants expressed greater confidence in performing daily activities and reported less reliance on supplemental oxygen (Doğantekin *et al.*, 2023).

4. DISCUSSION

The findings of this study strongly support the role of structured exercise programs in improving functional capacity, reducing dyspnea, and enhancing overall quality of life in COPD patients. The observed improvements in six-minute walk distance (6MWD), quadriceps strength, and dyspnea severity align with previous research, demonstrating the efficacy of pulmonary rehabilitation programs in COPD management (Cui *et al.*, 2024; Tounsi *et al.*, 2021).

4.1 COMPARISON WITH PREVIOUS STUDIES

The results of this study are consistent with those of studies, who demonstrated that pulmonary rehabilitation incorporating aerobic and resistance training significantly enhances exercise capacity and reduces symptoms of dyspnea. Similarly, some studies found that structured exercise programs led to significant improvements in 6MWD and decreased hospitalizations. These findings corroborate the results of our study, where a 15.6% increase in 6MWD and a 30% reduction in dyspnea severity were observed post-intervention (Franssen *et al.*, 2019; Vaes *et al.*, 2024).

Maltais *et al.* (2014) emphasized the role of resistance training in mitigating muscle atrophy and improving functional endurance in COPD patients (Maltais *et al.*, 2014) (Maltais 2014). Our study supports these findings, with the intervention group experiencing a 21.1% increase in quadriceps strength, highlighting the importance of incorporating resistance training into pulmonary rehabilitation programs (Astania & Noermalita, 2024; Tonga & Oliver, 2023).

4.2 EFFECTS ON PULMONARY FUNCTION AND DYSPNEA

Despite significant improvements in exercise tolerance and muscle function, the observed changes in pulmonary function, as measured by FEV1, were minimal and non-significant ($p = 0.12$). This aligns with prior studies, which suggest that while exercise training enhances functional outcomes, it does not necessarily alter lung function metrics (Berry, 2007; Zhu *et al.*, 2024). However, reductions in dyspnea severity, as demonstrated in this study, indicate that improvements in ventilatory efficiency and muscle conditioning may contribute to perceived symptom relief despite stable spirometric values (Florian *et al.*, 2024).

4.3 ADHERENCE, SAFETY, AND FEASIBILITY

High adherence rates (82%) in our study indicate the feasibility of structured exercise interventions in COPD patients (Paneroni *et al.*, 2015). Some studies reported that supervised exercise programs exhibit higher adherence compared to unsupervised or home-based programs (Hoaas *et al.*, 2016). Moreover, the incidence of severe adverse events (2% in the intervention group) was lower than that in the control group (4%), reinforcing the safety of supervised exercise interventions (Timmerman *et al.*, 2017).

While mild adverse events, such as transient muscle soreness and fatigue, were reported in 15% of participants, these were manageable and did not lead to discontinuation of the program. These findings are in agreement with previous studies, which highlight that the benefits of structured exercise outweigh the minimal risks associated with mild discomfort (Burkow *et al.*, 2018).

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4.4 QUALITY-OF-LIFE IMPROVEMENTS

Quality-of-life improvements were substantial in the intervention group, as evidenced by a 22.6% reduction in St. George's Respiratory Questionnaire (SGRQ) scores. These findings align with, who demonstrated that pulmonary rehabilitation programs contribute to enhanced psychological well-being, reduced anxiety, and greater self-efficacy in COPD patients. The ability to perform daily activities with greater ease, coupled with reduced breathlessness, may explain these improvements in patient-reported outcomes (Parekh *et al.*, 2017; Wallace *et al*., 2015).

4.5 FUTURE DIRECTIONS AND RECOMMENDATIONS

While this study confirms the benefits of structured exercise interventions, several areas warrant further exploration:

- **LONG-TERM BENEFITS:** Future research should assess the long-term sustainability of pulmonary rehabilitation benefits, particularly in reducing exacerbation and hospitalizations (Masror-Roudsary *et al.*, 2021).
- **REMOTE AND HOME-BASED REHABILITATION:** The integration of telerehabilitation and home-based exercise programs should be explored to enhance accessibility for patients with mobility constraints (Bernocchi *et al*., 2018).
- **PERSONALIZED EXERCISE INTERVENTIONS:** Further studies should investigate tailored exercise regimens based on COPD severity, comorbidities, and phenotypes (Franssen *et al*., 2019).
- **STRATEGIES TO IMPROVE ADHERENCE:** Identifying factors influencing adherence and implementing behavioral interventions could enhance long-term participation in pulmonary rehabilitation programs (Peters *et al*., 2017).

4.6 CONCLUSION

This study highlights the substantial benefits of structured exercise programs in COPD management, demonstrating significant improvements in exercise capacity, dyspnea severity, and quality of life. While pulmonary function remains relatively unchanged, the observed functional and symptomatic enhancements reinforce the necessity of integrating exercise interventions as a fundamental component of COPD treatment. Future research should focus on optimizing pulmonary rehabilitation delivery, improving adherence, and expanding accessibility through digital health solutions (Cannon *et al*., 2016; Ghanem *et al*., 2010).

5. SUMMARY OF KEY FINDINGS

The findings of this study indicate that structured exercise interventions significantly improve exercise capacity, as demonstrated by increased six-minute walk distance and quadriceps strength. Dyspnea severity showed a notable reduction, leading to an enhanced ability to perform daily activities. While pulmonary function (FEV1) exhibited slight but non-significant improvements, the intervention yielded substantial benefits in functional and symptomatic aspects (O'Donnell *et al*., 2020). High adherence rates and minimal adverse events further underscore the feasibility of exercise programs in COPD management. Moreover, significant enhancements in quality of life, as reflected in improved SGRQ scores, reinforce the importance of integrating structured exercise training into COPD rehabilitation protocols (Wadell *et al*., 2013).

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