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Effectiveness of circuit training in pulmonary rehabilitation for patients with COPD, post-COVID syndrome and asthma

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ABSTRACT

Introduction: Pulmonary rehabilitation plays a central role in the management of chronic respiratory diseases, including chronic obstructive pulmonary disease (COPD), post-COVID syndrome, and asthma. Circuit training is a well-established method in COPD, but has been less studied in post-COVID and asthma. This study evaluated the effectiveness of a structured circuit training program on pulmonary function, exercise capacity, and dyspnea across these three groups. *Methodology:* A prospective, quasi-experimental study was conducted with 30 patients (15 COPD, 11 post-COVID, 4 asthma). Participants completed a 12-week supervised circuit training program, which was delivered four times per week in 60-min sessions. Assessments at baseline and post-intervention included spirometry (FEV_1, FVC, TLC, IVC), six-minute walk distance (6MWD), and the modified Medical Research Council (mMRC) dyspnea score. *Results:* In COPD patients, FEV_1 increased by 7.7% of the predicted value ($P < 0.001$), FVC by 5.7% ($P < 0.01$), and 6MWD by 59 m ($P < 0.01$), with mMRC decreasing from 3.2 ± 0.8 to 1.4 ± 0.6 ($P < 0.01$). In post-COVID participants, FEV_1 increased by 9.1% ($P < 0.001$), FVC by 6.6% ($P < 0.001$), and 6MWD by 82 m ($P < 0.01$), while mMRC improved from 3.5 ± 0.9 to 1.4 ± 0.6 ($P < 0.01$). Asthma patients demonstrated a 4.9% increase in FEV_1 ($P = 0.012$), a 3.5% increase in FVC ($P = 0.045$), and a 41-m increase in 6MWD ($P < 0.01$), with mMRC improving from 2.7 ± 0.7 to 1.5 ± 0.5 ($P < 0.01$). IVC improved in all groups ($P \leq 0.051$). There were no adverse events; adherence exceeded 85%. *Conclusion:* Circuit

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training produced clinically meaningful spirometric improvements in COPD, as well as functional and symptomatic benefits across all groups. The findings support circuit training as a safe, feasible, and scalable modality in pulmonary rehabilitation for heterogeneous respiratory populations.

KEYWORDS

pulmonary rehabilitation, circuit training, COPD, post-COVID, asthma, 6MWD, dyspnea

INTRODUCTION

Chronic respiratory diseases, including Chronic Obstructive Pulmonary Disease (COPD), post-COVID syndrome, and asthma, represent a growing global health challenge. These conditions are associated with persistent respiratory symptoms, reduced exercise capacity, physical deconditioning, and impaired quality of life [1]. According to the World Health Organization, COPD is now the third leading cause of death worldwide, and asthma affects more than 262 million individuals [2]. As the population of patients requiring long-term respiratory care continues to increase, the development of effective and adaptable rehabilitation strategies has emerged as a critical priority [3].

Pulmonary rehabilitation (PR) is recognized as a cornerstone in the management of chronic respiratory diseases. It is a comprehensive, multidisciplinary intervention that combines exercise training, patient education, and behavioral support to improve physical functioning, alleviate symptoms, and enhance overall quality of life [3]. Of its components, exercise training is the most evidence-based and impactful, with well-documented benefits in increasing exercise tolerance, reducing dyspnea, and promoting long-term self-management of the disease [3, 4]. However, conventional exercise approaches—typically involving continuous aerobic or resistance training—may not adequately address the complex and heterogeneous needs of patients with comorbidities, post-viral fatigue, or fluctuating symptoms [5, 6].

Circuit training has emerged as a promising and potentially superior alternative for delivering exercise in PR programs [7]. It consists of multiple exercise stations, each targeting a different functional domain (e.g., cardiovascular endurance, muscular strength, balance, and respiratory control), performed in sequence with minimal rest [8]. This format facilitates the integration of diverse training goals within a single session, allows for individualized adjustment of intensity, and promotes variety key factors in maintaining patient motivation and adherence. When implemented in a supervised, group-based setting, circuit training can also enhance social support and psychological outcomes [9, 10].

In COPD patients, circuit training has demonstrated effectiveness in improving not only aerobic capacity, but also peripheral muscle strength, fatigue resistance, and dyspnea management [11]. Its intermittent structure permits periods of partial recovery, which can reduce dynamic hyperinflation and improve tolerance to higher training intensities—critical in patients with limited ventilatory reserve. Importantly, circuit-based PR may incorporate targeted lower-limb strength training to combat sarcopenia and functional decline, especially in advanced COPD [12, 13].

Patients with post-COVID-19 syndrome often experience multifactorial limitations, including exertional dyspnea, fatigue, autonomic instability, and psychological distress. Circuit training offers the flexibility needed to adjust training volume and intensity based on individual symptom trajectories [14]. Aerobic modalities such as treadmill walking or cycling can be combined with resistance and respiratory muscle training to address the multisystem sequelae of post-viral syndromes. Early evidence suggests that this approach may accelerate recovery, reduce disability, and restore functional independence in this emerging patient population [15].

Asthma patients, although often younger and more physically capable, face unique barriers, such as exercise-induced bronchoconstriction (EIB) and fear of symptom provocation. With appropriate precautions, such as pre-exercise bronchodilation and breathing control techniques, circuit training can improve cardiopulmonary fitness, reduce airway reactivity, and enhance confidence in physical activity [16, 17]. Moreover, incorporating breathing exercises (e.g., pursed-lip breathing, diaphragmatic training) within the circuit can help optimize ventilation efficiency and reduce exercise-related anxiety [18].

A further advantage of circuit training lies in its group-based, resource-efficient structure. Social interaction, peer support, and shared progress can counteract common psychosocial challenges such as depression, isolation, and low motivation factors that frequently undermine adherence in long-term rehabilitation programs [19].

The aim of this study is to assess the clinical effectiveness of a standardized circuit training program consisting of treadmill walking, cycling, and group-based respiratory exercises in patients with COPD, post-COVID syndrome, and asthma. The study evaluates changes in pulmonary function, exercise tolerance, and health-related quality of life, while also examining adherence, safety, and patient-reported experiences. By adopting a cross-diagnostic approach, this research seeks to generate evidence for a more dynamic, inclusive, and patient-centered model of pulmonary rehabilitation that is suitable for a wide spectrum of chronic respiratory conditions.

METHODOLOGY

Study design

This study employed a prospective, quasi-experimental design with pre- and post-intervention assessments to evaluate the efficacy of a structured circuit training program in pulmonary rehabilitation for individuals diagnosed with COPD, post-COVID syndrome, and asthma. The intervention was conducted over a 12-week period and included supervised sessions that incorporated aerobic and respiratory training components in a circuit format. The study received ethical approval (3/2024, Semmelweis University) from the institutional review board and adhered to the Declaration of Helsinki guidelines for human research.

Participant recruitment and eligibility criteria

Thirty participants were recruited from outpatient pulmonary clinics, primary care referrals, and post-hospital discharge programs. Written informed consent was obtained from all participants prior to enrollment. The final cohort consisted of 15 patients with COPD, 11 with post-COVID syndrome, and 4 with asthma who met the inclusion criteria and were invited to participate in the rehabilitation program through their pulmonologists (Table 1).

Table 1. Inclusion and exclusion criteria for enrolment

Inclusion criteria	Exclusion criteria
Age between 35 and 70 years	Severe orthopedic, neurological, or cardiac conditions contraindicating exercise
Clinically diagnosed with one of the following: COPD (GOLD II–IV), persistent post-COVID-19 symptoms ≥12 weeks after infection (confirmed by RT-PCR/antigen test), physician-diagnosed moderate to severe asthma	Uncontrolled hypertension or unstable angina
Medically stable condition (no acute exacerbation or hospitalization in the past 4 weeks)	Cognitive impairment preventing active participation
Ability to ambulate independently (with or without assistive devices)	Participation in another structured rehabilitation program within the past 3 months
Pulmonologist clearance to participate in supervised exercise	Rheumatologic diseases, coagulation disorders, or suspected cardiac origin of symptoms

Participants were stratified into three groups based on diagnosis (COPD, post-COVID, asthma) and underwent similar intervention protocols, with minor adjustments tailored to each condition.

Measurements

Assessments were conducted at baseline (Week 0) and after rehabilitation (Week 12).

Pulmonary function

Post-bronchodilator lung function testing was performed according to ATS/ERS standards [20], using Piston and Autobox 6200 devices. COPD patients received 400 μg of salbutamol 20 min prior to testing. Spirometry was performed to measure FEV_1, FVC, and the FEV_1/FVC ratio, and slow vital capacity (VC) in order to evaluate lung volumes and airflow obstruction [21].

Six-minute walk test (6MWT)

Functional capacity was assessed using the 6MWT in a standardized hallway. Oxygen saturation, heart rate, and Borg ratings for dyspnea and fatigue were recorded before, during, and after the test. Patients walked as far as possible at a brisk self-paced speed, and total distance (6MWD) was recorded [20].

Chest wall expansion (CWE)

CWE was measured at the xiphoid level as the difference in chest circumference between maximal inspiration and expiration. Three trials were performed, and the mean was analyzed [22].

Maximal inspiratory pressure (MIP)

MIP, reflecting inspiratory muscle strength, was assessed. After complete exhalation, patients performed three maximal inspiratory efforts; the mean was recorded [23]. Although not the ATS/ERS gold standard, this device provides an acceptable clinical estimate.

Breath-holding time

The breath-holding time, an indicator of respiratory neural control, was measured after maximal inhalation. Patients held their breath for as long as possible with both mouth and nose closed [24].

Modified Medical Research Council dyspnea questionnaire (mMRC-modified questionnaire)

The mMRC questionnaire classifies the severity of breathlessness on a scale of 0–5, ranging from no limitation to severe dyspnea at rest. Items correspond to daily activities, are simple for patients to understand, and require only seconds to complete [25].

Circuit training intervention protocol

Before training, all participants underwent medical evaluation, including physical and orthostatic examinations, assessment of vital signs, and laboratory testing (inflammatory, coagulation, and myocardial injury markers). Patients also received physical, emotional, social, nutritional, and psychological assessments. Participants with unsafe conditions (e.g., rheumatologic or coagulation disorders, suspected cardiac origin of symptoms) were excluded. The intensive preparatory phase, which was limited to 30 stable participants, involved four supervised sessions per day combining breathing, chest mobility, muscle strengthening (body weight, dumbbells), and low-intensity aerobic training (bicycle, treadmill, arm ergometer), personalized by age, comorbidities, and capacity. Oxygen saturation and pulse were continuously monitored. Participants then progressed to a structured 12-week circuit training program, four 60-min sessions per week, aimed at improving cardiopulmonary endurance and functional capacity under professional supervision.

Session structure

1. **Warm-up (10 min)**

The warm-up phase was designed to progressively prepare the cardiovascular and musculoskeletal systems, while integrating respiratory control strategies to support pulmonary function. It consisted of three sequential components: approximately 5 min of low-intensity walking on a level surface or treadmill at 30–40% of Heart Rate Reserve (HRR), to gradually increase cardiac output and promote vascular and muscular readiness [26], about 2 min of targeted breathing exercises, including diaphragmatic and pursed-lip breathing, performed both during and immediately after walking to enhance ventilatory efficiency, reduce dynamic hyperinflation, and promote parasympathetic activation [18], and approximately 3 min of gentle, dynamic stretching of the major muscle groups, with particular emphasis on thoracic mobility and postural alignment to optimize biomechanical efficiency and minimize musculoskeletal strain. This standardized warm-up was performed by all participants at the beginning of each training session.

2. **Main Circuit Training (40 min)**

The core component of the session consisted of a circuit of six exercise stations, performed sequentially with minimal rest periods (<1 min) between stations to maintain cardiovascular engagement. Each station was performed for 5–7 min, with individualized adjustments based on patient tolerance and clinical status. Exercise intensity was progressively increased throughout the intervention, guided by patient-reported exertion (Borg Rating of Perceived Exertion [RPE] Scale), heart rate responses, and oxygen saturation levels [27]. The detailed description of each circuit training station, including prescribed intensity, is presented in Table 2.

3. **Cool-down (10 min)**

The cool-down phase was implemented to support a gradual return to baseline physiological states following the structured exercise circuit, facilitating cardiovascular recovery and promoting respiratory relaxation. This phase began with slow-paced walking performed at approximately 30–40% of Heart Rate Reserve (HRR), allowing for a progressive reduction in heart rate and systemic blood flow while preventing venous pooling [28]. It was then followed by guided breathing and relaxation techniques, emphasizing controlled expiration and mindful body awareness to alleviate dyspnea, restore ventilatory efficiency, and enhance parasympathetic reactivation [29]. The session concluded with a brief discussion or feedback segment, during which participants were encouraged to report any symptoms experienced during the session, reflect on their performance, and receive individualized guidance. This component also reinforced principles of self-monitoring and symptom management, thereby promoting long-term adherence to rehabilitation strategies and enhancing patient empowerment [30].

Intensity progression and individualization

During the 12-week program, training intensity was progressively increased based on the clinical status, functional capacity, and individual response of each participant to exercise. Adjustments

Table 2. Description of circuit training stations with prescribed exercise intensity in pulmonary rehabilitation program

Station	Activity	Prescribed intensity
1	Treadmill walking (with incline if tolerated)	50–70% HRR*
2	Bicycle ergometer cycling	50–70% HRR
3	Upper limb ergometry	Moderate RPE 11–13
4	Resistance training (leg press, step-ups, dumbbell rows)	2 sets of 12 repetitions per exercise
5	Group respiratory exercises (e.g., balloon blowing, inspiratory muscle training with threshold devices)	5–7 min, self-paced to achieve moderate exertion
6	Flexibility and posture-focused exercises (chest expansion techniques, thoracic mobility drills)	Self-paced

*HRR (Heart Rate Reserve) was calculated using the Karvonen formula: HRR = [(HR_max − HR_rest) × training intensity%] + HR_rest.

were systematically implemented every two weeks to ensure a safe yet effective training stimulus [31]. For aerobic stations (treadmill and cycle ergometer), intensity was initially set at 50% of Heart Rate Reserve (HRR) or Borg RPE 11 ("light"), and progressed by ~5–10% HRR every two weeks depending on tolerance, targeting an RPE of 12–13 ("somewhat hard") by Week 12. For resistance training, participants began with 2 sets of 10–12 repetitions at 50–60% of their estimated one-repetition maximum (1-RM); a third set was introduced by Week 6, and load was increased by ~5% every two weeks if the previous load was completed comfortably [32].

Station duration was also extended gradually, from 5 min in Weeks 1–2 to 6–7 min by Weeks 9–12, with rest intervals shortened from 60 s to 30–45 s depending on tolerance.

Individualization was guided by real-time monitoring, including Borg RPE, pulse oximetry (SpO_2), heart rate responses, and clinical observations of ventilatory limitation or excessive fatigue. For participants with asthma, the protocol included a ≥15-min warm-up, use of bronchodilators before sessions as indicated, and close monitoring for exercise-induced bronchospasm [17]. For post-COVID-19 patients, progression was applied more cautiously with pacing strategies and symptom monitoring to prevent post-exertional malaise and autonomic dysfunction [33]. This structured yet individualized progression allowed for consistent advancement while minimizing the risk of overexertion or adverse events.

Safety and monitoring

Ensuring participant safety was a central objective, with systematic monitoring and risk-mitigation strategies implemented during all training sessions [34]. Continuous pulse oximetry (SpO_2) was used to detect desaturation and guide activity modification or supplemental oxygen administration. Vital signs, including heart rate (HR), blood pressure (BP), and respiratory rate (RR) were measured before and after sessions to establish baseline values and identify post-exercise abnormalities [35]. The facility was equipped with emergency tools, including an automated external defibrillator (AED), supplemental oxygen, and a defined emergency plan to ensure rapid response if needed [36]. Dyspnea was routinely assessed using the Modified Medical Research Council (mMRC) Dyspnea Scale to tailor exercise requirements. Participants were educated to recognize warning signs such as chest pain, severe breathlessness, dizziness, or unusual fatigue, and instructed to report them immediately to supervising staff [37]. In the event of acute illness, respiratory exacerbation, or clinical deterioration, sessions were postponed or rescheduled to allow for medical evaluation and recovery.

Outcome measures

Data collection was performed at two time points, baseline (Week 0) and post-intervention (Week 12), using standardized and validated assessment tools. All tests were administered by the same trained physiotherapist at each site, following established protocols, and equipment was calibrated prior to each measurement session to ensure consistency and minimize inter-rater variability.

Exercise capacity was assessed using the Six-Minute Walk Test (6MWT), which was performed in accordance with American Thoracic Society (ATS) guidelines to determine submaximal functional endurance. The 6MWT has high inter-rater reliability when standardized encouragement and procedures are applied [38].

Pulmonary function was evaluated using spirometry to measure forced expiratory volume in 1 s (FEV_1), forced vital capacity (FVC), and the FEV_1/FVC ratio, in line with ATS/ERS standards. Spirometric measures demonstrate high reproducibility when ATS/ERS criteria are followed [39].

Maximal inspiratory pressure (MIP), reflecting inspiratory muscle strength, was assessed using the *Piston, Body plethysmograph (Budapest, Hungary)* device in test mode. Although this device is primarily designed for respiratory muscle training and is not the gold-standard manometer recommended by ATS/ERS, it has been shown to provide a reasonable estimate of inspiratory pressure in clinical settings [23].To enhance reliability, each patient performed three maximal efforts after full exhalation, and the average value was recorded, provided that the two closest efforts differed by <10%.

Chest wall expansion (CWE) was measured at the xiphoid level using a flexible tape placed, and then the mean of three trials was recorded. This method has been shown to have good intra-rater reliability when standardized landmarks are used [23].

Breath-holding time was measured as the maximal voluntary inspiratory breath-hold, repeated three times, with the longest reproducible value recorded. Intra-rater reliability is generally acceptable when consistent instructions and encouragement are applied [23].

Dyspnea severity was quantified using the Modified Medical Research Council (mMRC) Dyspnea Scale, a validated and widely used instrument for grading perceived breathlessness during daily activities.

Collectively, these outcomes provided a comprehensive and reproducible profile of respiratory and functional status of the participant before and after the intervention.

Data management and confidentiality

All data were anonymized and stored in secure electronic databases accessible only to the research team. Participants were assigned unique identifiers. Paper-based records (e.g., consent forms) were stored in locked cabinets at the rehabilitation center.

Statistical analysis

A *P*-value of <0.05 was considered statistically significant.

- Descriptive Statistics: Mean ± SD for continuous variables; frequencies for categorical data.
- Inferential Tests:
  - Paired *t*-tests: Pre-post comparisons (normality confirmed via Shapiro-Wilk test).
  - ANOVA: Between-group differences (post hoc Tukey test for pairwise comparisons).
- Effect Sizes: Cohen's *d* (thresholds: small = 0.2, medium = 0.5, large = 0.8).
- Software: SPSS v28 ($\alpha = 0.05$).

RESULTS

Participant characteristics

Before our 30 patients (17 females, 13 males) were enrolled, comprehensive assessments were conducted to record baseline clinical and demographic data. The study population was divided into three groups: COPD (n = 15), post-COVID syndrome (n = 11), and asthma (n = 4). The average age was 56.4 ± 10.2 years, ranging from 35 to 76 years. Mean body weight was 76.3 ± 16.5 kg, and the average BMI was 27.8 ± 5.4 (kg m^{-2}), with values ranging from 16 to 40.4. Half of the participants were former smokers. Detailed baseline characteristics of the study cohort are presented in Table 3.

Rehabilitation resulted in clinically and statistically significant improvements in pulmonary function, exercise capacity, dyspnea, and chest wall mechanics in all three diagnostic groups. As shown in Table 4, spirometric outcomes improved in all groups, with the most pronounced changes observed in COPD and post-COVID participants. FEV_1 increased by 7.7% in COPD ($P < 0.001$, $d = 0.72$), 9.1% in post-COVID ($P < 0.001$, $d = 0.81$), and 4.9% in asthma ($P = 0.012$, $d = 0.45$), with parallel gains in FVC, FEV_1/FVC, IVC, and TLC. These improvements in pulmonary function were most clinically relevant in COPD, whereas in asthma and post-COVID patients—who already had near-normal baseline values—changes remained within normal functional limits.

Functional outcomes also improved markedly. As illustrated in Fig. 1, the 6-minute walk distance (6MWD) increased by 59 m in COPD, 82 m in post-COVID, and 41 m in asthma patients (*all* $P < 0.01$). Symptom burden, as measured by mMRC dyspnea scores (Fig. 2), significantly decreased in all groups, with the greatest improvement in post-COVID (−2.1 points), followed by COPD (−1.8) and asthma (−1.2) (*all* $P < 0.01$), reflecting meaningful relief in perceived breathlessness.

Additional improvements were observed in chest wall expansion patterns, particularly in COPD and post-COVID patients. According to Table 5, rib cage contribution to tidal volume increased by 5.6% ($P < 0.05$) in COPD and 8.4% ($P < 0.05$) in post-COVID, while abdominal contribution decreased significantly in both groups. These shifts suggest enhanced thoracic breathing mechanics and reduced respiratory effort. No adverse events were reported throughout the intervention, and adherence exceeded 85%, confirming the safety, acceptability, and feasibility of circuit-based pulmonary rehabilitation in a diverse patient population.

DISCUSSION

This study demonstrated that a 12-week circuit-based pulmonary rehabilitation program resulted in significant improvements in lung function, exercise tolerance, and dyspnea in COPD,

Table 3. Patient demographics and baseline characteristics

	COPD (n = 15)	Asthma (n = 4)	Post-COVID (n = 11)	Total (N = 30)
Age (years)	63.3 ± 6.5	42.5 ± 7.9	51.2 ± 8.3	56.4 ± 10.2 (35–76)
Gender (M/F)	11 M/4 F	1 M/3 F	1 M/10 F	13 M/17 F
Weight (kg)	78.2 ± 14.9	71.5 ± 12.1	74.3 ± 18.7	76.3 ± 16.5 (53–128)
BMI (kg m^{-2})	28.5 ± 4.6	25.3 ± 3.9	27.0 ± 6.1	27.8 ± 5.4 (16–40.4)
Smoking history	100% former smokers	0% smokers	27% former smokers	50% former smokers

Table 4. Pulmonary function outcomes by diagnosis group (pre- vs. post-rehabilitation)

Parameter	Group	Pre-Rehab (Mean ± SD)	Post-Rehab (Mean ± SD)	Δ (Change)	*P*-value	Effect size (Cohen's *d*)
FEV_1 (% pred.)	COPD	62.4 ± 18.2	70.1 ± 16.5	+7.7	<0.001*	0.72 (large)
	Asthma	78.3 ± 15.6	83.2 ± 14.1	+4.9	0.012*	0.45 (medium)
	Post-COVID	73.8 ± 20.1	82.9 ± 17.4	+9.1	<0.001*	0.81 (large)
FVC (% pred.)	COPD	79.5 ± 16.3	85.2 ± 14.8	+5.7	<0.01*	0.53 (medium)
	Asthma	88.6 ± 12.4	92.1 ± 10.9	+3.5	0.045*	0.38 (small-medium)
	Post-COVID	91.2 ± 17.5	97.8 ± 15.2	+6.6	<0.001*	0.67 (large)
FEV_1/FVC	COPD	65.2 ± 19.8	71.4 ± 18.3	+6.2	<0.01*	0.55 (medium)
	Asthma	89.5 ± 14.2	91.7 ± 12.6	+2.2	0.078	0.29 (small)
	Post-COVID	82.1 ± 20.3	87.3 ± 18.7	+5.2	<0.01*	0.51 (medium)
TLC (% pred.)	COPD	102.4 ± 18.7	108.9 ± 16.2	+6.5	<0.05*	0.48 (medium)
	Asthma	94.2 ± 15.3	98.5 ± 13.8	+4.3	0.062	0.34 (small-medium)
	Post-COVID	96.8 ± 20.1	104.3 ± 18.5	+7.5	<0.01*	0.59 (medium)
IVC (% pred.)	COPD	80.3 ± 17.2	86.1 ± 15.4	+5.8	<0.01*	0.54 (medium)
	Asthma	90.1 ± 13.8	93.6 ± 12.1	+3.5	0.051	0.36 (small-medium)
	Post-COVID	89.5 ± 18.3	95.7 ± 16.0	+6.2	<0.001*	0.63 (large)
FEV_1/IVC	COPD	77.8 ± 20.1	83.6 ± 18.5	+5.8	<0.01*	0.52 (medium)
	Asthma	87.2 ± 15.4	89.5 ± 13.9	+2.3	0.085	0.28 (small)
	Post-COVID	84.3 ± 19.7	89.8 ± 17.2	+5.5	<0.01*	0.57 (medium)

(*P < 0.05).

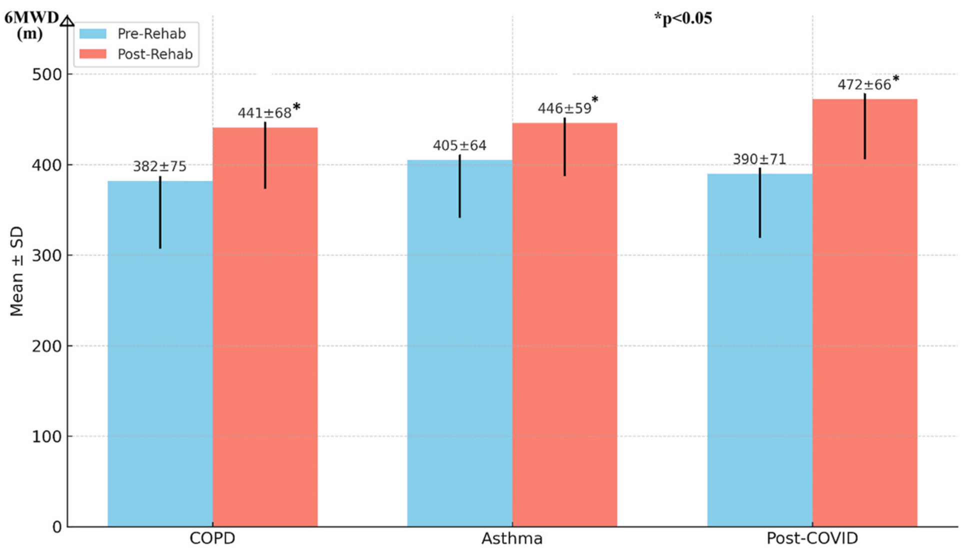

Fig. 1. Pre- and post-rehabilitation changes in 6-minute walk distance (6MWD)

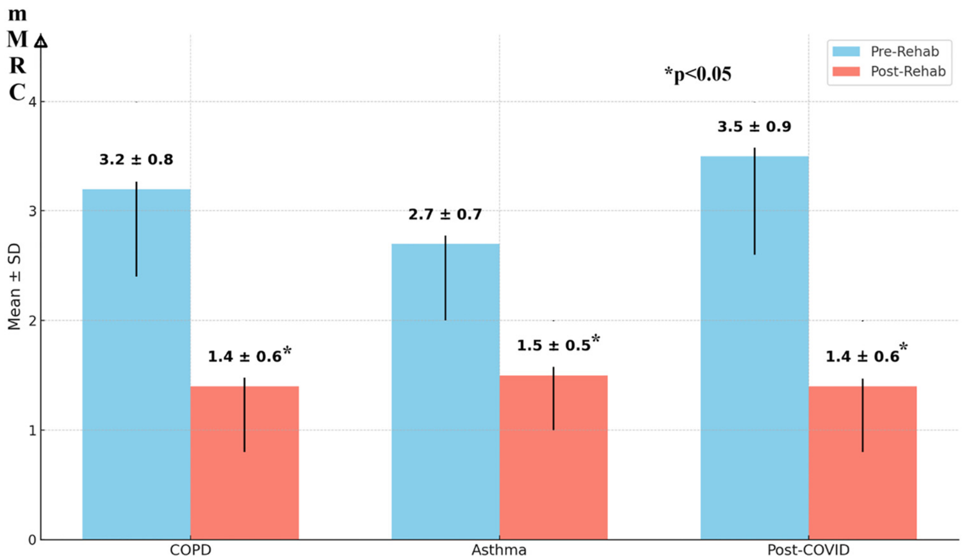

Fig. 2. Pre- and post-rehabilitation changes in mMRC score

Table 5. Chest wall expansion (CWE) before and after rehabilitation

Parameter	Group	Pre-Reha (Mean ± SD)	Post-Rehab (Mean ± SD)	Δ (Change)	*P*-value
Rib cage contribution to tidal volume (%)	COPD	45.2 ± 9.1	50.8 ± 8.6	+5.6	<0.05*
	Asthma	48.7 ± 8.4	51.9 ± 7.7	+3.2	n.s.
	Post-COVID	46.5 ± 10.3	54.9 ± 9.7	+8.4	<0.05*
Abdominal contribution to tidal volume (%)	COPD	39.6 ± 10.8	34.7 ± 9.9	−4.9	<0.05*
	Asthma	36.1 ± 9.5	33.8 ± 8.8	−2.3	n.s.
	Post-COVID	38.7 ± 11.2	31.6 ± 10.5	−7.1	<0.05*

(*$P < 0.05$)
CWE: Chest Wall Expansion measured via tidal volume distribution.

post-COVID, and asthma patients. The most clinically relevant spirometric gains were observed in COPD, where FEV_1 increased by 7.7% predicted, accompanied by improvements in FVC, IVC, and TLC. These findings indicate reduced airflow limitation and enhanced lung compliance, which are central therapeutic goals in COPD rehabilitation [40]. Consistent with earlier randomized trials, circuit training provided comparable or superior outcomes to traditional continuous modalities [41], suggesting that its intermittent structure may facilitate higher intensity exercise with better symptom tolerance. Similar improvements have been reported in meta-analyses of exercise-based pulmonary rehabilitation [42].

In the asthma and post-COVID groups, baseline spirometry values were already within or close to normal limits. Although statistically significant improvements were observed - FEV_1 increased by 4.9% in asthma and 9.1% in post-COVID patients -, the clinical significance of these changes remains uncertain. These improvements may reflect training effects, including enhanced inspiratory muscle performance, improved breathing coordination, or greater effort during testing, rather than a true reversal of pathophysiology [23, 39, 40]. This observation is consistent with GINA reports that asthma patients often exhibit normal lung function between exacerbations [43] and with studies showing that post-COVID patients may have persistent symptoms despite near-normal spirometry [44, 45]. In these populations, functional outcomes such as six-minute walk distance (6MWD), fatigue scores, and dyspnea ratings may provide more clinically meaningful indicators of recovery [23, 40].

Measurement of chest wall expansion (CWE) provided important insights into respiratory adaptations [23]. After training, increased thoracic excursion was observed in both COPD and post-COVID patients, reflecting more effective use of inspiratory muscles and a shift in tidal volume distribution toward the rib cage. These adaptations may reduce dynamic hyperinflation, which is a major contributor to exertional dyspnea in COPD [22, 46], while supporting improved ventilatory efficiency in post-COVID syndrome [15]. Asthma patients showed smaller, non-significant changes in CWE, reflecting their near-normal baseline thoracic mechanics. These results underscore CWE as a complementary assessment tool that can capture mechanical adaptations not reflected in spirometry alone [22].

Circuit training offers unique advantages in pulmonary rehabilitation. Its modular format combines aerobic, resistance, flexibility, and respiratory control exercises in a single session, enabling individualized progression and variety [8]. The intermittent rest intervals reduce ventilatory load and allow patients with limited inspiratory capacity to sustain training at higher intensities [47]. Beyond physiological effects, circuit training can enhance adherence, enjoyment, and psychosocial engagement compared with continuous endurance training [8]. These features are particularly valuable for patients with heterogeneous symptoms such as those recovering from COVID-19, who experience fatigue, cognitive impairment, and deconditioning simultaneously [44].

Post-COVID participants in this study demonstrated the greatest functional gains, including substantial increases in 6MWD and reductions in fatigue and dyspnea. These findings align with preliminary evidence that circuit-based rehabilitation supports multi-system recovery after COVID-19 [15]. The varied, task-oriented nature of circuit training may also confer neurocognitive benefits, supporting concentration, motivation, and executive function domains, which are frequently impaired in post-viral syndromes. The adaptability of circuit training thus makes it well suited to address the diverse rehabilitation needs of this population [19].

In asthma, although spirometric changes were modest, patients reported improved tolerance and absence of exercise-induced bronchoconstriction, likely due to structured warm-up, breathing techniques, and gradual progression. Evidence from randomized trials confirms that supervised exercise programs can improve peak expiratory flow, asthma control, and quality of life beyond standard aerobic training [16]. The group-based format may further reduce fear of symptom exacerbation and encourage sustained participation. By integrating respiratory education, supervised breathing strategies, and medication adherence reinforcement into the training sessions, circuit training can also promote self-management and psychological well-being [4, 40].

Systematic reviews reinforce these observations. Priego-Jiménez et al. [48] found circuit training to be at least as effective as conventional modalities in COPD for exercise capacity and quality-of-life outcomes, while patients often reported greater enjoyment and motivation. Although evidence in asthma and post-COVID populations remains limited, emerging trials and narrative reviews consistently recommend multimodal, adaptive approaches – principles that are inherently integrated into circuit training [15, 16].

Taken together, the results of this study highlight the versatility of circuit training as a pulmonary rehabilitation modality. In COPD, it provides robust improvements in ventilatory mechanics and exercise tolerance [12]. In post-COVID syndrome, it addresses functional, respiratory, and cognitive dimensions of recovery [49]. In asthma, it enhances adherence, control, and confidence despite modest spirometric changes [16]. These findings suggest that circuit-based pulmonary rehabilitation can be safely and effectively applied across heterogeneous chronic respiratory conditions, supporting its broader adoption in clinical practice.

LIMITATIONS

This study has several limitations. The overall sample size was modest (15 COPD, 11 post-COVID, 4 asthma), which limits statistical power and generalizability. Diagnostic heterogeneity, such as variation in asthma phenotypes and post-COVID severity, may also have introduced uncontrolled variability. These deviations may affect accuracy and should be considered when interpreting the results. Due to the absence of long-term follow-up, no conclusions can be drawn regarding the durability of functional and symptomatic improvements. Objective physiological markers, such as lactate thresholds or imaging-based assessments of respiratory muscles, were not included but would strengthen future studies. Psychosocial outcomes were inferred from adherence and informal feedback rather than standardized tools. Although circuit training was safe and well tolerated in this cohort, it may not be appropriate for patients with severe cardiovascular or musculoskeletal comorbidities, highlighting the importance of tailored pre-screening.

CONCLUSION

This study demonstrated that a 12-week circuit training program is a feasible and effective adjunct to pulmonary rehabilitation in patients with COPD, post-COVID syndrome, and asthma, yielding significant improvements in lung function, exercise capacity, and dyspnea, with the largest spirometric gains in COPD. These findings support circuit training as a versatile, safe, and scalable modality that can be integrated into rehabilitation protocols, although larger controlled studies with long-term follow-up are needed to confirm its durability and generalizability.

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GLOSSARY OF ABBREVIATIONS

6MWD	Six-Minute Walk Distance
ATS/ERS	American Thoracic Society/European Respiratory Society
BMI	Body Mass Index
BP	Blood Pressure
COPD	Chronic Obstructive Pulmonary Disease
CWE	Chest Wall Expansion
EIB	Exercise-Induced Bronchoconstriction
FEV_1	Forced Expiratory Volume in One Second
FVC	Forced Vital Capacity
GINA	Global Initiative for Asthma
GOLD	Global Initiative for Chronic Obstructive Lung Disease
HR	Heart Rate
HR_max	Maximum Heart Rate
HR_rest	Resting Heart Rate
HRR	Heart Rate Reserve
IVC	Inspiratory Vital Capacity
mMRC	Modified Medical Research Council
MIP	Maximal Inspiratory Pressure
PEFR	Peak Expiratory Flow Rate
PR	Pulmonary Rehabilitation

RPE	Rating of Perceived Exertion
RR	Respiratory Rate
RT-PCR	Reverse Transcription Polymerase Chain Reaction
SpO_2	Peripheral Capillary Oxygen Saturation
TLC	Total Lung Capacity
VC	Vital Capacity
VO_2 max	Maximal Oxygen Uptake

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