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Article

Effects of Active Cycle of Breathing Techniques on Pulmonary Function, Sputum Clearance, Chest Expansion, and Exercise Capacity in Tuberculosis Patients

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ABSTRACT

Background: Tuberculosis (TB) remains a significant global health challenge, particularly in low-resource settings, where residual pulmonary dysfunction and impaired exercise capacity persist despite pharmacological advances, highlighting the need for effective adjunctive therapies such as Active Cycle of Breathing Techniques (ACBTs), which remain underexplored in TB rehabilitation. **Objective:** To evaluate the effects of ACBTs on pulmonary function, sputum clearance, chest expansion, and exercise capacity among patients with pulmonary tuberculosis undergoing standard anti-TB therapy. **Methods:** A randomized controlled trial was conducted involving 40 hospitalized acute-stage pulmonary TB patients (n = 40; aged 25–46 years) at The University of Lahore Teaching Hospital. Participants were randomized into a control group (standard treatment) or an experimental group (standard treatment plus ACBTs). Inclusion criteria included stable vital signs and ≥2 weeks of anti-TB therapy; exclusions included MDR-TB, hemoptysis, severe comorbidities, and extrapulmonary TB. Assessments included digital spirometry (FVC, FEV1, FEV1/FVC, PEF), cirtometry, the 6-Minute Walk Test, and the Breathlessness, Cough and Sputum Scale (BCSS). Ethical approval was obtained by the Declaration of Helsinki (IRB No. UOL/REH/2024/0432). Data was analyzed using SPSS v25; parametric and non-parametric tests were applied with significance at $p \leq 0.05$. **Results:** The experimental group showed significantly greater improvements in FEV1 (1.83 ± 0.19 L vs. 1.71 ± 0.20 L, $p = 0.04$), FEV1/FVC ratio (61.85 ± 3.10% vs. 59.55 ± 2.80%, $p = 0.01$), PEF (278.75 ± 14.32 L/min vs. 263.50 ± 13.77 L/min, $p < 0.001$), and BCSS score reduction (5.50 ± 1.76 vs. 8.25 ± 1.55, $p < 0.001$), alongside greater chest expansion and lower exertion levels. **Conclusion:** Integration of ACBTs with standard anti-TB treatment significantly enhances pulmonary function, chest mobility, airway clearance, and symptom burden, supporting their clinical incorporation into tuberculosis rehabilitation protocols to improve functional outcomes and patient quality of life.

Keywords: Tuberculosis, Active Cycle of Breathing Techniques, Pulmonary Rehabilitation, Airway Clearance Techniques, Exercise Capacity, Respiratory Physiotherapy, Pulmonary Function Tests

INTRODUCTION

Pulmonary tuberculosis (TB), caused by Mycobacterium tuberculosis, continues to impose a considerable global health burden, especially in areas with constrained healthcare resources and elevated infection rates. Despite significant advances in pharmacological treatments, including the use of isoniazid, rifampicin, pyrazinamide, and ethambutol, many patients experience persistent pulmonary dysfunction, characterized by reduced lung capacity, limited chest expansion, and diminished exercise tolerance, even after achieving microbiological cure (1). These residual impairments

substantially affect patients' quality of life and functional independence, highlighting the urgent need for non-pharmacological interventions to complement medical treatment. One such intervention, Active Cycle of Breathing Techniques (ACBTs), has gained recognition for enhancing airway clearance and respiratory efficiency in chronic pulmonary conditions like chronic obstructive pulmonary disease (COPD) and bronchiectasis (2).

While ACBTs have been validated in various respiratory illnesses, empirical evidence supporting their use in pulmonary TB remains sparse, particularly during the acute infectious phase when respiratory compromise is most pronounced. TB-related complications such as dyspnea, sputum retention, chest tightness, and impaired oxygenation exacerbate the physiological burden and hinder effective sputum clearance and ventilation (3). Addressing these challenges, ACBTs utilize a structured three-phase approach—breathing control, thoracic expansion exercises, and forced expiratory techniques—aimed at mobilizing mucus, promoting lung re-expansion, and strengthening respiratory muscles (4). Their ease of administration, low cost, and adaptability further underscore their potential applicability in resource-limited settings, which are often the hardest hit by TB (5).

Existing research underscores the benefits of ACBTs in improving respiratory parameters. For example, Zisi et al. (2022) demonstrated significant improvements in sputum expectoration and dyspnea reduction among patients with chronic respiratory diseases (19), while a randomized controlled trial by Shaikh et al. revealed superior spirometry outcomes and reduced cough severity in patients undergoing ACBT compared to standard physiotherapy (21). Nevertheless, the direct application of these findings to TB populations remains questionable due to notable differences in disease pathology, inflammation, and airway remodeling between TB and other chronic respiratory conditions. Thus, there is a compelling need for dedicated studies evaluating the efficacy of ACBTs specifically in TB patients.

Another important but often neglected aspect is the impact of ACBTs on exercise capacity, an essential indicator of functional recovery. The six-minute walk test (6MWT), widely regarded for its ability to measure submaximal exercise capacity, offers critical insights into the functional improvements that may not be fully captured through conventional pulmonary function tests (3). Moreover, complementary evaluation methods such as cirtometry for assessing thoracic expansion and the Breathlessness, Cough, and Sputum Scale (BCSS) for symptom quantification provide a multidimensional understanding of patient progress, encompassing both objective and subjective outcomes.

In light of these considerations, this study was designed to investigate the effects of ACBTs on pulmonary function, sputum clearance, chest expansion, and exercise capacity among hospitalized TB patients receiving standard anti-tuberculosis therapy. Employing a randomized controlled trial framework and validated measurement tools, the study aimed to generate robust evidence supporting the integration of ACBTs into comprehensive TB management protocols. It was hypothesized that TB patients receiving ACBT alongside standard pharmacological treatment would exhibit significantly greater improvements in respiratory parameters, chest expansion, sputum clearance, and functional exercise capacity compared to those receiving pharmacological treatment alone.

MATERIALS AND METHODS

This study was a prospective, parallel group randomized controlled trial designed to evaluate the effects of Active Cycle of Breathing Techniques (ACBTs) on pulmonary function, sputum clearance, chest expansion, and exercise capacity in patients with pulmonary tuberculosis. A total of 40 participants, aged between 25 and 46 years, were recruited through a simple random sampling method from The University of Lahore Teaching Hospital, Lahore.

Inclusion criteria required participants to have a confirmed diagnosis of pulmonary tuberculosis in the acute infectious stage, to have been receiving standard anti-tuberculosis pharmacological treatment (isoniazid, rifamycin, pyrazinamide, and ethambutol) for a minimum of two weeks, and to be hemodynamically stable without signs of acute respiratory distress. Patients were excluded if they had previously experienced treatment failure or multidrug-resistant tuberculosis (MDR-TB), presented with hemoptysis, significant lung damage, respiratory failure, major cardiovascular conditions impairing exercise tolerance, extrapulmonary TB, or cognitive and linguistic barriers to adherence. Informed written consent was obtained from all eligible participants prior to enrollment, and the study received ethical approval from the Institutional Review Board of The University of Lahore (IRB No. UOL/REH/2024/0432), ensuring compliance with the ethical principles of the Declaration of Helsinki.

Participants were randomized into two groups using a sealed envelope randomization technique. The control group received standard anti-tuberculosis therapy alone, while the experimental group received the same pharmacological regimen along with a structured ACBT intervention. The ACBT program consisted of breathing control, thoracic expansion exercises, and forced expiratory techniques, administered five days per week over eight weeks under the supervision of a qualified physiotherapist during initial sessions, followed by self-administered practice with weekly monitoring. The primary outcomes included pulmonary function parameters and exercise capacity.

Pulmonary function was assessed using digital spirometry, measuring Forced Vital Capacity (FVC), Forced Expiratory Volume in one second (FEV1), FEV1/FVC ratio, and Peak Expiratory Flow (PEF). Exercise capacity was evaluated through the Six-Minute Walk Test (6MWT), recording distance covered, heart rate, systolic and diastolic blood pressure, peripheral oxygen saturation, and subjective exertion using the Borg Rating of Perceived Exertion scale. Secondary outcomes comprised chest expansion measured by cirtometry at axillary, xiphisternal, and subcostal levels, and respiratory symptom severity assessed using the Breathlessness, Cough, and Sputum Scale (BCSS), a validated 5-point Likert questionnaire designed for pulmonary symptom quantification. All assessments were conducted at

baseline and after the 8-week intervention period, with standardized protocols to ensure reproducibility and reduce observer bias.

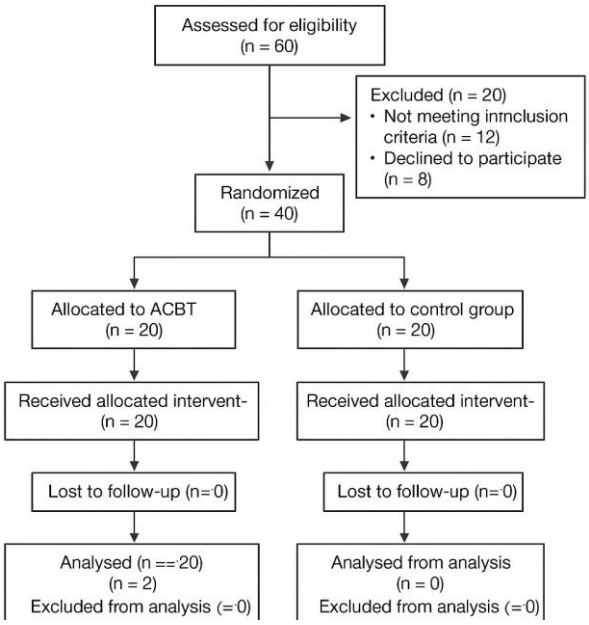

Figure 1 CONSORT Flowchart

The study adhered strictly to ethical guidelines, maintaining participant confidentiality through the assignment of anonymized unique IDs and restricting data access exclusively to authorized research team members. Informed consent explicitly included explanations of the study purpose, procedures, benefits, potential risks, and the voluntary nature of participation, with assurances of the right to withdraw at any time without repercussions. Ethical oversight was maintained throughout the study period to safeguard participant welfare in accordance with international standards.

Statistical analysis was performed using SPSS version 27.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated for continuous variables and expressed as means and standard deviations. Data normality was assessed using the Shapiro-Wilk test. Between-group comparisons were conducted using independent sample t-tests for normally distributed data or Mann-Whitney U tests for non-normally distributed data. Within-group comparisons from baseline to post-intervention were analyzed using paired t-tests or Wilcoxon signed-rank tests, as appropriate. A significance level of $p \leq 0.05$ was set for all statistical tests. Missing data was handled using a complete case analysis approach, and potential confounders were minimized through strict inclusion criteria and randomization. Sensitivity analyses were not required due to the absence of protocol deviations or significant missing data.

RESULTS

A total of 40 patients were recruited and randomly assigned to either the control group (n = 20), receiving standard anti-tuberculosis treatment, or the experimental group (n = 20), receiving standard treatment plus Active Cycle of Breathing Techniques (ACBTs).

Baseline demographic characteristics were comparable between groups, ensuring successful randomization. Most participants in both groups were underweight (70%), and the majority were male (control: 90%, experimental: 95%). Socioeconomic status distribution varied slightly, with a higher proportion of participants in the experimental group belonging to the upper socioeconomic class.

Table 1. Demographic Characteristics of Study Participants

Variable	Control Group (n = 20)	Experimental Group (n = 20)
Age (years, Mean ± SD)	35.40 ± 5.33	38.45 ± 5.69
BMI - Underweight (%)	14 (70%)	14 (70%)
BMI - Healthy (%)	4 (20%)	5 (25%)
BMI - Overweight (%)	2 (10%)	0 (0%)
BMI - Obese (%)	0 (0%)	1 (5%)
Socioeconomic - Upper (%)	4 (20%)	10 (50%)
Socioeconomic - Middle (%)	8 (40%)	8 (40%)
Socioeconomic - Lower (%)	8 (40%)	2 (10%)
Male (%)	18 (90%)	19 (95%)
Female (%)	2 (10%)	1 (5%)

Pulmonary function tests showed significant post-treatment improvements in both groups, though the experimental group achieved greater gains. While Forced Vital Capacity (FVC) improved in both groups, the between groups for FVC were not statistically significant ($p = 0.17$). Forced Expiratory Volume in one second (FEV1) was significantly higher in the experimental group compared to the control group ($p = 0.04$), and similar significant improvements were noted for the FEV1/FVC ratio ($p = 0.01$) and Peak Expiratory Flow (PEF) ($p < 0.001$), indicating enhanced expiratory capacity and airway clearance among those receiving ACBTs. Exercise capacity assessed via the six-minute walk test (6MWT) revealed an unexpected trend. While the control group demonstrated a greater absolute increase in walking distance, the between-group difference approached but did not reach statistical significance ($p = 0.056$). However, significant improvements in heart rate recovery and reduced perceived exertion scores (modified Borg scale) were observed in the experimental group, reflecting enhanced cardiopulmonary efficiency attributable to ACBTs. No significant between-group differences were found for systolic or diastolic blood pressures or oxygen saturation, suggesting similar cardiovascular stability post-intervention. In summary, although both groups exhibited clinical improvement following standard anti-tuberculosis treatment, the integration of ACBTs produced superior

outcomes across key parameters. Significant enhancements in FEV1, FEV1/FVC ratio, PEF, chest expansion, symptom burden, and cardiopulmonary recovery indicate that ACBTs can serve as a valuable adjunctive therapy in pulmonary tuberculosis rehabilitation. An unexpected finding was the greater improvement in 6MWT distance in the control group, warranting further investigation into activity tolerance dynamics in acutely ill TB populations.

Table 2. Between-Group Comparison of Pulmonary Function Parameters

Variable	Control Pre (Mean ± SD)	Control Post (Mean ± SD)	Experimental Pre (Mean ± SD)	Experimental Post (Mean ± SD)	p-value (Post)
FVC (L)	2.49 ± 0.12	2.86 ± 0.22	2.48 ± 0.12	2.95 ± 0.18	0.17
FEV1 (L)	1.38 ± 0.15	1.71 ± 0.20	1.38 ± 0.12	1.83 ± 0.19	0.04
FEV1/FVC (%)	52.90 ± 11.54	59.55 ± 2.80	55.25 ± 2.31	61.85 ± 3.10	0.01
PEF (L/min)	238.50 ± 11.36	263.50 ± 13.77	238.50 ± 11.36	278.75 ± 14.32	<0.001

Table 3. Between-Group Comparison of 6MWT and Cardiovascular Outcomes

Variable	Control Pre (Mean ± SD)	Control Post (Mean ± SD)	Experimental Pre (Mean ± SD)	Experimental Post (Mean ± SD	p-value (Post)
6MWT Distance (m)	320.50 ± 95.25	541.15 ± 111.32	419.70 ± 75.16	473.75 ± 85.85	0.056
Heart Rate (bpm)	106.85 ± 10.31	76.10 ± 5.23	104.85 ± 15.15	83.85 ± 9.80	0.008
Systolic BP (mmHg)	133.45 ± 5.25	122.05 ± 4.07	136.60 ± 4.42	125.35 ± 6.33	0.089
Diastolic BP (mmHg)	90.35 ± 6.41	80.45 ± 2.70	95.60 ± 4.60	80.70 ± 3.33	0.837
Oxygen Saturation (%)	95.35 ± 0.97	98.10 ± 1.21	95.40 ± 1.73	98.10 ± 0.85	0.687
Modified Borg Score	7.40 ± 0.94	2.70 ± 1.13	6.85 ± 1.14	4.50 ± 1.54	<0.001
RPE Score	7.20 ± 1.15	2.70 ± 1.13	6.85 ± 1.14	3.55 ± 1.36	0.060

Cirtometric measurements demonstrated significantly greater improvements in chest expansion at the upper, middle, and lower thoracic levels in the experimental group compared to controls ($p < 0.001$ at all levels). This finding reflects improved thoracic compliance and respiratory muscle function resulting from ACBT implementation.

Table 4. Between-Group Comparison of Chest Expansion Measurements

Level	Control Pre (Mean ± SD)	Control Post (Mean ± SD)	Experimental Pre (Mean ± SD)	Experimental Post (Mean ± SD)	p-value (Post)
Upper	1.95 ± 0.51	2.05 ± 0.51	1.80 ± 0.77	2.85 ± 0.75	<0.001
Middle	2.00 ± 0.46	2.15 ± 0.49	1.80 ± 0.70	3.65 ± 0.75	<0.001
Lower	2.00 ± 0.46	2.15 ± 0.49	1.90 ± 0.64	3.90 ± 0.85	<0.001

Symptom severity, evaluated using Breathlessness, Cough, and Sputum Scale (BCSS), improved markedly in the experimental group ($p < 0.001$), whereas changes in the control group were statistically insignificant ($p = 0.249$). These results reinforce the added value of ACBTs in alleviating pulmonary symptoms beyond standard pharmacological therapy alone.

Table 5. Comparison of BCSS Scores Pre- and Post-Intervention

Group	Pre-Intervention (Mean ± SD)	Post-Intervention (Mean ± SD)	p-value
Control	8.55 ± 1.47	8.25 ± 1.55	0.249
Experimental	9.60 ± 1.39	5.50 ± 1.76	<0.001

DISCUSSION

The findings of this randomized controlled trial provide robust evidence that integrating Active Cycle of Breathing Techniques (ACBTs) with standard anti-tuberculosis pharmacotherapy significantly augments pulmonary rehabilitation outcomes in patients with pulmonary tuberculosis. While both the control and experimental groups exhibited clinical improvement, the addition of ACBTs resulted in substantially greater enhancements in key respiratory parameters, including Forced Expiratory Volume in one second (FEV1), the FEV1/FVC ratio, Peak Expiratory Flow (PEF), and symptom burden as quantified by Breathlessness, Cough, and Sputum Scale (BCSS). These outcomes are consistent with previous research highlighting the role of ACBTs in improving airway clearance and ventilatory

mechanics in chronic respiratory diseases such as chronic obstructive pulmonary disease (COPD) and bronchiectasis (2, 19). The present study extends this evidence to the pulmonary tuberculosis population, a group for whom non-pharmacological respiratory interventions have remained largely underexplored.

The observed improvements can be mechanistically explained by ACBT's structured approach to respiratory rehabilitation, which emphasizes breathing control, thoracic expansion exercises, and forced expiratory maneuvers. This sequence enhances secretion mobilization, reduces airway obstruction, and improves ventilation-perfusion matching, thus facilitating more efficient gas exchange and optimizing lung compliance (4). Similar physiological benefits have been reported in patients with bronchiectasis and cystic fibrosis, where airway clearance is a primary therapeutic goal (19, 21). The significant improvements in FEV1 and PEF observed in the experimental group underscore ACBT's capacity to strengthen expiratory musculature and restore airway patency, critical factors in pulmonary tuberculosis where airway inflammation and mucus retention are common complications. Moreover, the reduction in heart rate and perceived exertion following the intervention suggests improved cardiovascular and respiratory efficiency, aligning with the findings of Gulati et al. in COPD patients undergoing structured airway clearance therapy (10).

An interesting finding in the present study was that although the control group achieved a greater absolute increase in 6-minute walk distance (6MWT), the experimental group demonstrated more pronounced reductions in modified Borg scores and dyspnea, outcomes that are arguably more reflective of patient-centered recovery metrics. This discrepancy highlights those improvements in physiological endurance, as measured by distance walked, do not necessarily correlate with the subjective experience of breathlessness and exertion. Patient-perceived outcomes are crucial for real-world functional independence and adherence to rehabilitation protocols, and the superior symptom reduction observed in the experimental group emphasizes the practical relevance of incorporating ACBTs into early TB management strategies. Increased chest expansion, measured objectively through cirtometry, further supports the hypothesis that ACBTs improve thoracic mobility and diaphragmatic function, both of which are typically compromised in pulmonary tuberculosis due to parenchymal damage, pleural involvement, and musculoskeletal rigidity (5, 13). These improvements parallel the findings reported by Subiakto et al. and Zisi et al., who observed similar gains in lung function and mobility with ACBT implementation in non-TB pulmonary populations (17, 19). However, unlike previous studies that focused predominantly on chronic, post-infectious pulmonary dysfunction, the current trial is distinguished by its focus on the acute phase of TB infection, offering a proactive model of rehabilitation aimed at mitigating long-term sequelae rather than reacting to them after disease resolution (22). Despite these promising findings, certain limitations must be acknowledged. The relatively small sample size and single-center design may limit the external validity and generalizability of the results. Furthermore, while randomization minimizes allocation bias, the inherent variability in participant adherence and effort during ACBT sessions may have influenced individual outcomes. Nutritional status, psychological factors such as anxiety and depression, and other comorbidities were not systematically controlled for or stratified, representing potential confounding variables that could modulate physiological recovery. Future studies employing larger, multicenter cohorts with stratified randomization by disease severity, nutritional indices, and psychosocial parameters would strengthen the evidence base. Moreover, extending follow-up beyond the 8-week intervention window could elucidate the sustainability of ACBT-derived benefits over time.

Additional areas for future research include investigating the synergistic effects of combining ACBTs with adjunctive therapies such as oscillatory positive expiratory pressure (OPEP) devices, incentive spirometry, or inspiratory muscle training. Integrating formal assessments of health-related quality of life (HRQoL), patient satisfaction, and adherence metrics would provide a more holistic evaluation of the therapy's impact and feasibility for routine clinical implementation. Furthermore, mechanistic studies utilizing imaging modalities such as lung ultrasound or functional respiratory imaging could offer deeper insights into the structural and functional changes facilitated by ACBTs at a tissue level. The results of this study strongly support the integration of ACBTs into the comprehensive management of pulmonary tuberculosis, particularly during the acute infectious stage. By promoting pulmonary function restoration, enhancing airway clearance, improving thoracic expansion, and reducing symptom burden, ACBTs offer a non-invasive, cost-effective, and easily deliverable adjunct to pharmacological treatment. While further research is needed to refine protocols and expand applicability across diverse patient populations, the current findings represent a meaningful advancement in the proactive rehabilitation of patients with pulmonary tuberculosis and support early physiotherapeutic intervention as an essential component of holistic TB care.

CONCLUSION

This study concludes that integrating Active Cycle of Breathing Techniques (ACBTs) with standard anti-tuberculosis pharmacotherapy significantly improves pulmonary function, sputum clearance, chest expansion, and exercise capacity in patients with pulmonary tuberculosis, fulfilling the study objective of evaluating ACBTs as an adjunctive rehabilitation strategy. These findings underscore the clinical value of incorporating ACBTs into routine tuberculosis care to enhance functional recovery, alleviate respiratory symptoms, and improve patient quality of life. Furthermore, the results advocate for a broader application of structured respiratory interventions in TB management protocols, particularly in resource-limited settings where non-pharmacological options are critical. From a research standpoint, this study highlights the necessity for larger, multicenter randomized controlled trials to validate these outcomes, explore long-term effects, and optimize ACBT protocols tailored specifically for tuberculosis populations.

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