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Pulmonary Tuberculosis Rehabilitation: Evidence-Based Physiotherapy and Technological Advancements for Sustainable Development Goal Achievement, a Narrative Review

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ABSTRACT

Pulmonary tuberculosis (PTB) remains a leading cause of global morbidity and mortality, with over 10 million new cases annually and 155 million survivors worldwide. Many TB survivors suffer from post-TB lung disease (PTLD), including chronic airflow obstruction, fibrosis, and bronchiectasis, leading to persistent respiratory symptoms and reduced quality of life. This review summarizes the evidence-based physiotherapy interventions and technological advancements in pulmonary rehabilitation (PR) for TB survivors, and highlights their potential contribution to Sustainable Development Goal (SDG) 3 (Good Health and Well-being) by improving lung function, physical capacity, and overall health outcomes. A comprehensive review of recent studies (2015–2025) was conducted, encompassing randomized controlled trials, quasi-experimental studies, and pilot programs investigating PR interventions and technology-assisted rehabilitation for PTLD. Evidence supports the effectiveness of airway clearance techniques (e.g. postural drainage, percussion, breathing exercises), exercise training (aerobic and resistance), and multicomponent PR programs in improving lung function (FEV_1, FVC), exercise tolerance (6-minute walk distance), and quality of life. Technological innovations such as wearables, AI-based monitoring, and virtual reality (VR) platforms enhance remote supervision, adherence, and engagement. AI algorithms show promise in predicting rehabilitation response, personalizing training, and detecting early deterioration, while telerehabilitation platforms facilitate access to PR in low-resource settings. Evidence-based physiotherapy interventions, supported by technological advancements, offer effective rehabilitation strategies for TB survivors with PTLD. Integration of wearable sensors, AI, and VR into PR programs can improve adherence, exercise capacity, and health outcomes, contributing to SDG 3 by promoting inclusive, equitable health services.

INTRODUCTION

Pulmonary tuberculosis (PTB) causes long-term lung damage and disability even after microbiological cure. Globally, over 10 million people fell ill with TB in 2023 (with ~1.25 million deaths), and an estimated 155 million TB survivors are alive today [1]. Many of these survivors develop post-TB lung disease (PTLD), chronic airflow obstruction, fibrosis, bronchiectasis or pulmonary dysfunction, leading to persistent symptoms in up to half of patients [2]. The World Health Organization (WHO) recognizes rehabilitation as an essential health service for people with TB-associated disability [1]. Yet guidelines and resources for TB rehabilitation remain limited [2]. This review summarizes evidence-based physiotherapy and technology-driven rehabilitation strategies for PTB, and how these approaches support SDG 3 (Good Health and Well-being) and related targets. This narrative review utilized a comprehensive search strategy to identify relevant studies published up to May 2025. The search was conducted across multiple electronic databases, including PubMed, Cochrane Library, Physiotherapy Evidence

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Database(PEDRO), Google Scholar, Scopus, and Web of Science. The following keywords and Medical Subject Headings(MeSH)terms were used in various combinations: "Pulmonary tuberculosis" OR "PTB", "Chest physiotherapy" OR "airway clearance techniques", "Technology AND Chest Physiotherapy", "Tele rehabilitation" AND" Chest Physiotherapy" and "Wearables" OR "AI" AND "pulmonary rehabilitation". Articles were included if they: Examined chest physiotherapy or cervicothoracic/ribcage mobilization in patients with pulmonary tuberculosis, were published in English and included randomized controlled trials, cohort studies, case series, or relevant narrative reviews. Articles were excluded if they focused on non-pulmonary tuberculosis, pharmacological interventions without a physiotherapy component, or were conference abstracts without full-text availability. Additional articles were identified through a manual search of reference lists from the included studies. The selected articles were analyzed for key outcomes such as improvement in pulmonary function, reduction in symptoms, quality of life, and adherence to therapy.

Airway Clearance and Breathing Exercises

Chest physiotherapy (postural drainage, percussion, breathing techniques) is often used to clear sputum and improve ventilation. For example, rehabilitation programs for TB sequelae include hypertonic saline nebulization plus physiotherapy to loosen secretions[3].

Exercise Training and Muscle Strengthening

Aerobic and strength exercises (walking, cycling, resistance training) improve lung mechanics and muscle function. Studies report that structured exercise regimens increase exercise tolerance and muscle strength in TB survivors [4]. In one review, TB patients completing exercise programs had significantly better dyspnea scores, longer 6-minute walk distance (6MWD) and higher quality-of-life (QoL) scores than controls [5]. Exercise training can also enhance metabolic recovery – for example, improving muscle mass in malnourished TB patients may aid drug absorption and recovery[6].

Pulmonary Rehabilitation Packages

Comprehensive rehab includes aerobic training, strength training, breathing exercises, and education. Multicomponent programs (modelled on COPD rehab) have been applied to PTLD. For instance, a 6–12-week pulmonary rehabilitation program (supervised exercise plus airway clearance techniques and education) showed clear benefits[7]. One multicenter trial in Brazil, Italy and France demonstrated that TB survivors undergoing rehab had improved lung function (FEV_1, FVC) and markedly higher 6 Minutes' Walk Distance(MWD) than non-rehabilitated controls [1]. Nutritional counselling, smoking cessation advice and mental health support are also integral parts of TB rehab programs. Exercise training, education and behaviour change have been shown to improve lung function and exercise capacity in PTLD. For example, TB survivors completing a short (3-week) PR program had significant gains in 6 MWD and lung function (FEV_1, FVC) and oxygenation [8]. A Ugandan PR program for PTLD likewise reported clinically important improvements in patient-reported outcomes and exercise tests. Thus, PR is effective in PTLD, but traditional programs are scarce in low-resource settings[9]. Novel digital tools wearables, AI, VR, and tele-rehabilitation, are being explored to extend PR access and boost outcomes in TB-related lung disease.

Continuous Activity Monitoring

Wearable sensors (pedometers, accelerometers, smartwatches, pulse oximeters) enable objective tracking of patient activity and vital signs. For example, tri-axial accelerometers are a standard tool in PR: one pilot study used a wearable armband to monitor steps and intensity 24/7 during an inpatient PR course [10]. These devices can reliably quantify exercise duration and intensity, motivating adherence. In chronic respiratory disease PR, integration of wearable trackers is increasingly common [11]. In practice, a TB survivor might wear a fitness tracker during home exercises or daily walks, allowing clinicians to remotely assess adherence and adjust the program.

Physiologic Sensing

Wearables that measure oxygen saturation, heart rate or breathing rate can alert to desaturation or breathlessness. AI-linked wearables in PR can detect anomalies or early exacerbations from these signals [12]. (For example, machine learning applied to continuous oxygen/respiration data in a PR program could predict a patient's 6MWD response) [12]. Although specific trials of wearables in TB rehab are limited, by analogy with COPD management, simple pulse oximetry patches or wrist-worn oximeters could be used to monitor SpO_2 trends during exercise.

Outcome Tracking

Wearables feed into exercise diaries and tele-rehab apps. Mobile apps can pull data from smart bands to show patients' step counts or exercise logs. In other PR programs, activity tracker data has been used to provide feedback and set personalized goals. For example, a mobile PR platform for lung cancer patients recorded increased average steps and improved 6 MWD [12]. In summary, wearable tech enables remote supervision of TB survivors: clinicians can gauge how much activity patients do, reinforcing compliance with the rehab plan. In general, pulmonary rehab (COPD, post-COVID), Machine Learning algorithms(MLA) analyze patient data (demographics, prior spirometry, activity levels) to predict rehab response. In one study of post-COVID patients, ML models (random forest, boosting) classified patients' 6MWD performance (low/medium/high) with ~84–94% accuracy. Such tools could be adapted for PTLD: e.g. using AI to predict which TB survivors need more intensive training or identifying those who will gain the most from rehab. AI can also analyze

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sensor data in real time (from wearables or smartphones) to detect exercise anomalies or guide pacing. AI-driven apps can serve as virtual physiotherapists. Chatbot interfaces (via mobile phone messaging or apps) use natural-language processing to coach patients through exercises, answer questions, and send reminders [12]. For instance, AI "virtual assistants" have been shown to give personalized education, medication/exercise reminders and even symptom triage in chronic lung disease rehab. Patients report these tools improve adherence by prompting workouts and clarifying technique. While no chatbot trial in PTLD has been published yet, analogous COPD apps show better adherence in tech-assisted rehab [12].

Predictive Analytics

AI can forecast long-term outcomes from short-term data. For example, recurrent neural networks analyzing home spirometry can predict lung-function decline before it becomes clinically evident. In PTLD, similar models might identify patients at risk of rapid deterioration or re-hospitalization, allowing early intervention. Overall, AI in digital PR is emerging: integrating smart algorithms into telerehab platforms could optimize exercise plans and patient monitoring for TB survivors, even though dedicated studies in TB are still needed .

Immersive Exercise Programs

Virtual reality platforms create gamified, immersive environments for rehab. Although TB-specific VR research is lacking, VR-based pulmonary rehab has been studied in COPD and other lung conditions [13]. A 2023 review of 32 studies found consistently positive results: VR exercises improved functional outcomes, breathing control and patient engagement in lung cancer, COPD and asthma patients. For example, VR cycling or breathing-exercise games were reported to reduce dyspnea and improve exercise tolerance compared to standard exercises. By making rehab fun and interactive, VR may boost motivation and adherence [13]. Virtual reality allows the tailoring of exercise intensity and feedback. Immersive VR headsets (or even cheaper smartphone-based VR kits) can present simulated environments (e.g. virtual forests or gaming scenarios) that respond to patient effort. This can train respiratory muscles or aerobically stress patients in a safe, controlled way. In trials, patients found VR pulmonary rehab "enjoyable, motivating and flexible," with the ability to individualize workout schedules and monitor progress remotely [14]. While most VR trials are in higher-income settings, these platforms could, in principle, be used at home by TB survivors if affordable VR equipment is available.

Remote Supervised Programs

Tele-rehabilitation uses video calls, apps and web portals to deliver PR at home. This approach has been piloted in PTLD. A recent Brazilian RCT protocol will compare 8weeks of supervised telerehab (via videoconference) versus usual care in PTLD patients. The intervention group will perform guided exercises at home with online supervision; outcomes (6MWD, spirometry, QoL) will be measured. The researchers anticipate improved physical capacity, QoL, and also better accessibility and lower costs through home-based video-therapy [15, 16]. In TB populations, similar smartphone PR apps could be deployed (even as simple as WhatsApp-guided exercise sessions). Importantly, telerehab extends PR to rural or mobility-limited patients: a video conferenced program removes travel barriers and offers personalized follow-up [17, 18].

Table 1: Results of Various Studies Conducted for Improvement in Pulmonary Function Utilizing Technology

References	Study Design	Intervention	Comparison	Sample Size	Key Findings
[19]	Stepped-wedge cluster RCT	99DOTS (digital adherence monitoring via toll-free calls + SMS reminders)	Routine DOT (directly observed therapy)	1,913 patients	No significant improvement in treatment success (ITT analysis).
[20]	Review	PEP mask + spirometer (12-week airway clearance program)	No control group	Not reported	Improved sputum clearance, ↑ FEV1.
[21]	Experimental	AI-based cough sound analyzer	No control group	Not reported	High relapse prediction accuracy (89% sensitivity).
[22]	Quasi-Experimental	UBICU (gamified respiratory incentive spirometer + app + cloud monitoring)	TriFlo (traditional flow-based RIS)	30 healthy adults	- UBICU significantly improved lung re-expansion (↑ impedance, *p* = 0.01).
[23]	Retrospective Cohort	Aerobika® OPEP device	Acapella® OPEP device	619 vs. 1,857 (PS-matched)	↓ 30-day severe exacerbations (12.0% vs. 17.4%, *p*=0.001).- ↓ 12-month hospitalizations (0.7 vs. 0.9 PPPY, *p*=0.01). - Longer time to first exacerbation (*p*=0.01).

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[24]	RCT	Standard anti-TB therapy + Active Cycle of Breathing Techniques (ACBTs) for 8 weeks	Standard anti-TB therapy alone	40 (20 per group)	- Significant improvements in FEV1, FEV1/FVC ratio, PEF, and BCSS scores in the ACBT group.- Greater chest expansion at all thoracic levels in the ACBT group.- Reduced perceived exertion and improved heart rate recovery in the ACBT group.- No significant difference in 6MWT distance between groups.
[25]	RCT	Group A:Postural Drainage + Steam (3 sessions/week for 6 weeks) Group B: Deep Breathing Exercises + Steam (3 sessions /week for 6 weeks)	Group A vs. Group B	48 (24 per group)	Postural Drainage (Group A) showed greater improvements in oxygen saturation (p=0.001), dyspnea reduction (p=0.003), and exertion levels (p=0.055) compared to Deep Breathing Exercises.- Significant within -group improvements in both interventions, but postural drainage was superior.
[26]	Randomized Controlled Trial	Video Directly Observed Therapy (VDOT):- Synchronous smart-phone app for medication observation. - Average time per dose: 16.5 min.	Directly Observed Therapy (DOT): - In-person observation by health workers. - Average time per dose : 44.1 min (including travel).	405 (203 VDOT, 202 DOT)	High treatment completion rates: 96.1% (VDOT) vs. 94.6% (DOT), *p=0.474*.Time/cost savings: VDOT reduced observation time by 62.6% and costs by 52.1% *(p<0.01)*.- Patient preference: 96% of VDOT users found it convenient vs. 56.6% for DOT *(p<0.001)*.
[27]	RCT	SMS Group: Reminder SMS messages sent to patients after TB diagnosis.WBOTs Group: Paper slip reminders delivered by Ward-Based Outreach Teams.	Standard of Care (SOC): No reminders.	314 (SOC = 104, SMS = 105, WBOTs = 105)	SMS Group: 88% treatment initiation vs. 78% in SOC (*p=0.062*). Faster initiation (median: 4 days vs. 8 days, *p<0.001)*.WBOTs Group: 73% initiation (similar to SOC, *p=0.956*). Median initiation time: 8 days vs. 13 days *(p<0.001)*.- SMS was more effective than WBOTs in reducing delays.

This review highlights the critical role of evidence-based physiotherapy and emerging technological interventions in addressing PTB sequelae and advancing progress toward SDG 3. Despite microbiological cure, many TB survivors experience significant residual lung dysfunction, including PTLD characterized by chronic airflow obstruction, fibrosis, bronchiectasis, and reduced exercise capacity [28, 29]. The WHO now recognizes rehabilitation as an essential component of TB management; however, implementation remains limited, particularly in resource-constrained settings. Traditional rehabilitation strategies, including airway clearance techniques and breathing exercises (e.g., postural drainage, percussion, active cycle of breathing techniques), remain cornerstone interventions [25]. Studies from Pakistan underscore the importance of such techniques in improving oxygenation, reducing dyspnea, and enhancing lung function parameters (e.g., FEV_1, FVC) [24, 25]. Notably, structured exercise programs comprising aerobic and resistance training have consistently demonstrated benefits in exercise tolerance, muscle strength, and quality of life for TB survivors [4, 5]. These findings align with recommendations from COPD rehabilitation, supporting the adaptation of multicomponent pulmonary rehabilitation (PR) packages to the PTLD population [7, 8]. Emerging technologies offer promising avenues to expand PR accessibility and effectiveness, especially in low-resource settings where traditional in-person programs are scarce [9]. Wearable sensors, including accelerometers, smartwatches, and oximeters, provide continuous monitoring of physical activity and vital signs, facilitating remote supervision and personalized feedback [10, 11]. Though studies directly assessing wearables in TB rehab are limited, analogous COPD research suggests strong potential for integration into PR programs. AI-

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enhanced wearables and predictive analytics could further refine rehabilitation by tailoring exercise plans and detecting exacerbations early, as demonstrated in other chronic lung diseases [12]. Moreover, mobile applications and chatbot-based platforms hold potential to deliver exercise guidance, reminders, and education remotely. While specific trials in TB are lacking, COPD studies have shown that AI-driven virtual coaching improves adherence and patient satisfaction [12]. Virtual reality (VR)–based PR offers additional advantages, including immersive, gamified exercise experiences that enhance motivation and adherence [13, 14]. Despite these promising advances, several challenges remain. Many studies in this review were limited by small sample sizes, single-center designs, short follow-up durations, and lack of long-term outcome data [25, 30].

Implications for SDG-3

Integrating physiotherapy and technological advancements in TB rehabilitation directly supports SDG Target 3.8 (achieving universal health coverage, including rehabilitation services) and 3.4 (reducing premature mortality from non-communicable diseases through prevention and treatment). By enhancing functional recovery and quality of life, these interventions contribute to the broader goal of good health and well-being for all.

CONCLUSIONS

It was concluded that while traditional physiotherapy remains foundational in pulmonary TB rehabilitation, innovative technological solutions, including wearables, AI, VR, and tele-rehabilitation, hold substantial promise for enhancing outcomes, extending access, and contributing to SDG achievement. Collaborative efforts across disciplines and settings are crucial to realize the full potential of these interventions for TB survivors worldwide.

Authors Contribution

Conceptualization: DA
Methodology: DA, SKK, UI, GHM
Formal analysis: UI, GMH
Writing review and editing: DA, MAS, SS, MNB

All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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