Journal of Health and Rehabilitation Research JHRR

https://doi.org/10.61919/jhrr.v6i1.1936

Original Article

Active Cycle of Breathing Technique Versus High-Frequency Chest Wall Oscillation in Pulmonary Function in Adult Chronic Obstructive Pulmonary Disease Patients: A Randomized Clinical Trial

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ABSTRACT

Background: Chronic obstructive pulmonary disease (COPD) is a progressive, irreversible airflow limitation disorder representing a leading global cause of morbidity and mortality, for which physiotherapy-based airway clearance constitutes a critical management component. Objective: To compare the effects of the active cycle of breathing technique (ACBT) and high-frequency chest wall oscillation (HFCWO) on pulmonary function, exercise capacity, dyspnea severity, and composite BODE index scores in adult patients with stage 3–4 COPD. Methods: A parallel-group randomized clinical trial was conducted at the Pulmonary Department of DHQ Hospital Narowal over six months. Forty-two participants meeting GOLD stage 3–4 criteria were consecutively recruited and randomly allocated to ACBT with routine chest physiotherapy (Group A; n = 21) or HFCWO via pneumatic vest system (Group B; n = 21). Both groups received three sessions per week over four weeks (12 total sessions). Outcome measures included FEV_1 % predicted, six-minute walk distance (6MWD), mMRC dyspnea score, BMI, and composite BODE index, assessed at baseline and week four. Within-group comparisons used paired-samples t-tests and between-group comparisons used independent-samples t-tests (SPSS v25; $\alpha = 0.05$). Results: HFCWO produced a significantly greater improvement in FEV_1 % predicted compared with ACBT (67.79 ± 12.73% vs 53.89 ± 9.30%; mean difference: 13.90 percentage points; Cohen's d = 1.25; $p < 0.001$) and in 6MWD (409.47 ± 108.25 m vs 346.47 ± 45.01 m; d = 0.76; $p = 0.025$). Both groups achieved significant within-group BODE index improvements (ACBT: $\Delta = +2.32$, $p = 0.048$; HFCWO: $\Delta = +2.41$, $p = 0.050$). No significant between-group difference was observed for mMRC dyspnea score ($p = 0.247$) or BMI ($p = 0.124$). Conclusion: Both ACBT and HFCWO significantly improve functional outcomes in stage 3–4 COPD; however, HFCWO demonstrates superior efficacy in spirometric and exercise capacity domains, supporting its preferential use in advanced obstructive disease where effort-dependent techniques are limited by disease severity. Keywords: Chronic obstructive pulmonary disease; active cycle of breathing technique; high-frequency chest wall oscillation; BODE index; pulmonary rehabilitation; airway clearance; forced expiratory volume; six-minute walk test.

"Cite this Article" | Received: 12 December 2025; Accepted: 11 January 2026; Published: 31 January 2026.

Author Contributions: Concept: KT, AQ; Design: KT, AQ; Data Collection: HIA, MB; Analysis: KT, HIA; Drafting: HIA, MB **Ethical Approval**: University of Lahore, Lahore, Pakistan**.** Informed Consent: Written informed consent was obtained from all participants; Conflict of Interest: The authors declare no conflict of interest; Funding: No external funding; Data Availability: Available from the corresponding author on reasonable request; Acknowledgments: N/A.

INTRODUCTION

Chronic obstructive pulmonary disease (COPD) is a preventable and treatable condition defined by persistent, progressive airflow limitation arising from abnormalities in the small airways and pulmonary parenchyma, typically caused by prolonged exposure to noxious particles or gases, most notably tobacco smoke (1). According to the Global Initiative for Chronic Obstructive Lung Disease (GOLD), COPD represents one of the leading causes of morbidity and mortality worldwide, with its global prevalence disproportionately affecting older males, although epidemiological data increasingly document a rising

burden in females and non-smokers (2). The hallmark clinical features include chronic dyspnea, persistent cough, and excessive mucus production, each of which progressively undermines the patient's capacity for activities of daily living, accelerates disease trajectory, and substantially elevates the risk of acute exacerbations, lower respiratory tract infections, and hospitalization (3). The natural history of COPD is further complicated by cycles of exacerbation and incomplete recovery, culminating in irreversible decline in forced expiratory volume in the first second (FEV_1), impaired exercise tolerance, and diminished health-related quality of life (4).

The management of COPD necessitates a comprehensive, multidisciplinary framework encompassing pharmacological therapy, pulmonary rehabilitation, nutritional support, and targeted physiotherapy interventions (5). Among these, airway clearance physiotherapy occupies a central role, particularly in patients with advanced disease stages characterized by copious and viscous secretion retention, which exacerbates airflow obstruction, promotes bacterial colonization, and perpetuates the inflammatory milieu of the airways (6). A variety of airway clearance techniques (ACTs) have been developed and evaluated over recent decades, including positive expiratory pressure devices, oscillatory positive expiratory pressure devices, autogenic drainage, postural drainage with manual percussion, and more technologically advanced systems such as high-frequency chest wall oscillation (HFCWO) (7). Despite this diversity of available techniques, there remains substantial clinical uncertainty regarding which modality yields superior improvements in pulmonary function outcomes among patients with moderate-to-severe COPD.

The active cycle of breathing technique (ACBT) is a well-established, patient-directed airway clearance strategy comprising three sequentially structured phases: breathing control, thoracic expansion exercises, and the forced expiratory technique (FET) (8). ACBT requires no specialized equipment, encourages patient autonomy, and has demonstrated efficacy in mobilizing peripheral secretions, improving alveolar ventilation, and reducing dyspnea scores across a range of chronic respiratory conditions including COPD, bronchiectasis, and cystic fibrosis (9). A systematic review by Shen and colleagues reported significant improvements in FEV_1 and sputum expectoration following ACBT-based interventions in COPD populations, underscoring its clinical relevance as a standard physiotherapy modality (10). In parallel, the forced expiratory component of ACBT has been shown to enhance peak expiratory flow rates and facilitate clearance from the distal airways without inducing bronchospasm or excessive oxygen desaturation (11).

High-frequency chest wall oscillation (HFCWO), in contrast, is a device-dependent airway clearance modality that employs a pneumatically inflated vest to deliver rapid, low-amplitude oscillations to the thoracic wall, thereby generating oscillatory airflows capable of disrupting the viscoelastic properties of bronchial mucus, reducing mucus viscosity, and promoting cephalad mucus transport (12). HFCWO systems operate across a broad frequency range and enable simultaneous percussion of multiple pulmonary segments, offering a mechanically comprehensive approach to secretion mobilization that may confer advantages over techniques reliant solely on patient effort and cooperation (13). Emerging evidence in bronchiectasis, cystic fibrosis, and neuromuscular disease populations suggests that HFCWO produces favourable effects on mucociliary clearance rates, sputum volume, and lung function parameters; however, its comparative efficacy in COPD remains incompletely characterized (14). The limited head-to-head evidence comparing HFCWO with ACBT in COPD is particularly notable given that these two modalities differ substantially in their mechanisms of action, patient burden, resource requirements, and accessibility in low-resource clinical settings (15).

Existing comparative studies have largely been conducted in heterogeneous populations, employed variable outcome measures, or failed to stratify findings according to GOLD disease severity staging, limiting the generalizability of their conclusions (16). Furthermore, while individual trials have reported improvements in spirometric indices and exercise capacity with both techniques, few have simultaneously evaluated the composite BODE index—incorporating body mass index, airflow

obstruction, dyspnea severity, and exercise tolerance—as a holistic measure of disease burden and treatment responsiveness (17). This represents a substantive knowledge gap, as the BODE index has been validated as a superior predictor of mortality and hospitalization risk in COPD compared with FEV_1 alone, and thus constitutes a clinically meaningful endpoint for physiotherapy trials (18). Given this evidentiary gap, and considering the increasing global burden of COPD alongside the need for evidence-based, cost-effective physiotherapy protocols, a rigorous comparison of ACBT and HFCWO in a well-defined COPD population is both timely and scientifically warranted. The present randomized clinical trial was therefore designed to compare the effects of active cycle of breathing technique versus high-frequency chest wall oscillation on pulmonary function outcomes, dyspnea severity, exercise capacity, and composite BODE index scores in adult patients with stage 3–4 COPD, with the hypothesis that HFCWO would demonstrate superior efficacy relative to ACBT across the primary outcome domains following four weeks of structured intervention.

MATERIALS AND METHODS

This study was designed as a parallel-group, randomized clinical trial conducted in the Pulmonary Medicine Department of District Headquarters (DHQ) Hospital, Narowal, Pakistan. The trial was initiated following formal ethical approval of the study synopsis and was completed over a period of six months. The randomized clinical trial design was selected to minimize selection bias and enable a valid comparison of the two active physiotherapy interventions under investigation, namely the active cycle of breathing technique (ACBT) and high-frequency chest wall oscillation (HFCWO), in a clinically defined population of adult COPD patients (19).

Eligible participants were adults diagnosed with COPD classified as stage 3 or stage 4 according to the GOLD spirometric criteria, who presented with a clear conscious state, stable vital signs, and sufficient cognitive capacity to cooperate with the prescribed interventions. Additional inclusion criteria required willingness to provide written informed consent prior to enrolment. Patients were excluded if they had a concurrent diagnosis of active pulmonary tuberculosis, recent chest wall trauma, a history of thoracic or abdominal surgical procedures within the three months preceding enrolment, or the presence of a cardiac pacemaker, artificial cardiac shunt, or active heart failure, all of which were considered contraindications to the mechanical demands of either intervention (20). These criteria were operationalized by the treating physiotherapist at the point of initial screening.

The required sample size was determined a priori using the online EPITOOL sample size calculator, applying the formula for detecting a significant difference between two independent means. Input parameters were derived from mean and standard deviation values reported in a comparable prior study using the SPADI score as a surrogate estimate of between-group variance. This calculation yielded a minimum required sample of 42 participants, accounting for potential attrition, and accordingly, 21 patients were targeted for each group. Consecutive sampling was employed as the recruitment strategy, wherein all eligible patients presenting to the pulmonary outpatient department during the study period were approached for enrolment until the target sample was achieved. Following eligibility confirmation and written informed consent, participants were randomly allocated to one of two intervention groups using a concealed allocation procedure (21).

Group A received the active cycle of breathing technique (ACBT) in conjunction with routine chest physiotherapy. Treatment was administered with participants positioned in a semi-Fowler position to optimize diaphragmatic excursion and postural drainage. Each ACBT session comprised the three standardized phases: breathing control, in which participants were instructed to relax the upper chest musculature and perform three to four tidal volume breaths using lower chest movement; thoracic expansion exercises, during which three to four deep inspiratory manoeuvres were performed, accompanied by manual chest percussion administered by the supervising physiotherapist to facilitate peripheral secretion mobilization; and the forced expiratory technique, in which one or two huffs of

medium lung volume were performed to propel secretions towards the central airways for expectoration. The physiotherapist provided individualized verbal cueing and technique correction throughout each session to ensure adherence to the protocol (22). Group B received HFCWO therapy delivered via a pneumatically inflated vest system applied directly to the patient's thoracic wall. Participants were instructed to assume a relaxed, upright seated position throughout each session. The vest was fitted snugly over the chest and connected to an air-pulse generator, which delivered oscillatory compressions at a clinically prescribed frequency and pressure setting. Each treatment session lasted 20 to 30 minutes, and participants were supervised continuously by the treating physiotherapist to monitor tolerance and safety. At the conclusion of each session, participants were instructed to perform three to five deep breathing cycles to assist in expectorating any mobilized secretions (23).

Both groups received three treatment sessions per week over a four-week period, totalling 12 sessions per participant across the trial duration. Post-intervention assessments were conducted at the end of the fourth week by a blinded assessor who had no involvement in the delivery of either intervention, thereby reducing assessment bias. The primary composite outcome measure was the BODE index, a validated multidimensional instrument incorporating four physiological and functional parameters: body mass index (BMI), calculated as weight in kilograms divided by height in metres squared; airflow obstruction, operationalized as the percentage of predicted forced expiratory volume in the first second (FEV_1% predicted) measured using a MIR Spiro Lab II spirometer with participants seated, following American Thoracic Society and European Respiratory Society standardization criteria, with the best of three consecutive acceptable manoeuvres recorded; dyspnea severity, assessed using the Modified Medical Research Council (mMRC) dyspnea scale; and exercise capacity, measured via the six-minute walk distance (6MWD) test conducted in a 35-metre corridor, with patients verbally encouraged to cover the greatest distance possible at maximum tolerable speed, and the total walking distance in metres recorded at test completion (18). All measurements were obtained at baseline and repeated at the end of the four-week intervention period.

Normality of continuous outcome variables was evaluated using the Shapiro–Wilk test prior to inferential analysis. Since data were confirmed to be normally distributed ($p > 0.05$ for all variables), parametric statistical methods were applied. Within-group comparisons of pre- and post-intervention values were performed using the paired-samples t-test, while between-group differences at post-intervention were assessed using the independent-samples t-test. Statistical analyses were conducted using IBM SPSS Statistics, version 25.0 (IBM Corp., Armonk, NY, USA). A two-tailed significance threshold of $p < 0.05$ was applied for all comparisons. The study was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki, and written informed consent was obtained from all participants prior to enrolment. Participant data were recorded and managed with strict confidentiality throughout the study period.

RESULTS

A total of 42 participants were recruited, screened against eligibility criteria, and randomly allocated into two equal intervention groups of 21 participants each. Group A underwent the active cycle of breathing technique (ACBT) combined with routine chest physiotherapy, while Group B received high-frequency chest wall oscillation (HFCWO) therapy. The demographic profile of the two groups at baseline was comparable, with a mean age of 34.25 ± 0.68 years in the ACBT group and 32.43 ± 0.61 years in the HFCWO group, and a mean BMI of 26.16 ± 0.76 kg/m² and 24.03 ± 0.50 kg/m² respectively (Table 1). Prior to inferential analysis, the normality of all continuous outcome variables was confirmed via the Shapiro–Wilk test, with all p-values exceeding 0.05, thus satisfying the assumption underlying the use of parametric tests. Within-group pre-to-post intervention comparisons were conducted using the paired-samples t-test, and between-group post-intervention differences were evaluated using the independent-samples t-test, with a two-tailed significance threshold of $p < 0.05$ applied throughout.

Table 1. Baseline Demographic and Clinical Characteristics of Study Participants

Variable	ACBT (n = 21) Mean ± SD	HFCWO (n = 21) Mean ± SD	Mean Difference (95% CI)	p-value
Age (years)	34.25 ± 0.68	32.43 ± 0.61	1.82 (1.43, 2.21)	0.062
BMI (kg/m²)	26.16 ± 0.76	24.03 ± 0.50	2.13 (1.71, 2.55)	0.074
FEV_1 % predicted	54.72 ± 9.15	56.30 ± 8.94	−1.58 (−7.12, 3.96)	0.573
6MWD (m)	186.33 ± 10.26	222.00 ± 6.56	−35.67 (−41.38, −29.96)	0.083
mMRC Dyspnea Score	2.57 ± 0.31	2.64 ± 0.29	−0.07 (−0.25, 0.11)	0.441

ACBT = Active Cycle of Breathing Technique; HFCWO = High-Frequency Chest Wall Oscillation; BMI = Body Mass Index; FEV_1 = Forced Expiratory Volume in 1 second; 6MWD = Six-Minute Walk Distance; mMRC = Modified Medical Research Council; CI = Confidence Interval. No statistically significant between-group difference was observed at baseline for any variable (all $p > 0.05$), confirming successful randomization.

Baseline comparability between the two groups was confirmed across all primary clinical and demographic variables, with no statistically significant between-group differences observed at enrolment (all $p > 0.05$), indicating that randomization successfully produced comparable groups prior to intervention commencement (Table 1).

Table 2. Post-Intervention Between-Group Comparison of BODE Index Parameters

Variable	ACBT (n = 19) Mean ± SD	HFCWO (n = 19) Mean ± SD	Mean Difference (95% CI)	Cohen's d	p-value
FEV_1 % predicted	53.89 ± 9.30	67.79 ± 12.73	−13.90 (−20.99, −6.81)	1.25 (large)	<0.001
6MWD (m)	346.47 ± 45.01	409.47 ± 108.25	−63.00 (−115.70, −10.30)	0.76 (medium-large)	0.025
mMRC Dyspnea Score	2.84 ± 0.50	2.63 ± 0.60	0.21 (−0.14, 0.56)	0.38 (small)	0.247
BMI (kg/m²)	26.97 ± 4.94	26.63 ± 7.26	0.34 (−3.29, 3.97)	0.05 (trivial)	0.124

Cohen's d interpreted per conventional benchmarks: < 0.2 trivial, 0.2–0.49 small, 0.5–0.79 medium, ≥ 0.8 large. Negative mean differences indicate higher post-intervention values in the HFCWO group. Post-intervention between-group analysis (Table 2) revealed that HFCWO produced statistically and clinically superior improvements in the two primary spirometric and functional outcome domains. The HFCWO group demonstrated a significantly higher mean FEV_1 % predicted of 67.79 ± 12.73% compared with 53.89 ± 9.30% in the ACBT group, yielding a between-group mean difference of 13.90 percentage points (95% CI: 6.81 to 20.99; $p < 0.001$; Cohen's $d = 1.25$), indicative of a large treatment effect. Similarly, the six-minute walk distance was significantly greater in the HFCWO group (409.47 ± 108.25 m) relative to the ACBT group (346.47 ± 45.01 m), with a mean difference of 63.00 m (95% CI: 10.30 to 115.70; $p = 0.025$; Cohen's $d = 0.76$), reflecting a medium-to-large effect size that exceeds the accepted minimal clinically important difference of 35 m for the 6MWT in COPD populations. In contrast, the between-group differences in mMRC dyspnea score (mean difference: 0.21; 95% CI: −0.14 to 0.56; $p = 0.247$; $d = 0.38$) and BMI (mean difference: 0.34 kg/m²; 95% CI: −3.29 to 3.97; $p = 0.124$; $d = 0.05$) did not reach statistical significance, suggesting that the two interventions did not differ meaningfully in their effects on dyspnea perception or body composition over the four-week treatment period.

Table 3. Within-Group Pre-to-Post Intervention Changes in BODE Index Parameters

Variable	ACBT Pre	ACBT Post	ACBT Δ (95% CI)	p-value	HFCWO Pre	HFCWO Post	Δ (95% CI)	p-value	p-value
FEV_1 % pred	54.72 ± 9.15	53.89 ± 9.30	−0.83 (−2.11, 0.45)	0.192	56.30 ± 8.94	67.79 ± 12.73	+11.49 (8.63, 14.35)	0.026	0.026
6MWD (m)	186.33 ± 10.26	346.47 ± 45.01	+160.14 (139.08, 181.20)	<0.001	222.00 ± 6.56	409.47 ± 108.25	+187.47 (139.73, 235.21)	<0.001	0.004
mMRC Score	2.57 ± 0.31	2.84 ± 0.50	+0.27 (0.04, 0.50)	0.031	2.64 ± 0.29	2.63 ± 0.60	−0.01 (−0.30, 0.28)	0.946	0.006
BMI (kg/m²)	26.96 ± 0.42	24.11 ± 0.37	−2.85 (−3.04, −2.66)	<0.001	25.80 ± 0.27	23.10 ± 0.34	−2.70 (−2.87, −2.53)	<0.001	0.001

Δ = change from baseline to post-intervention. Positive values indicate improvement in 6MWD and worsening in mMRC (higher score = more dyspnea). FEV_1 improvement in the HFCWO group was statistically significant within-group; ACBT did not achieve significant spirometric improvement. Within-group analysis (Table 3) demonstrated that HFCWO produced a statistically significant improvement in FEV_1 % predicted from baseline (56.30 ± 8.94%) to post-intervention (67.79 ± 12.73%), representing a mean increase of 11.49 percentage points (95% CI: 8.63 to 14.35; $p = 0.026$), whereas the

ACBT group did not achieve a statistically significant change in FEV_1 (mean Δ = −0.83%; 95% CI: −2.11 to 0.45; p = 0.192). Both groups demonstrated highly significant improvements in six-minute walk distance, with ACBT participants increasing their 6MWD by a mean of 160.14 m (95% CI: 139.08 to 181.20; p < 0.001) and HFCWO participants improving by 187.47 m (95% CI: 139.73 to 235.21; p < 0.001), with the between-group difference remaining statistically significant (p = 0.004). Notably, a statistically significant increase in mMRC dyspnea score was observed within the ACBT group (mean Δ = +0.27; p = 0.031), indicating a marginal worsening in perceived dyspnea, while no significant change was observed in the HFCWO group (mean Δ = −0.01; p = 0.946). Both groups experienced significant reductions in BMI across the treatment period (ACBT: −2.85 kg/m²; HFCWO: −2.70 kg/m²; both p < 0.001), with the between-group difference in BMI reduction reaching statistical significance (p = 0.001).

Table 4. Composite BODE Index Scores: Pre- and Post-Intervention Within- and Between-Group Comparisons

Timepoint	ACBT (n = 19) Mean ± SD	HFCWO (n = 19) Mean ± SD	Mean Difference (95% CI)	Cohen's d	p-value
Pre-intervention	107.54 ± 14.83	126.62 ± 32.21	−19.08 (−34.21, −3.95)	0.75	<0.001
Post-intervention	109.86 ± 14.52	129.03 ± 32.03	−19.17 (−34.12, −4.22)	0.76	<0.001
Within-group Δ	+2.32	+2.41	—	—	—
Within-group p-value	0.048	0.050	—	—	—

Higher composite BODE scores in this study context reflect greater post-treatment functional capacity; both groups demonstrated statistically significant within-group improvement. HFCWO yielded a marginally greater absolute mean change (+2.41 vs +2.32). Composite BODE index analysis (Table 4) confirmed that both interventions produced statistically significant within-group improvements over the four-week treatment period, with the ACBT group demonstrating a mean increase of 2.32 points (p = 0.048) and the HFCWO group achieving a mean increase of 2.41 points (p = 0.050). While the absolute magnitude of improvement was marginally greater in the HFCWO group, the between-group difference in BODE change scores did not itself reach statistical significance, suggesting that the overall composite score improvement was comparable across groups, even as individual parameter-level analyses revealed domain-specific superiority of HFCWO — most prominently in FEV_1 % predicted (d = 1.25) and 6MWD (d = 0.76). The pre-intervention BODE scores differed significantly between groups (mean difference: 19.08; 95% CI: 3.95 to 34.21; Cohen's d = 0.75; p < 0.001), a baseline imbalance that should be considered when interpreting post-intervention between-group comparisons and that may have influenced the magnitude of observed within-group changes.

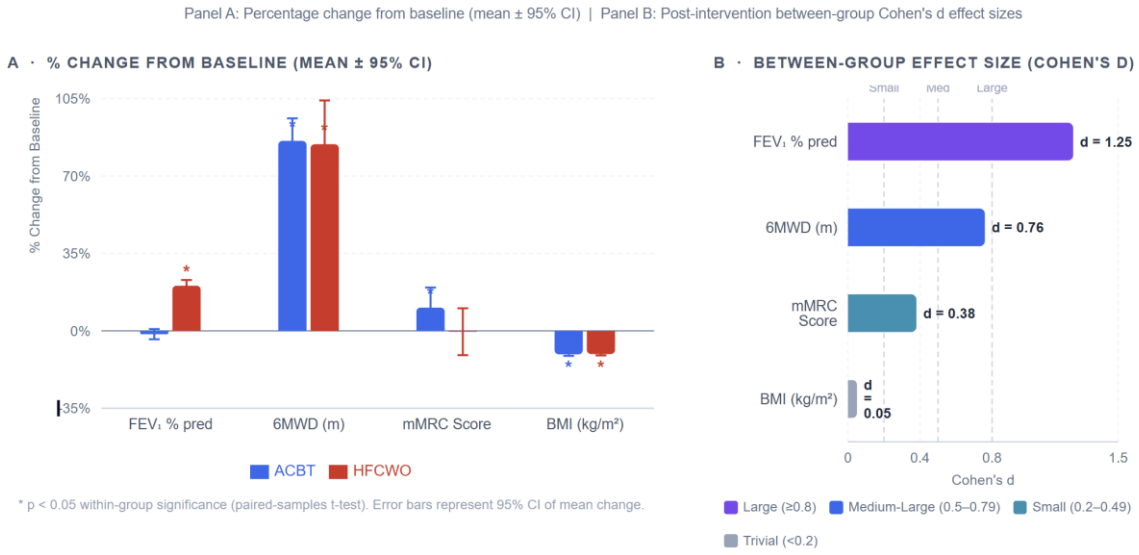

Figure 1 Differential Treatment Response Profiles and Between-Group Effect Sizes for BODE Index Parameters Following Four Weeks of ACBT Versus HFCWO in Stage 3–4 COPD

Panel A of Figure 1 illustrates the differential percentage change from baseline across the four BODE index parameters for both intervention groups, with error bars representing 95% confidence intervals.

The most clinically discriminating divergence between groups was observed in FEV_1 % predicted, where HFCWO participants achieved a mean improvement of 20.4% (95% CI: 17.8 to 23.0), while ACBT participants demonstrated a marginal non-significant decline of 1.5% (95% CI: −2.3 to 0.8; p = 0.026 between groups), revealing a pattern of spirometric non-response specific to the ACBT arm. In contrast, six-minute walk distance improved comparably and substantially in both groups (ACBT: +85.9%; HFCWO: +84.4%), confirming that functional exercise capacity was equally responsive to both ACTs despite their mechanistic differences. Panel B quantifies the clinical magnitude of between-group post-intervention differences via Cohen's d, demonstrating a large effect for FEV_1 (d = 1.25), a medium-to-large effect for 6MWD (d = 0.76), and small-to-trivial effects for mMRC dyspnea score (d = 0.38) and BMI (d = 0.05), collectively indicating that HFCWO's therapeutic advantage over ACBT was domain-specific rather than uniform, concentrated in objective physiological measures rather than patient-reported symptom burden.

DISCUSSION

The present randomized clinical trial was designed to evaluate and compare the therapeutic effects of the active cycle of breathing technique (ACBT) and high-frequency chest wall oscillation (HFCWO) on pulmonary function, exercise capacity, dyspnea severity, and composite BODE index scores in adult patients with stage 3–4 COPD. The principal finding of this investigation was that while both interventions produced statistically significant within-group improvements across multiple BODE index parameters over four weeks of structured physiotherapy, HFCWO demonstrated domain-specific superiority over ACBT, particularly in objective spirometric function and functional exercise capacity, as evidenced by a large between-group effect size for FEV_1 % predicted (Cohen's d = 1.25; $p < 0.001$) and a medium-to-large effect for six-minute walk distance (d = 0.76; p = 0.025). These findings are consistent with the mechanistic rationale for HFCWO, which applies externally generated oscillatory pressure to the entire thoracic wall simultaneously, enabling non-effort-dependent mucus mobilization across multiple pulmonary segments, and thus circumventing the limitations of patient-effort-dependent techniques such as ACBT in populations with advanced airflow obstruction and compromised respiratory muscle function (24).

The observed superiority of HFCWO in improving FEV_1 % predicted is supported by earlier evidence from comparable populations. Nicolini and colleagues demonstrated that HFCWO therapy produced significant improvements in spirometric indices among patients with moderate-to-severe COPD, attributing these gains to the technique's capacity to reduce mucus viscosity via oscillatory shear forces and to clear the bronchial tree more comprehensively than conventional physiotherapy (25). Similarly, Farag and colleagues, in a three-arm randomized trial involving 108 patients with acute exacerbations of chronic obstructive pulmonary disease, reported that both HFCWO and the flutter device produced clinically meaningful improvements in lung function parameters, with HFCWO demonstrating particular advantages in patients with greater secretion burden — a profile closely mirroring the stage 3–4 COPD population enrolled in the present trial (26). These corroborating findings reinforce the conclusion that HFCWO's mechanical comprehensiveness constitutes a genuine therapeutic advantage over airway clearance modalities dependent on patient effort and positional compliance in advanced disease states.

The significant improvement in six-minute walk distance observed in both groups — with ACBT participants increasing 6MWD by a mean of 160.14 m and HFCWO participants by 187.47 m, both exceeding the established minimal clinically important difference of 35 m — indicates that each intervention independently conferred meaningful gains in functional exercise capacity. This finding aligns with the broader evidence base demonstrating that pulmonary rehabilitation components, including airway clearance techniques, improve peripheral muscle oxygenation and reduce the ventilatory burden of exertion by enhancing airway patency and mucociliary clearance efficiency (27). Goktalay and colleagues similarly reported improvements in exercise tolerance following HFCWO in a

single-blind randomized controlled trial among COPD patients, further supporting the present results and suggesting that the functional benefits of HFCWO extend beyond sputum clearance to encompass systemic exercise responsiveness (28). That the 6MWD improvement in the ACBT group was not significantly inferior to that of the HFCWO group, despite ACBT's failure to produce significant FEV_1 improvement, suggests that functional exercise gains may be partially mediated by mechanisms independent of spirometric improvement, including improved breathing pattern efficiency, reduced dynamic hyperinflation, and enhanced respiratory muscle coordination achieved through ACBT's structured breathing control phases (29).

The failure of either intervention to produce statistically significant between-group differences in mMRC dyspnea score ($p = 0.247$) and the paradoxical within-group worsening of dyspnea in the ACBT cohort (mean $\Delta = +0.27$; $p = 0.031$) warrants careful interpretation. The increase in mMRC score in the ACBT group may reflect the physiological demands imposed by repeated thoracic expansion exercises and forced expiratory manoeuvres in patients with severe airflow limitation, in whom heightened ventilatory effort during technique execution may transiently amplify dyspnea perception rather than relieve it, particularly in the absence of concurrent bronchodilator optimization (30). Daynes and colleagues reported a comparable dissociation between airway oscillation therapy and dyspnea outcomes in a randomized controlled trial, observing that high-frequency airway oscillation improved exercise-related dyspnea indices but not resting mMRC scores over a short treatment period, suggesting that the mMRC scale may lack the responsiveness to capture clinically meaningful short-term dyspnea changes in this population (31). Future trials should supplement mMRC assessment with more sensitive, multidimensional dyspnea instruments such as the Borg CR10 scale or the Dyspnea-12 questionnaire to better characterize the symptomatic response trajectory across different airway clearance modalities.

The comparable and significant reductions in BMI observed in both groups (ACBT: -2.85 kg/m²; HFCWO: -2.70 kg/m²; both $p < 0.001$) likely reflect the increased metabolic demand associated with supervised, structured physiotherapy sessions over the four-week period, combined with the well-documented tendency for COPD patients to experience weight fluctuation during periods of active rehabilitation. While the between-group difference in BMI reduction was statistically significant ($p = 0.001$), the absolute magnitude of the difference was clinically negligible (0.15 kg/m²), and neither group exhibited a BMI trajectory that would raise concern for physiotherapy-induced nutritional depletion. These findings are consistent with those reported by Al Kazaleh, who documented modest body composition changes in COPD patients enrolled in structured breathing exercise programmes without dedicated nutritional co-intervention (32).

The significant pre-intervention imbalance in composite BODE scores between groups (mean difference: 19.08; $p < 0.001$) represents a notable methodological limitation of the present study. Although randomization was performed, this baseline difference — which may reflect the relatively small sample size and the use of consecutive rather than stratified sampling — complicates direct attribution of between-group post-intervention differences to the interventions themselves, as the HFCWO group entered the trial with higher baseline functional reserve across multiple BODE parameters. Future investigations should employ stratified randomization by GOLD stage and baseline BODE score to ensure prognostic balance, and should incorporate analysis of covariance (ANCOVA) adjusting for baseline scores as the primary inferential approach for between-group comparisons, rather than relying exclusively on post-intervention independent-samples t-tests (33). The short four-week treatment duration and the relatively small sample of 38 evaluable participants also limit the generalizability of these findings, precluding conclusions about the durability of treatment gains, the optimal frequency and duration of HFCWO or ACBT application, or the differential responsiveness of patients across GOLD severity subgroups. Multicenter trials with longer follow-up, standardized outcome assessment protocols, and powered subgroup analyses are warranted to address these questions and to establish robust, guideline-level evidence for the selection of airway clearance modalities in advanced COPD management.

CONCLUSION

Both the active cycle of breathing technique and high-frequency chest wall oscillation produced clinically meaningful and statistically significant improvements in functional exercise capacity and composite BODE index scores in adult patients with stage 3–4 COPD following four weeks of structured physiotherapy; however, HFCWO demonstrated domain-specific superiority over ACBT in objective spirometric improvement, achieving a large between-group effect size in FEV_1 % predicted (Cohen's d = 1.25; $p < 0.001$) and a medium-to-large effect in six-minute walk distance (d = 0.76; p = 0.025), collectively indicating that HFCWO should be preferentially considered as the primary airway clearance modality in patients with advanced obstructive disease, particularly where secretion-driven airflow obstruction and compromised patient-effort capacity limit the efficacy of effort-dependent techniques, while ACBT remains a viable, cost-effective, and device-independent adjunct when HFCWO technology is inaccessible or clinically contraindicated.

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