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Original Article

Long-term Effect of Pulmonary Rehabilitation in Pulmonary Tuberculosis Patients

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Abstract

OBJECTIVE: Post-pulmonary tuberculosis (post-PTB) sequelae, including impaired lung function, reduced exercise capacity, and diminished quality of life (QoL), pose significant challenges even after successful anti-tuberculosis treatment. While pulmonary rehabilitation (PR) is an established intervention for chronic respiratory diseases, its long-term effectiveness in post-PTB patients is not well-documented. This study aimed to evaluate the long-term impact of an 8-week outpatient PR program on respiratory function, exercise performance, and QoL in post-PTB patients.

MATERIAL AND METHODS: In a randomized controlled trial, 90 post-PTB patients aged ≥18 years were allocated to either the PR group or a control group. The PR program included supervised endurance and resistance training, breathing exercises, and patient education, delivered over 8 weeks. Primary outcomes, including the 6-minute walk distance (6MWD), Saint George's Respiratory Questionnaire (SGRQ), and pulmonary function tests, were assessed at baseline, immediately post-intervention, and at 12 months. Data were analyzed using repeated measures ANOVA.

RESULTS: The PR group demonstrated significant and sustained improvements across all measures. The 6MWD increased by 217 meters post-PR and remained 143 meters higher at 12 months ($P < 0.05$). SGRQ scores showed a 28-point reduction post-PR and a 32-point reduction at 12 months ($P < 0.05$). FEV1 improved by 41% post-PR, and by 45% at 12 months ($P < 0.05$). No significant changes were observed in the control group.

CONCLUSION: An 8-week PR program delivers long-term benefits in respiratory function, exercise capacity, and QoL in post-PTB patients. Incorporating PR into post-PTB care is a promising strategy to mitigate chronic sequelae and enhance patient outcomes.

KEYWORDS: Post-pulmonary tuberculosis, pulmonary rehabilitation, long-term outcomes, quality of life, respiratory health, exercise capacity

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INTRODUCTION

The World Health Organization's End Tuberculosis Strategy aspires to achieve a world free of pulmonary tuberculosis (PTB) by 2035, with the ambitious goal of eradicating deaths, disease, and suffering associated with the condition. While nearly 20 million individuals globally survived PTB in 2020 due to advancements in anti-tuberculosis treatment, there is a significant gap in knowledge regarding long-term respiratory sequelae, the effects on quality of life (QoL), and the potential need for continued rehabilitation among these survivors.[1] Despite effective treatments since the 1950s, TB remains a major global health issue, with over 10 million new cases annually.[2] Many post-TB survivors experience long-term respiratory issues that negatively affect their QoL, leading to ongoing costs for them, their families, and healthcare

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systems. Additionally, survivors often face persistent stigma, contributing to social exclusion, unemployment, unstable housing, and limited access to healthcare.[3]

Regular follow-ups with post-TB survivors can help reduce hospital admissions. Yet, the primary focus of care remains to achieve a microbiological "cure," with little attention given to patients' health-related QoL (HRQoL).[4] Recently, pulmonary rehabilitation (PR) has been recommended by the American Thoracic Society (ATS) and the European Respiratory Society (ERS) to improve the mental and physical health of patients with respiratory conditions and encourage healthy lifestyle practices. However, post-treatment PTB patients are not typically assessed for impairments or provided with follow-up care.[5] Despite effective anti-tubercular treatment, preventable mortality remains a significant issue, and the lengthy treatments result in poor adherence, worse outcomes, and ongoing pulmonary complications.[6]

Although some studies have evaluated PR in PTB, there is limited research on its long-term effects on patients with post-tuberculosis sequelae (PTS).[7] Regardless of significant progress towards the "End PTB Strategy" goal of a 90% treatment success rate, many PTB survivors still suffer from poor HRQoL.[8] PR has proven effective for other chronic lung diseases, including chronic obstructive pulmonary disease (COPD), but its long-term benefits for post-PTB lung disease are unknown.[9] This study aims to assess whether a multidisciplinary outpatient PR program, including unsupervised home exercise, can help PTB patients maintain respiratory function, exercise capacity, and QoL for at least one year after an 8-week PR program.

MATERIAL AND METHODS

This randomized controlled trial received ethical approval from the Institutional Ethics Committee, SMA & R and Sharda Hospital, Sharda University approved on 26 July 2021, (approval no: SU/SM&R/76-A/2021/91) and was registered with the Clinical Trials Registry of India (CTRI/2022/08/045006). The study design followed the CONSORT guidelines for reporting randomized controlled trials. All participants were screened for eligibility and provided with detailed information about the study protocol. Written informed consent was obtained from each participant in accordance with the ethical standards outlined in the Declaration of Helsinki (1964). To ensure full understanding and voluntary participation, participants were thoroughly briefed on the procedures before the commencement of the trial, with measures taken to address potential discomfort and foster informed engagement.

The study included PTB patients aged 18 years or older with exertional shortness of breath and limitations in daily activities; who had a documented history of smear-positive PTB, with pharmacological therapy completed at least six months before enrolment and no participation in physical activity or rehabilitation programs during that period.[10] Exclusion criteria encompassed asymptomatic individuals with a history of treated PTB, patients with a known history of multidrug-resistant TB to ensure homogeneity in disease severity, and those diagnosed with cardiovascular conditions such as myocardial infarction, angina, or congestive heart failure. Patients with coexisting respiratory diseases—including COPD, asthma, or interstitial lung disease—were also excluded. Additional exclusion criteria comprised individuals with medical, surgical, cognitive, psychological, or orthopedic impairments that could hinder participation in rehabilitation, as well as patients aged over 80 years.[11]

Sample Size Calculation

Software G*Power 3.1.9.2 (Franz F, Universitat Kiel, Kiel, Germany) was used to determine the sample size from a previous study conducted by Singh et al.,[12] using data on changes in the 6MWD. A total of ninety subjects were considered necessary, (forty-five in each group), which includes an additional 10% for dropouts, based on the effect size of 0.384, alpha level of 0.05, and power (1-beta) of 0.95.

Study Procedure

First, the therapist gathered records of the patient from the TB-DOT Centre. The patient records were analyzed, and patients were selected based on eligibility criteria derived from this analysis. Then, appointments were made at a clinic to gather data following the screening. Ninety stable patients with PTB who had finished their chemotherapy were drawn from the centers according to the inclusion criteria. The selected patients were briefed about the study. Those who declared their willingness to participate and filled out the written informed consent were included in the study. All the patients were randomly assigned in a 1:1 ratio using a computer-generated random number table and allocated into the experimental group and control group. All the outcome measures were assessed upon enrolment, on the last PR session, and at 12-month follow-up by a physiotherapist blinded to the intervention.

Patients who were allocated to the rehabilitation group had to complete a minimum of 24 sessions of an outpatient PR program over eight weeks (three sessions per week). The program was run at the outpatient TB-DOT Centers from March

Main Points

- Chronic respiratory impairments in post-pulmonary tuberculosis (post-PTB) patients are often neglected, despite their significant impact on quality of life (QoL), highlighting the need for long-term management strategies.
- An 8-week pulmonary rehabilitation (PR) program demonstrated measurable improvements in lung function, exercise capacity, and overall QoL in post-PTB patients.
- The positive outcomes of PR were sustained up to 12 months post-intervention, showcasing its potential for long-term efficacy and durability in managing post-TB respiratory issues.
- PR offers a feasible and affordable solution, making it an attractive addition to existing TB management strategies, particularly in resource-limited settings.
- The study underscores the importance of integrating PR into global TB care frameworks and calls for further research to optimize protocols, enhance accessibility, and address diverse patient populations.

2022 until July 2023. The complete exercise prescription for this PR program was implemented under the guidance of a licensed physiotherapist at the TB DOT hospital. The therapist also motivated the patients to continue all exercises at home. Moreover, all the patients were requested to contact the therapist in case of doubt regarding any exercise, and supervised follow-ups were conducted at regular intervals during the study, extending up to 12 months.

Immediately after the PR session, all the biomedical waste used in this study, such as gloves, masks, and tissue papers, were disposed of in the different colored dustbins available at the study site. Waste handlers were provided with masks and gloves, which prevent their exposure to infectious agents.

Various measures were taken to improve the adherence rate of the program, such as daily telephone calls to patients and their attendants to report to the center so that they would not skip the PR session. Transportation was also arranged for those having difficulty traveling to the center. Since patients with PTB often feel isolated because of social stigma, therefore we made a "buddy" scheme in which new patients were paired with patients who have previously completed the PR program so they get social support and enthusiasm to continue the program.[13] Another barrier was a lack of motivation, therefore, we regularly encouraged patients not to discontinue the PR program by explaining its various benefits with no side effects. Lastly, we rescheduled the sessions for the patients who skipped them due to unavoidable reasons.

Assessment

One week before baseline testing, all participants were informed about the research procedures and potential risks. Each participant underwent a primary health examination before the initial testing. The baseline testing took place over two days. On day one, participants completed the Saint George Respiratory Questionnaire (SGRQ), a generic HRQoL assessment, followed by a dyspnea assessment using the Borg Dyspnea Scale (0-10). On day two, participants underwent a pulmonary function test (PFT) in accordance with the guidelines of the ATS/ERS. This included measurements of forced vital capacity (FVC), forced expiratory volume in the first second (FEV_1), and the FEV_1/FVC ratio. Following ATS/ERS guidelines, blood pressure, heart rate, oxygen saturation (SpO_2), and dyspnea were recorded before and after the 6-minute walk distance (6MWD). Participants were instructed to walk at their own pace, aiming to cover the maximum distance possible in six minutes. The total distance covered was recorded in meters and as a percentage, and the Enright[14] equation was used to estimate the predicted 6MWD for both males and females.

After the baseline testing, participants were randomly assigned to either the PR group or the control group. Those in the control group received maximal medical care and were instructed to continue their usual routines for eight weeks. All measurements were taken at enrollment, 8 weeks after completing the PR program, and 12 months after the start of the study (Figure 1).

Pulmonary Rehabilitation Intervention

The PR sessions were customized for each patient based on their performance during the initial assessment. These sessions included supervised endurance and resistance training, stretching of the upper and lower extremity muscles, self-management, patient education, and static circuit training to improve peripheral muscle strength and general mobility with breathing exercises. Each session consists of 30 minutes of breathing exercises.[15]

Ground walking was used as part of the endurance workout regimen. The walking prescription primarily reflects everyday activities. It is practical, easy to use, affordable, and widely applicable.[16] According to Chandrasekaran and Reddy[17] (2018), the distance traveled during 6MWD was used to determine the walk speed or training intensity. For the majority of individuals, a baseline walking speed was established, starting at 80% to 90% of the true 6MWD pace. A walk of 15 to 20 minutes was recommended. The walk duration was divided into normal ranges, known as interval training (5-6 or 6-8 minutes), if the patient's disability was significant. The maximum distance that may be walked in 20 minutes, measured in meters '20MWD', equals the actual 6MWD multiplied by 3.33 m.

The recommended walking program involved walking for 20 minutes, twice a day, for 8 weeks. On three weekdays, participants followed the training under the supervision of a physical therapist, while on weekends, they were instructed to walk independently. To promote good posture proper body mechanics, prevent muscle and joint injuries, and enhance respiratory function, stretching exercises were also incorporated. The first and last five minutes of each session were dedicated to stretching and flexibility exercises. Initially, patients were taught how to perform these stretches, and later, they carried out the stretches on their own. Each of the four or five different stretches (such as hamstring stretch, quadriceps stretch, pectoralis major stretch, and overhead reach) was held for 15 to 30 seconds.[18,19]

Participants engaged in resistance training for both the upper and lower extremities three times a week. The lower body exercises target muscles such as the quadriceps, hamstrings, hip flexors, hip abductors, and hip extensors. These exercises were performed in both sitting and standing positions, using ankle weights for added resistance. For the upper body, exercises using free weights focused on the biceps, triceps, and deltoids, while resistance bands were used for the pectoral muscles. Participants were instructed to complete 15 to 20 repetitions per exercise, with resistance adjusted based on their capacity. Progression was determined by each participant's ability to tolerate the given load. If they could manage the load, the number of sets was increased from 1 set to 2 sets and then to 3 sets as they adapted. Exercise intensity was closely monitored by asking participants to rate their level of dyspnoea on the Borg scale (0-10).[20,21]

Each session concluded with an educational component focused on improving patient adherence, mood, and disease understanding. The intervention group received a structured

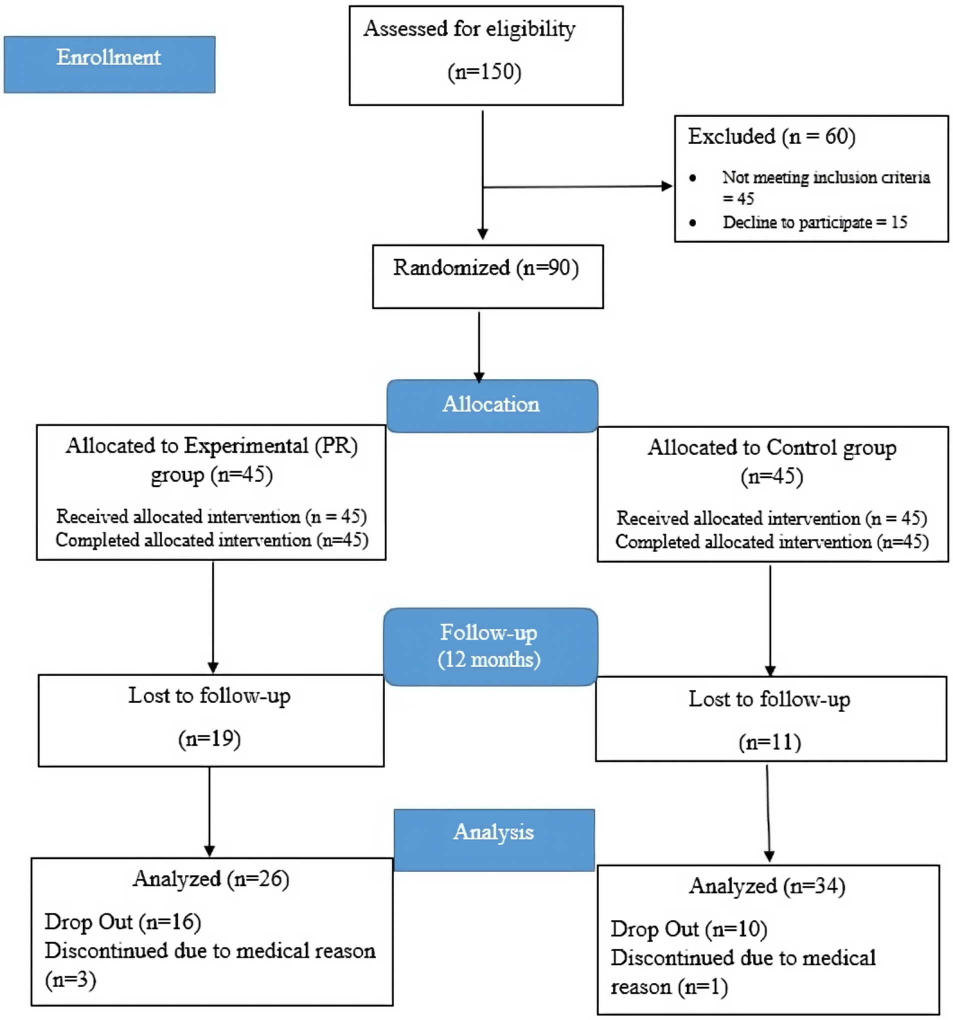

Figure 1. Depicts the study flowchart as per CONSORT guidelines

PR: pulmonary rehabilitation

program on self-management, including information about lung anatomy and physiology, the impact of PTB on the lungs, and chronic lung disease pathophysiology. They were also taught how to manage stress, prevent risk factors, recognize and treat exacerbations, control shortness of breath, conserve energy during daily tasks, and use medical devices effectively.[22] Additionally, patients were educated on secretion clearance, the benefits of physical activity, and essential dietary measures.[23]

The control group continued their routine daily activities and did not receive any form of structured exercise training or educational intervention during the study period.[24] Wherever practicable, standard care and spirometry were utilized to check for airway illnesses: practitioner-administered antibiotic therapy for infectious exacerbations (where appropriate), and verbal encouragement to give up smoking and limit exposure to biomass smoke. If necessary, medical care as prescribed by a qualified practitioner should be administered.

Adherence was measured as the ratio of attended to prescribed sessions or follow-ups. No adverse effects related to the exercise training were noted during the program. Reasons for lack of adherence included lack of motivation, excessive focus on respiratory symptoms, insufficient family support, non-medical reasons such as holidays or family obligations, financial difficulties, relocation, or a belief that their condition was too mild to benefit from PR.

Statistical Analysis

The data were analyzed using Statistical Package for the Social Sciences (SPSS) (IBM SPSS Statistics for Windows, version 23.0). The baseline characteristic is indicated as mean±standard deviation (SD) for the PR group and is indicated as mean±SD for the control group. The normality of the data was assessed using the Shapiro-Wilk test, skewness, and histograms. The outcome variables between groups were compared at baseline and four weeks later using an independent t-test. A 2x3 repeated measures ANOVA was used to evaluate the main effects of time, group, and their interaction, with Bonferroni pairwise corrections applied for post hoc analysis when significant effects were found. When baseline differences in outcome measures existed between groups, a 2x3 repeated measures ANCOVA was used, with baseline values as covariates. The significance level was set at $P \leq 0.05$, with a 95% confidence interval.

RESULTS

As shown in Table 1, there were no significant differences in baseline demographic characteristics between the PR and control groups. However, at baseline, the PFT and SGRQ scores differed significantly between the groups, while the 6MWD and Borg scores did not, as shown in Table 1. The t-test analysis reveals significant improvements in 6MWD in the experimental group after 24 sessions of PR and at 12-month follow-up, with large effect sizes, $P = 0.002$. Repeated measures ANOVA confirms significant group, time, and interaction effects, with post hoc comparisons showing 88.89% improvement in 6MWD after PR, and 58.33% improvement at 12-month follow-up, respectively as shown in Tables 2, 3. The experimental intervention significantly improved Borg scores compared to the control group, with large effect sizes and a low P value ($P = 0.002$) at both post-treatment and follow-up. Repeated measures ANOVA showed significant group, time, and interaction effects, with post hoc comparisons revealing a 4-point reduction in Borg after 24 sessions and a 3-point reduction at 12 months, follow-up as shown in Tables 4, 5.

SGRQ scores significantly differed between groups after 24 sessions of PR ($P = 0.002$) and at 12-month follow-up ($P = 0.002$). Repeated measures ANOVA revealed significant group, time, and interaction effects, with post hoc comparisons showing significant differences between pre-intervention and

Table 1. Baseline clinical and demographic features of the subject (n = 90)

Variables	PR group (n = 45) Mean±SD	Control group (n = 45) Mean±SD	*P* value
Age	35.20±11.66	35.04±7.74	0.955
Height	163.76±6.591	157.92±7.28	0.005*
Weight	65.07±6.59	63.19±9.69	0.431
BMI	24.29±4.26	25.35±2.60	0.293
6MWD (m)	243.84±59.74	255.28±68.31	0.532
6MWD (%)	38.34±10.28	41.12±12.65	0.398
6MWD, RHR (bpm)	81.95±9.36	76.3±11.4	0.48
PFT FEV_1 L	1.19±0.44	1.24±0.31	0.670
FEV_1 (%)	24.80±7.18	35.32±10.89	<0.001*
FVC (L)	1.88±0.496	1.48±0.348	0.002*
FVC (%)	23.76±8.60	34.64±12.93	0.001*
FEV_1/FVC	39.64±19.30	32.80±11.59	0.135
Borg	8.64±0.90	8.72±0.678	0.726
SGRQ Impact	78.32±9.62	75.32±9.84	0.281
Activity	72.12±10.80	75.53±6.50	0.183
Symptom	86.48±7.98	81.68±8.73	0.048*
Total	74.72±11.62	82.20±9.20	0.015*

Except as otherwise noted, in terms of values, mean standard deviation is used. Level of importance PFT, PR, and BMI are abbreviations for pulmonary function testing and body mass index, respectively. $*P < 0.05$, statistically significant.
SD: standard deviation, PFT: pulmonary function test, PR: pulmonary rehabilitation, BMI: body mass index, FVC: stands for forced vital capacity, FEV_1: forced expiratory volume in one second, SGRQ: Saint George Respiratory Questionnaire, 6MWD: 6-minute walk distance

Table 2. Comparison of exercise capacity (6MWD) in two groups after 24 sessions of PR and at 12-month follow-up

Outcome measures	Experimental group	Control group	t-value	Effect size	Mean difference	95% of CI of difference	*P* value
6MWD (m)							
After 24 session	460.60±62.33	209.44±73.46	13.03	3.68	251.16	212.41 to 289.9	<0.001*
12-month follow-up	386.08±64.51	174.72±66.11	11.44	3.23	211.36	174.21 to 248.5	<0.001*
6MWD (%)							
After 24 sessions	71.89±11.92	33.50±12.09	11.3	3.19	38.39	31.56 to 45.22	<0.001*
12-month follow-up	59.80±12.59	27.68±10.70	9.71	2.74	32.12	25.47 to 38.76	<0.001*

$*P < 0.05$, statistically significant.
6MWD (m): 6-minute walk distance in meters, 6MWD (%): 6-minute walk distance in percentage predicted, PR: pulmonary rehabilitation, CI: confidence interval

post-treatment (P = 0.002) and pre-intervention and follow-up (P = 0.002), but no difference between post-treatment and follow-up (P = 0.199), as shown in Tables 6, 7. The experimental group showed a 46-unit decline after 24 sessions and a 42-unit decline after 12 months, compared to pre-intervention. FEV_1 (L) and FEV_1 (%) showed significant improvements in the experimental group after 24 PR sessions and at 12-month follow-up, with effect sizes indicating moderate to large effects. Repeated measures ANOVA confirmed significant group, time, and interaction effects, with a 41.1% increase in FEV_1 (L) after

Table 3. Comparison of ANOVA results of exercise capacity (6MWD) in both the groups

Outcome measure	Experimental group	Control group	Pairwise comparison					
			Group effect		Time effect		GxT interaction	
			ηp² (P value)	F value	ηp² (P value)	F value	ηp² (P value)	F value
6MWD (m)								
12-month follow-up	386.0±64.5	174.7±66.1	0.000	89.18	0.000	53.2	0.000	142.24
6MWD (%)								
12-month follow-up	59.8±12.5	27.6±10.7	0.000	60.15	0.000	45.8	0.000	128.03

6MWD (m): 6-minute walk distance in meters, 6MWD (%): 6-minute walk distance in percentage predicted, sizes (ηp)²: partial eta square, F value: f test statistic

Table 4. Comparison of breathlessness (Borg) in both the groups after 24 sessions of PR and at 12-month follow-up

Outcome measures	Experimental group	Control group	t-value	Effect size	Mean difference	95% of CI of difference	P value
After 24 sessions	4.40±0.957	8.80±0.764	17.96	5.11	-4.4	-4.89 to -3.9	<0.001*
12-month follow-up	4.92±0.997	9.52±0.586	19.89	5.66	-4.6	-5.06 to -4.1	<0.001*

*P < 0.05, statistically significant.
PR: pulmonary rehabilitation, CI: confidence interval

Table 5. Comparison of ANOVA results Borg dyspnoea scale scores in both groups

Outcome measure	Experimental group	Control group	Pairwise comparison					
			Group effect		Time effect		GxT interaction	
			ηp² (P value)	F value	ηp² (P value)	F value	ηp² (P value)	F value
12-month follow-up	4.92±0.997	9.52±0.586	0.000	343.7	0.000	107.529	0.000	153.7

Sizes (ηp)²: partial eta square, F value: f test statistic

Table 6. Comparison of HRQoL (SGRQ) in both the groups after 24 PR sessions and at 12-month follow-up

Outcome measures	Experimental group	Control group	t-value	Effect size	Mean difference	95% of CI of difference	P value
SGRQ Impact							
After 24 sessions of PR	27.24±7.54	76.64±7.07	23.877	6.758	-49.40	-53.56 to - 45.24	<0.001*
12-month follow-up	41.92±16.91	95.80±2.29	15.779	4.465	-53.88	-60.74 to - 47.01	<0.001*
SGRQ activity							
After 24 sessions of PR	39.77±11.95	76.40±6.09	13.643	3.862	-36.62	-42.02 to -31.22	<0.001*
12-month follow-up	55.37±14.02	78.00±6.87	7.241	2.049	-22.62	-28.90 to16.34	<0.001*
SGRQ symptom							
After 24 sessions of PR	27.56±6.23	82.08±8.14	26.561	7.521	-54.52	-58.6 to -50.3	<0.001*
12-month follow-up	51.64±6.95	84.92±9.09	14.535	4.113	-33.28	-37.88 to 28.67	<0.001*
SGRQ total							
After 24 sessions of PR	28.36±11.57	84.96±10.10	18.417	5.211	-56.60	-62.7 to -50.4	<0.001*
12-month follow-up	32.40±12.69	86.88±8.33	17.935	5.075	-54.48	-60.58 to 48.37	<0.001*

*P < 0.05, statistically significant.
HRQoL: health-related quality of life, SGRQ: Saint George's Respiratory Questionnaire, CI: confidence interval

24 sessions and a 45% increase at follow-up. FVC (L) showed significant differences between the groups after 24 PR sessions (*P* = 0.002) and at 12-month follow-up (*P* = 0.002). However, post hoc comparisons revealed no significant changes in FVC (L) after 12 months, despite a 4.78% increase after 24 sessions. FVC% showed a significant time effect, with no improvement in the experimental group after 24 sessions or 12 months, although significant changes were observed at follow-up compared to pre-intervention, as shown in Tables 8, 9.

DISCUSSION

This is the first study to show the long-term benefits of a 24-session outpatient PR program for patients with post-PTB at a 1-year follow-up. The experimental group demonstrated significant improvements in 6MWD after 24 PR sessions (>217 m, >33.5% predicted) and at one-year follow-up (>143 m, 21.5% predicted). This result confirms the observations of previous investigations conducted by other researchers. They concluded that after a complete rehabilitation program, the benefits are maintained for approximately 1 year, as evidenced

Table 7. Comparison of ANOVA results of health-related QoL (SGRQ) scores in both groups

Outcome measures	Experimental group	Control group	Pairwise comparison					
			Group effect		Time effect		GxT interaction	
			ηp^2 (*P* value)	F value	ηp^2 (*P* value)	F value	ηp^2 (*P* value)	F value
SGRQ (impact)								
12-month follow-up	41.92±16.91	95.80±2.29	0.000	331.5	0.000	96.27	0.000	149.12
SGRQ (activity)								
12-month follow-up	55.37±14.02	78.00±6.87	0.000	122.16	0.000	39.37	0.000	44.07
SGRQ (symptom)								
12-month follow-up	51.64±6.95	84.92±9.09	0.000	113.3	0.000	12.61	0.000	366.59
SGRQ (total)								
12-month follow-up	32.40±12.69	86.88±8.33	0.000	407.05	0.000	16.32	0.000	183.83

SGRQ: Saint George's Respiratory Questionnaire, effect sizes (ηp^2): Partial eta square, F value: f test statistic

Table 8. Comparison of forced expiratory volume in one second PFT after 24 sessions of PR and at 12-month follow-up in both the groups

Outcome measures	Experimental group	Control group	t-value	Effect size	Mean difference	95% of CI of difference	*P* value
FEV_1 (L)							
After 24 sessions	1.68±0.423	1.07±0.336	5.590	1.596	0.604	0.38 to 0.82	<0.001*
12-month follow-up	1.45±0.457	1.00±0.377	3.776	1.074	0.448	0.20 to 0.68	<0.001*
FEV_1 (%)							
After 24 sessions	27.08±8.81	34.36±11.75	2.478	0.701	-7.280	-13.18 to 1.37	0.017*
12-month follow-up	24.48±7.12	31.00±6.67	3.340	0.945	-6.520	-10.4 to 2.59	0.002*
FVC (L)							
After 24 sessions	1.97±0.520	1.25±304	6.030	1.690	0.727	0.48 to 0.96	0.000*
12-month follow-up	1.86±0.50	1.48±34	3.149	0.888	0.384	0.13 to 0.63	0.003
FVC (%)							
After 24 sessions	22.52±11.74	32.16±10.87	3.012	0.853	-9.640	-16.07 to -3.20	0.004*
12-month follow-up	21.32±8.43	28.56±9.0	2.936	0.830	-7.240	-12.19 to -2.28	0.005
FEV_1/FVC (%)							
After 24 sessions	40.96±17.20	31.28±9.96	2.434	0.688	9.680	1.68 to17.67	0.019*
12-month follow-up	40.12±14.19	29.60±9.02	3.127	0.884	10.520	3.75 to 17.28	0.003*

**P* < 0.05, statistically significant.
FEV_1 (L): forced expiratory volume in one second in liters, FEV_1 (%): forced expiratory volume in one second in percentage predicted, 95% CI: 95% confidence interval, FVC (L): forced vital capacity in (liters), FVC (%): forced vital capacity in percentage predicted, FEV_1/FVC: ratio of forced expiratory volume in one second to forced vital capacity, CI: confidence interval, PFT: pulmonary function test, PR: pulmonary rehabilitation

Table 9. Comparison of ANOVA results of pulmonary function test scores in both groups

Outcome measures	Experimental group	Control group	Pairwise comparison					
			Group effect		Time effect		GxT interaction	
			ηp² (*P* value)	F value	ηp² (*P* value)	F value	ηp² (*P* value)	F value
FEV_1 (L)								
12-month follow-up	1.45±0.45	1.00±0.37	0.001	13.22	0.009	5.365	0.000	18.93
FEV_1 (%)								
12-month follow-up	24.48±7.12	31.00±6.67	0.002	11.21	0.002	0.007	0.574	0.509
FVC (L)								
12-month follow-up	1.86±0.502	1.48±0.345	0.000	21.71	0.036	6.84	0.000	23.85
FVC (%)								
12-month follow-up	21.32±8.43	28.56±9.0	0.090	26.05	0.000	3.005	0.097	2.68
FEV_1/FVC								
12-month follow-up	40.12±14.19	29.60±9.02	0.020	364.42	0.409	0.855	0.255	1.384

Exp group: experimental group, FVC (L): forced vital capacity in liters, FVC (%): forced vital capacity percentage predicted, effect sizes ηp²: partial eta square, F value: f test statistic, FEV_1 (L): forced expiratory volume in one second in liters, FEV_1 (%): forced expiratory volume in one second in percentage predicted

by many clinical trials; therefore, these patients should always be reinstated in rehabilitation programs.[25] Post-PTB patients often experience muscle weakness due to inactivity, systemic inflammation, and poor nutrition, exacerbated by poverty, creating a vicious cycle of weight loss, increased morbidity, and higher mortality. PR helps break this cycle, improving activity capacity and overall health. Another factor contributing to improving functional capacity is a reduction in ventilation demand and blood lactic acid levels, which enhances muscle aerobic metabolism and, consequently, reduces muscle fatigue.[26]

Consistent with previous research, baseline SGRQ scores in PTB patients were elevated, indicating a decline in QoL. After 8 weeks of PR, significant improvements were observed: symptom score decreased by 27, activity score decreased by 39, impact score decreased by 27, and total score decreased by 28. At the 12-month follow-up, the scores were 51 (symptom), 41 (impact), 55 (activity), and 32 (total). These improvements exceeded the MCID value (13.5 U), indicating a meaningful enhancement in QoL. This suggests that rehabilitation, by increasing maximum oxygen consumption and work capacity, led to improved functional capacity and QoL over the long term.[27]

Similar to Withers et al.,[28] this study found that a multimodal PR program significantly reduced anxiety symptoms. Multi-component programs combining exercise and education effectively decrease anxiety severity. Exercise alone or in combination with stress management and education, helped patients experience less breathlessness, increased motivation, and reduced fear and sadness related to dyspnea. These improvements were reflected in significant gains in SGRQ scores. Cognitive-behavioral theories suggest that exercise may disrupt the link between physical symptoms and anxiety, acting as a form of exposure treatment.

Improvements in HRQoL in patients undergoing PR may be linked to reductions in dyspnoea, improved breathing patterns, and increased capacity for daily activities. Exercise during PR may also alleviate symptoms of depression and anxiety through biological mechanisms such as altered central monoamine function, enhanced hypothalamic-pituitary-adrenal axis regulation, improved endogenous opioid release, and reduced systemic inflammation.[29] After 24 sessions of PR, dyspnoea, as measured on the Borg scale, decreased significantly from 8.64 to 4.40 points, after 12 months. This reduction in exertion-induced dyspnoea suggests a substantial improvement in the patient's condition. Enhanced breathing mechanics, reduced ventilatory demand, and better ventilatory muscle performance, along with psychological benefits, likely contribute to this improvement in dyspnoea and overall HRQoL.

The experimental group showed an improvement of 41% improvement in FEV1 after 24 sessions of PR and an improvement of 45% improvement after 12 months, indicating significant gains in lung function at both the end of the program and during follow-up. After 12 months, while the intervention group's FVC values did not improve, the PR group saw a 4.78% increase in FVC. Notably, the PR group exhibited lower baseline FEV_1 and FVC values compared to controls, suggesting more advanced post-tuberculosis pulmonary impairment—potentially due to greater fibrotic damage or unresolved sequelae. This baseline disparity may have contributed to the magnitude of improvement observed. Alternatively, it could indicate heterogeneity in disease phenotype, underscoring the need for stratified analyses in future studies to better interpret treatment effects.

Additionally, the intervention group experienced a 3.3% increase in FEV_1/FVC after 24 sessions and a 1.2% increase at 12 months. PTB can lead to persistent airflow obstruction and limited ventilation due to fibrotic scarring, which may worsen with delayed diagnosis, severe disease, or prolonged treatments. These changes in lung mechanics and gas exchange can hinder daily activities, reduce exercise capacity, and lower QoL. Our findings highlight the importance of PR interventions to mitigate the long-term effects of PTB on lung function.

This study has several limitations. Patient motivation and incomplete contact information contributed to challenges in data collection. Key measures, such as arterial blood gases, DLCO, airway resistance, and radiographic surveillance [chest radiography and computed tomography (CT)], were not assessed as they were outside the study's primary objectives. Additionally, radiological assessments such as chest X-rays or CT scans were not incorporated into the study protocol. This limits the ability to correlate functional improvements with structural changes in the lung parenchyma. Future studies should include imaging-based classification to better understand the impact of PR in patients with varying extents of radiological sequelae. Attrition, particularly in the control group due to scheduling conflicts and missed appointments, introduced potential bias. Additionally, incomplete data on smoking habits and co-morbidities hindered the evaluation of their impact on lung function, and the single-site design limits the generalizability of the findings. Future studies should address these limitations by offering incentives to reduce dropout rates, conducting multi-site research, and collecting more comprehensive data on smoking and other relevant factors.

Despite these limitations, this study is the first of its kind to evaluate the long-term response to PR among post-treatment PTB sequelae. We believe that our findings make a significant contribution to the field despite the existence of published research on the short-term effects of PR for this particular set of participants. Furthermore, post-PTB complications have not been studied as extensively as COPD; hence there are no PR guidelines for PTB patients. This study's findings could be utilized to develop recommendations, for when these individuals should start receiving physical therapy as part of a tailored treatment plan.

Post-PTB patients often face long-term deficits in lung function, exercise capacity, and QoL, even after completing therapy, underscoring the need for further research into the underlying causes and whether these issues resolve over time. The absence of long-term follow-up data and clear post-PTB PR guidelines highlights the importance of a comprehensive approach to care beyond microbiological cure. Future studies should track patients after rehabilitation to assess sustained benefits and recurrence rates. Comparing different PR programs (e.g., duration, intensity, specific interventions) could identify optimal strategies for improving long-term outcomes. Additionally, integrating other healthcare disciplines, exploring telerehabilitation for remote areas, and evaluating the cost-effectiveness of PR will be key to enhancing care. Collaboration across research, clinical, and public health sectors is essential to translate findings into clinical practice and promote the widespread adoption of evidence-based rehabilitation.

CONCLUSION

The results of this study indicate the significant benefits of PR for patients with PTB, demonstrating improvements in functional capacity, QoL, and dyspnea after 24 sessions. Notably, these gains were sustained at the 12-month follow-up, underscoring the long-term effectiveness of structured rehabilitation programs. The findings provide strong evidence for incorporating PR into the comprehensive management of PTB, offering the potential for enhanced health outcomes and QoL in these patients.

Ethics

Ethics Committee Approval: This randomized controlled trial received ethical approval from the Institutional Ethics Committee, SMA & R and Sharda Hospital, Sharda University approved on 26 July 2021, (approval no: SU/SM&R/76-A/2021/91) and was registered with the Clinical Trials Registry of India (CTRI/2022/08/045006).

Informed Consent: Written informed consent was obtained from each participant in accordance with the ethical standards outlined in the Declaration of Helsinki (1964).

Clinical Trial Registry: CTRI/2022/08/045006.

Footnotes

Authorship Contributions

Concept: A.S., Design: A.M., Data Collection or Processing: M.O., R.K., Analysis or Interpretation: R.K., Literature Search: M.O., M.J., I.A., Writing: M.O., M.J., I.A.

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REFERENCES

1. Lu W, Zhu L, Liu Q, et al. Progress in epidemiology of tuberculosis in China. In: Ye DQ, ed. Progress in China Epidemiology: Volume 1. *Springer Nature*; 2022:151-186. **[Crossref]**
2. Dheda K, Perumal T, Moultrie H, et al. The intersecting pandemics of tuberculosis and COVID-19: population-level and patient-level impact, clinical presentation, and corrective interventions. *Lancet Respir Med*. 2022;10(6):603-622. **[Crossref]**
3. Mademilov M, Mirzalieva G, Yusuf ZK, et al. What should pulmonary rehabilitation look like for people living with post-tuberculosis lung disease in the Bishkek and Chui region of the Kyrgyz Republic? A qualitative exploration. *BMJ Open*. 2022;12(2):e053085. **[Crossref]**
4. Guo N, Marra F, Marra CA. Measuring health-related quality of life in tuberculosis: a systematic review. *Health Qual Life Outcomes*. 2009;7(1):14. **[Crossref]**
5. Spruit MA, Singh SJ, Garvey C, et al. An official American Thoracic Society/European Respiratory Society Statement: Key Concepts

and Advances in Pulmonary Rehabilitation. *Am J Respir Crit Care Med*. 2013;188(8):e13-e64. **[Crossref]**

6. Adane AA, Alene KA, Koye DN, Zeleke BM. Non-adherence to anti-tuberculosis treatment and determinant factors among patients with tuberculosis in northwest Ethiopia. *PLoS One*. 2013;8(11):e78791. **[Crossref]**
7. Ruta V, Alexescu T, Tarmure S, et al. Physical exercise - the friend or the enemy of the patient with pulmonary tuberculosis? *J Mind Med Sci*. 2019;6(1):11-18. **[Crossref]**
8. Maguire GP, Anstey NM, Ardian M, et al. Pulmonary tuberculosis, impaired lung function, disability and quality of life in a high-burden setting. *Int J Tuberc Lung Dis*. 2009;13(12):1500-1506. **[Crossref]**
9. van Kampen SC, Wanner A, Edwards M, et al. International research and guidelines on post-tuberculosis chronic lung disorders: a systematic scoping review. *BMJ Glob Health*. 2018;3(4):e000745. **[Crossref]**
10. Muñoz-Torrico M, Rendon A, Centis R, et al. Is there a rationale for pulmonary rehabilitation following successful chemotherapy for tuberculosis? *J Bras Pneumol*. 2016;42(5):374-385. **[Crossref]**
11. Ries AL, Bauldoff GS, Carlin BW, et al. Pulmonary rehabilitation: joint ACCP/AACVPR evidence-based clinical practice guidelines. *Chest*. 2007;131(5 Suppl):4-42. **[Crossref]**
12. Singh SK, Naaraayan A, Acharya P, Menon B, Bansal V, Jesmajian S. Pulmonary rehabilitation in patients with chronic lung impairment from pulmonary tuberculosis. *Cureus*. 2018;10(11):e3664. **[Crossref]**
13. Hayton C, Clark A, Olive S, et al. Barriers to pulmonary rehabilitation: characteristics that predict patient attendance and adherence. *Respir Med*. 2013;107(3):401-407. **[Crossref]**
14. Enright PL. The six-minute walk test. *Respir Care*. 2003;48(8):783-785. **[Crossref]**
15. Gosselink R. Controlled breathing and dyspnea in patients with chronic obstructive pulmonary disease (COPD). *J Rehabil Res Dev*. 2003;40(Suppl 2):25-33. **[Crossref]**
16. Leung RW, Alison JA, McKeough ZJ, Peters MJ. Ground walk training improves functional exercise capacity more than cycle training in people with chronic obstructive pulmonary disease (COPD): a randomised trial. *J Physiother*. 2010;56(2):105-112. **[Crossref]**
17. Chandrasekaran B, Reddy KC. Six-minute walk test as a guide for walking prescription for patients with chronic obstructive pulmonary diseases. *Indian J Respir Care*. 2022;7(2):73-76. **[Crossref]**
18. Carrieri-Kohlman V, Donesky-Cuenco D, Park SK, Mackin L, Nguyen HQ, Paul SM. Additional evidence for the affective dimension of dyspnea in patients with COPD. *Res Nurs Health*. 2010;33(1):4-19. **[Crossref]**
19. Williams JG, Laudner KG, McLoda T. The acute effects of two passive stretch maneuvers on pectoralis minor length and scapular kinematics among collegiate swimmers. *Int J Sports Phys Ther*. 2013;8(1):25-33. **[Crossref]**
20. O'Shea SD, Taylor NF, Paratz JD. Progressive resistance exercise improves muscle strength and may improve elements of performance of daily activities for people with COPD: a systematic review. *Chest*. 2009;136(5):1269-1283. **[Crossref]**
21. Houchen L, Steiner MC, Singh SJ. How sustainable is strength training in chronic obstructive pulmonary disease? *Physiotherapy*. 2009;95(1):1-7. **[Crossref]**
22. Awaisu A, Nik Mohamed MH, Mohamad Noordin N, et al. The SCIDOTS Project: evidence of benefits of an integrated tobacco cessation intervention in tuberculosis care on treatment outcomes. *Subst Abuse Treat Prev Policy*. 2011;6:26. **[Crossref]**
23. Bourbeau J, Nault D, Dang-Tan T. Self-management and behaviour modification in COPD. *Patient Educ Couns*. 2004;52(3):271-277. **[Crossref]**
24. Orooj M, Moiz JA, Mujaddadi A, Ali MS, Talwar D. Effect of pulmonary rehabilitation in patients with asthma COPD overlap syndrome: a randomized control trial. *Oman Med J*. 2020;35(3):e136. **[Crossref]**
25. Perez-Bogerd S, Wuyts W, Barbier V, et al. Short and long-term effects of pulmonary rehabilitation in interstitial lung diseases: a randomised controlled trial. *Respir Res*. 2018;19(1):182. **[Crossref]**
26. Wilches EC, Rivera JA, Mosquera R, Loaiza L, Obando L. Pulmonary rehabilitation in multi-drug resistant tuberculosis (TB MDR): a case report. *Colomb Med*. 2009;40(4):436-441. **[Crossref]**
27. Pasipanodya JG, Miller TL, Vecino M, et al. Pulmonary impairment after tuberculosis. *Chest*. 2007;131(6):1817-1824. **[Crossref]**
28. Withers NJ, Rudkin ST, White RJ. Anxiety and depression in severe chronic obstructive pulmonary disease: the effects of pulmonary rehabilitation. *J Cardpulm Rehabil*. 1999;19(6):362-365. **[Crossref]**
29. Hately J, Laurence V, Scott A, Baker R, Thomas P. Breathlessness clinics within specialist palliative care settings can improve the quality of life and functional capacity of patients with lung cancer. *Palliat Med*. 2003;17(5):410-417. **[Crossref]**