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Clinical, Radiological, and Functional Determinants of Health-Related Quality of Life in Post-Tuberculosis Lung Disease: A Cross-Sectional Study from South India

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ABSTRACT:

Background: Post-Tuberculosis Lung Disease (PTLD) occurs in individuals who have recovered from tuberculosis, leading to persistent respiratory problems and diminished quality of life (QoL), even after microbiological cure. In India, where there is a high burden of tuberculosis, long-term pulmonary effects present significant challenges.

Objective: The study evaluates the clinical features, radiological findings, pulmonary function trends, and prognosis of hospitalized patients with PTLD at a tertiary care center in South India.

Methodology: A cross-sectional examination of 60 adults with pulmonary tuberculosis assessed PTLD through radiological, clinical, spirometric, and quality-of-life evaluations. Sociodemographic and medical data were collected through questionnaires and hospital records, while QoL was assessed using the WHO-QOL-BREF tool. Statistical analysis was utilized with SPSS, determining significance at $p < 0.05$.

Results: Participants, averaging 54.82 years, predominantly male, presented with dyspnea (100%), wheezing (80%), and cough (76.67%). Spirometry revealed restrictive ventilatory defects in 53.33% of cases, with radiological findings of fibrotic changes and bronchiectasis. Quality of life, as evaluated by the WHO-QOL-BREF survey, averaged 66.71, highlighting moderate impairment without significant demographic correlations.

Conclusion: PTLD significantly affects respiratory health and quality of life in TB survivors, emphasizing the importance of early detection, structured follow-up, pulmonary rehabilitation, and collaborative management strategies.

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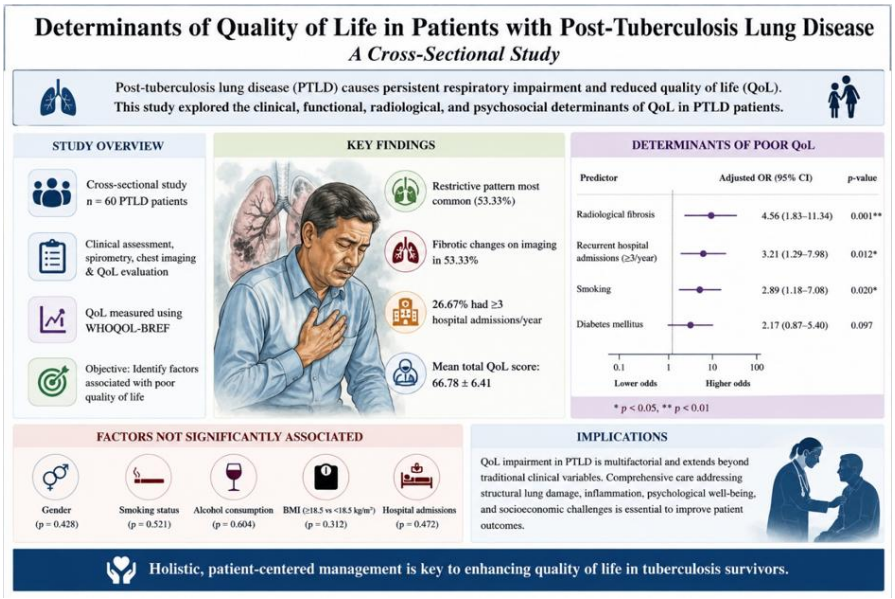
Graphical Abstract



1. INTRODUCTION

Tuberculosis continues to pose a major universal health related challenge, even with improvements in diagnosis and treatment. In 2023, the WHO estimates approximately 10.8 million new tuberculosis (TB) cases, with India experiencing the highest burden. TB is significantly associated with factors like poverty, inadequate healthcare access, and overcrowding, which contribute to ongoing transmission and unfavorable outcomes. While national TB programs and anti-tubercular therapy have improved treatment success, there is increasing focus on the long-term effects experienced by TB survivors post-treatment [3]. Historically, successful TB treatment was defined by the eradication of *Mycobacterium tuberculosis*. However, recent evidence shows that microbiological cure doesn't ensure normal respiratory health [4]. Many individuals completing anti-TB therapy still face ongoing respiratory symptoms, functional debility, lung impairment, and reduced Quality-of-life [5]. This understanding has led to a shift in TB management from a focus on survival to TB survivorship, which prioritizes long-term pulmonary recovery, functional rehabilitation, psychosocial well-being, and sustained Quality-of-life (QoL) post-treatment [6].

PTLD is a chronic respiratory condition that arises from previous pulmonary TB infection and can continue even after the completion of anti-TB treatment. It includes a range of abnormalities affecting the airways and lung structure, such as pulmonary fibrosis, bronchiectasis, and restrictive lung disease. Systematic reviews show that 42-47% of pulmonary TB survivors experience lasting pulmonary impairment, marking PTLD as a critical concern in high TB-burden settings [7, 8]. The pathophysiology of PTLD involves persistent inflammation and immune-mediated injury, leading to oxidative stress and tissue remodeling. In pulmonary TB, factors like inflammatory cytokines and profibrotic mediators, such as TGF-β, cause lung damage and airway remodeling [9,10]. This results in complications like fibrosis, bronchial distortion, and loss of alveolar units, contributing to ventilatory dysfunction and chronic respiratory disability, persisting even after microbiological cure.

Structural lung abnormalities are common in patients with PTLD, particularly evident through radiological sequelae like fibrosis, bronchiectasis, volume loss, cavitary lesions, pleural thickening, and emphysematous destruction seen on chest imaging and HRCT [11]. Studies indicate that nearly two-thirds of treated TB patients exhibit post-TB radiographic abnormalities, highlighting the lasting impact of TB-related pulmonary injury. These abnormalities significantly affect pulmonary mechanics and contribute to signs like chronic cough, wheezing, dyspnea, recurrent lower respiratory infections, hemoptysis, and exercise intolerance [11-15]. PTLD is documented as a significant contributor to chronic pulmonary diseases, particularly in middle and low-income countries with elevated TB rates. [3, 7]. Those with past TB infections face heightened risks for conditions like COPD, bronchiectasis, and recurrent respiratory infections, causative to long-term health related complications and premature death [16]. The socioeconomic impacts include frequent hospitalizations and reduced work productivity. Beyond physical health, PTLD significantly impacts patients quality-of-life, resulting in ongoing symptoms, anxiety, and social stigma. Quality-

of-life assessments reveal significantly lower scores among TB survivors compared to healthy individuals, underscoring the multidimensional impact of PTLD on health [14].

The assessment of Post-Tuberculosis Lung Disease (PTLD) necessitates a multidimensional approach, including clinical evaluations, pulmonary function tests, imaging, and Quality-of-life analyses. Spirometry is vital for diagnosing ventilatory defects linked to pulmonary damage post-TB, while HRCT is effective for identifying structural abnormalities like bronchiectasis and fibrosis [16, 17]. Risk factors for PTLD include delayed diagnosis, extensive pulmonary damage, recurrent TB, multidrug resistance, smoking, exposure to biomass fuels, malnutrition, diabetes, HIV, and poor socioeconomic conditions [3]. In regions like India, high TB prevalence leaves many at risk for chronic respiratory issues following treatment. However, PTLD remains underdiagnosed and underreported, overlooked in conventional TB control programs that focus mainly on microbiological cure, often neglecting post-treatment complications and follow-up care [3, 8, 16].

Tertiary care centers are essential for evaluating and managing PTLD, offering advanced diagnostics, specialized respiratory care, and multidisciplinary strategies. While hospital-based studies enhance understanding of disease severity in patients with pulmonary complications, regional data, especially from South India, are scarce [14, 18]. Differences in environmental factors, healthcare access, socioeconomic status, nutrition, and disease burden highlight the need for localized research to adequately assess the clinical and functional effects of PTLD [19]. Sympathetic the long-term consequences of pulmonary TB are critical for public health, particularly due to the burden of tuberculosis and chronic post-TB respiratory disability. This study assesses the clinical features and QoL of inpatients with PTLD at a tertiary care center in South India. The findings aim to improve recognition of PTLD, support long-term follow-up programs, and promote respiratory rehabilitation strategies to enhance the Quality-of-life and recovery of tuberculosis survivors.

2. METHODOLOGY

2. 1. Design and setting of the study

This observational evaluation was led in the Department of Respiratory Medicine at a tertiary care teaching hospital in South India from April 2025 to March 2026. The chosen institution acts as a referral center offering advanced respiratory treatment and diagnostic services to patients from both urban and rural settings. A significant number of patients with respiratory tuberculosis and related complications visit the hospital, making it suitable for reviewing the Quality-of-life and clinical profile of pulmonary TB sequelae (Fig. 1).

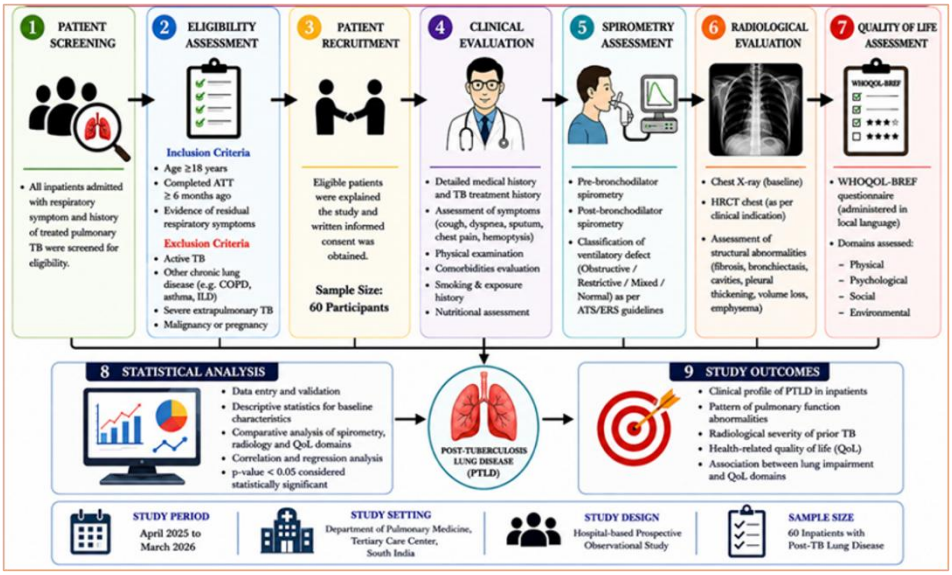


Fig. 1. Mechanistic Overview of Post-Tuberculosis Lung Disease Pathogenesis, highlighting persistent inflammation, immune dysregulation, pulmonary fibrosis, bronchiectasis, airway remodeling, reduced lung role, and decreased Quality-of-life for survivors.

2.2. Study population

The study contestants involved adult patients with TB sequelae who attended the wards of the Department of Respiratory Medicine at the study facility. Eligible participants for the study were adults with a history of tuberculosis who received appropriate treatment and continued to experience lung issues. Participants for this study were selected from consecutive attendances until the required number of participants was attained.

2.2.1. Sample quantity

The sample quantity was fixed at 60 subjects. All patients admitted to the pulmonary medicine inpatient unit of the hospital who met the inclusion norms were enrolled in the study sequentially until a sum of 60 samples were obtained. This sample size was considered appropriate to evaluate the clinical parameters and QoL of inpatients by respiratory tuberculosis sequelae.

2.2.2. Inclusion condition

The study included contestants aged 18 and older via a history of pulmonic tuberculosis who had completed anti-tuberculosis therapy. Patients with imaging features of post-tuberculosis lung architecture abnormalities, such as fibrosis, bronchiectasis, cavitation, and destroyed lungs, qualify as study subjects. Patients who consented to participate were recruited into the study group.

2.2.3. Exclusion criteria

Participants with active tuberculosis at the time of admission were excluded. Patients with chronic respiratory illnesses that were not related to tuberculosis, such as bronchial chronic disruptive pulmonary disease or asthma, but did not have any history of tuberculosis infection before were not included in the study. Participants with other health complications that made it impossible for them to fill out the questionnaire because they were very sick were also excluded from the investigation.

2.3. Data assortment

Data assortment involved using a semi-structured questionnaire that was designed and tested before the study began. Informed written consent was obtained from the selected individuals, after which their interviews were conducted, and relevant clinical information was gathered from the patient interviews as well as the medical records at the hospitals. The sociodemographic factors included age, gender, occupation, level of education, and socioeconomic status. The clinical factors included the duration of tuberculosis, the number of times the individual had suffered from tuberculosis, and the type of treatment administered.

2.4. Clinical assessment

All participants were clinically evaluated by competent physicians. The clinical features included cough, dyspnea, sputum, hemoptysis, chest pain, and fatigue. The brutality of dyspnea scale was evaluated with the MMRC (Modified Medical Research Council) method. Various vital signs were recorded at admission, including pulse rate, respiratory rate, blood pressure, and saturation levels. The respiratory examination findings are noted in detail.

2.5. Radiological assessment

Radiological findings in each patient were assessed using chest radiography. In addition to the above-mentioned data, any imaging records, such as high-resolution computed tomography (HRCT) scans available for the patients, were evaluated if needed. Radiological findings indicating the presence of tubercular complications, such as fibrosis, bronchiectasis, cavity formation, pleural thickening, and destruction of the lung parenchyma, were noted.

2.6. Pulmonary role testing

Spirometric testing of pulmonary function was performed for all stable patients during the study period. Parameters measured included forced vital capacity (FVC), forced expiratory volume in one second (FEV1), and the FEV1/FVC ratio. Spirometry results were analysed using standardized criteria for classifying ventilatory abnormalities as obstructive, restrictive, or mixed.

2.7. Quality-of-life assessment

The WHOQOL-BREF survey was used to assess the participants QoL. The WHOQOL-BREF is a twenty-six-item survey that measures quality-of-life in four dimensions: psychological, physical, social related relationship, and environmental. In

completing the WHOQOL-BREF, participants had to answer questions regarding their QoL within the past two weeks. Scores for the dimensions were calculated following the WHO scoring rules; high scores indicated a high QoL.

2.8. Data management and statistical investigation

Version 25 of SPSS was employed to analyse data inputted in Microsoft Excel. A graphic examination was performed to present the sociodemographic and clinical characteristics. Continuous data is summarized using standard deviation and mean, while definite data is expressed in terms of percentage and frequency. Inferential studies, like the independent t-test, and chi-square test assessed the correlation between clinical characteristics and QoL domains, with significance set at a P-value of less than 0.05.

2.9. Ethical contemplations

Approval from the Institutional Ethics Committee (IEC) was secured prior to informed consent, and data assortment was found from all contestants. Patient information was kept confidential throughout the study, adhering to ethical guidelines for biomedical research involving humans.

3. RESULTS

3.1. Clinical and demographic characteristics

The clinical and demographic features of the studied population are summarized in Table 1. The mean age of participants 54.82 ± 13.76 years, predominantly male (63.33%). The average body mass index (BMI) was 21.18 ± 4.12 kg/m², with 33.33% underweight. Common comorbidities included diabetes mellitus (23.33%) and hypertension (16.67%). Lifestyle factors showed that 25% were smokers and 20% consumed alcohol regularly. All participants had microbiologically-confirmed pulmonary tuberculosis and were treated with anti-tuberculosis drugs (Fig.2).

Table 1. Standard demographic, anthropometric, behavioral, and comorbidity features of TB survivors with PTLD enrolled in the study cohort (n = 60).

Characteristics	n (%) / Mean ± SD
Age (years)	54.82 ± 13.76
Male gender	38 (63.33%)
BMI (kg/m²)	21.18 ± 4.12
Underweight	20 (33.33%)
Smokers	15 (25%)
Alcohol consumption	12 (20%)
Diabetes mellitus	14 (23.33%)
Hypertension	10 (16.67%)

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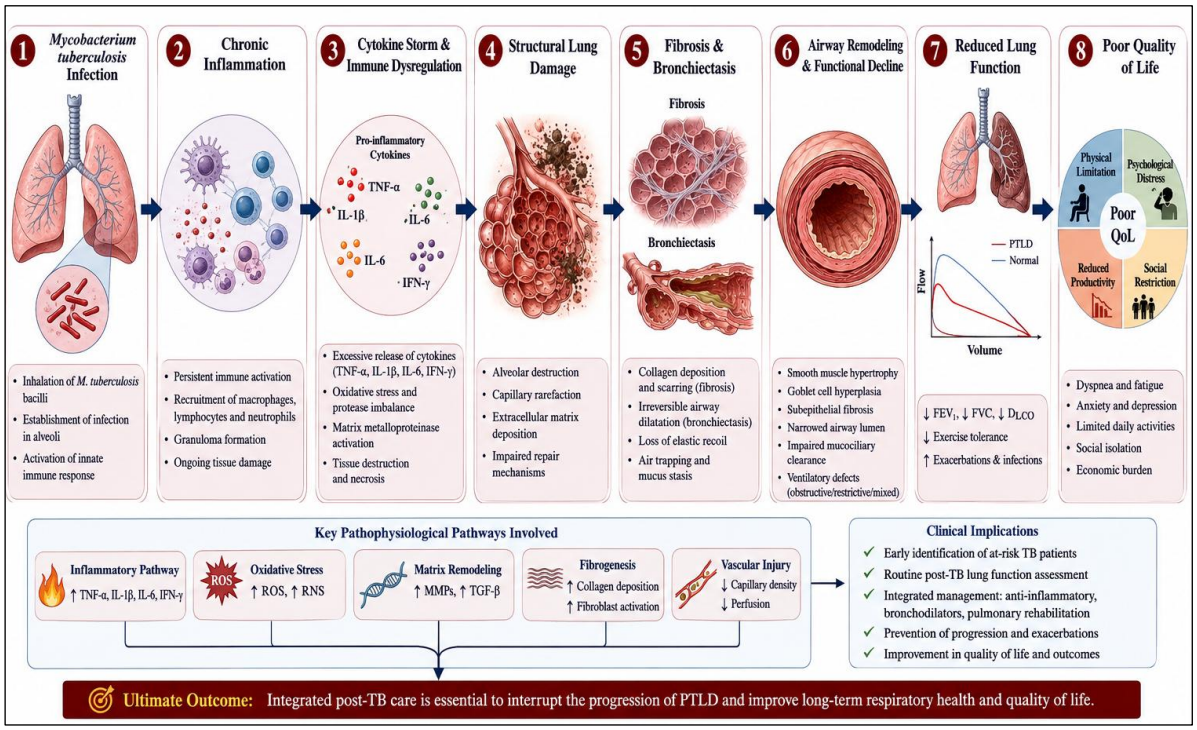

Fig. 2. Mechanistic framework of PTLD progression. Chronic inflammation and immune dysregulation following tuberculosis initiate structural and functional lung alterations characterized by fibrosis, bronchiectasis, and airway remodeling, culminating in impaired respiratory function and reduced quality of life in survivors.

3.2. Clinical manifestations

Dyspnea was the predominant symptom reported by 100% of participants in the study. Wheezing and coughing occurred in 80% and 76.67% of patients, respectively (Table 2; Fig. 2). A significant number of participants (26.67%) experienced recurrent hospital admissions, with three or more admissions for respiratory exacerbations. On average, dyspnea lasted 3.92 weeks. Other symptoms included fatigue (36.67%), lack of appetite (30%), and weight loss (23.33%), while hemoptysis was the least reported at 10%. Half of the patients had one hospitalization, and one-fourth had three or more. All participants used inhalers, but only one-third were vaccinated for respiratory infections (Table 2).

Table 2. Frequency distribution of persistent respiratory symptoms and clinical manifestations among patients with post-tuberculosis lung disease following completion of anti-tuberculosis therapy.

Clinical Feature	n (%)
Dyspnea	60 (100%)
Wheeze	48 (80%)
Cough	46 (76.67%)
Fatigue	22 (36.67%)
Loss of appetite	18 (30%)
Weight loss	14 (23.33%)
Hemoptysis	6 (10%)

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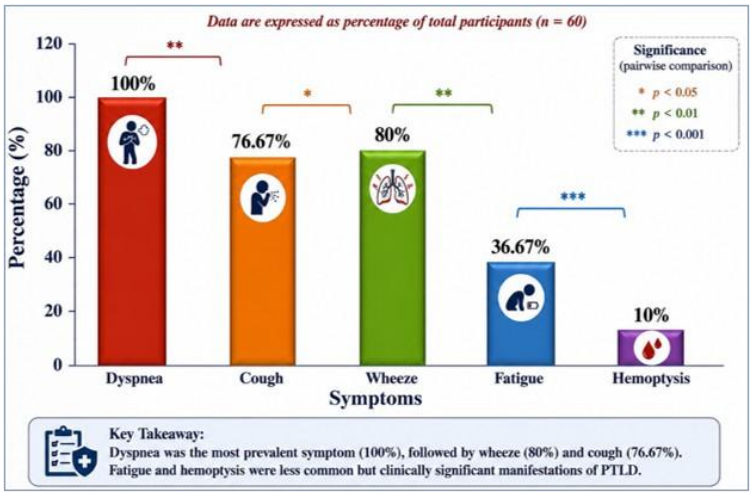

Fig. 3. Symptom distribution among patients with PTLD, the prevalence and percentage distribution of major respiratory and constitutional symptoms, including dyspnea, cough, wheeze, fatigue, and hemoptysis, among patients with post-tuberculosis lung disease. Statistical significance indicators represent comparative symptom burden analysis.

3.3. Pulmonary function patterns

The pulmonary function test results revealed that 53.33% of subjects exhibited a restrictive ventilatory defect, making it the most common abnormality. Obstructive defects were present in 26.67%, while a combination of both types occurred in 13.33%. Only 6.67% of patients demonstrated normal pulmonary function. Additionally, 23.33% showed a positive response to bronchodilators (Table 3; Fig. 4).

Table 3. Distribution of spirometric patterns among tuberculosis survivors with PTLD, indicating obstructive, restrictive, mixed, and normal ventilatory patterns.

Pulmonary Function Pattern	n (%)
Restrictive defect	32 (53.33%)
Obstructive defect	16 (26.67%)
Mixed pattern	8 (13.33%)
Normal spirometry	4 (6.67%)

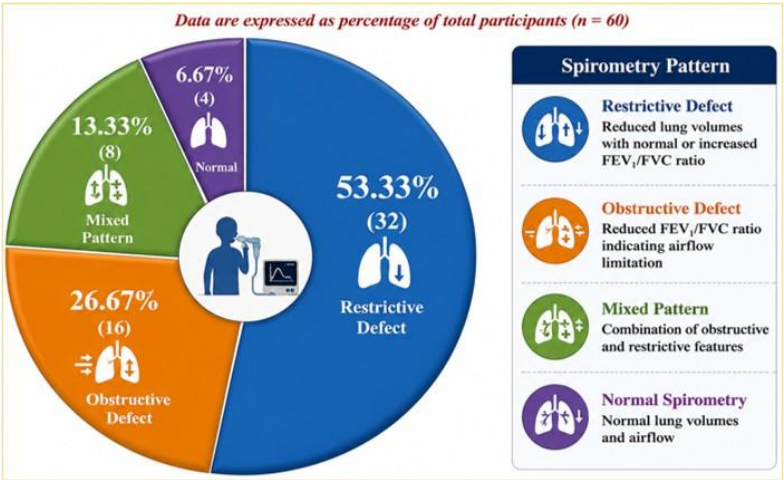

Fig. 4. The distribution of spirometric abnormalities among TB survivors with PTLD, including restrictive, obstructive, mixed ventilatory defects, and normal pulmonary function patterns.

3.4. Radiological findings

Fibrotic strands (30%) and parenchymal fibrosis (23.33%) were the most common radiological abnormalities detected in the study. Bronchiectasis was observed in 16.67%, while pleuroparenchymal fibrosis and fibrocavitary lesions each accounted for 10%. Hyperinflation was noted in 5%, and calcified nodules were relatively rare at 1.67%. Normal chest X-ray results were found in 3.33% of individuals (Table 4).

Table 4. Radiological spectrum of structural pulmonary abnormalities identified in patients with PTLD using chest radiography and available HRCT imaging.

Radiological Finding	n (%)
Fibrotic strands	18 (30%)
Parenchymal fibrosis	14 (23.33%)
Bronchiectasis	10 (16.67%)
Pleuroparenchymal fibrosis	6 (10%)
Fibrocavitary lesions	6 (10%)
Hyperinflation	3 (5%)

3.5. Quality-of-life (QoL) *assessment*

The mean overall QoL score among participants was 66.71 ± 6.43, demonstrating modest impairment. Functional activity was more severely affected than symptom burden, with a mean symptom score of 22.14 ± 3.12 and a mean activity score of 44.52 ± 5.28. This suggests that functional impairment significantly affects the quality-of-life (Table 5).

Table 5. Assessment of health-related QoL scores among patients with PTLD using standardized Quality-of-life estimation domains.

QoL Domain	Mean ± SD
Symptom score	22.14 ± 3.12
Activity score	44.52 ± 5.28
Total QoL score	66.71 ± 6.43

3.6. Influence of demographic and clinical variables on Quality-of-life among tuberculosis survivors with PTLD

The analysis in Table 6 indicates that clinical and demographic variables, such as gender, alcohol consumption, smoking status, and BMI (body mass index), do not significantly influence Quality-of-life (QoL) scores among TB survivors with PTLD. Male (66.12 ± 6.24) and female (67.53 ± 6.59) patients showed comparable QoL ($p = 0.428$), while smoking status ($p = 0.521$) and alcohol consumption ($p = 0.604$) also had no significant impact. Although BMI ≥18.5 kg/m² led to higher mean scores than underweight individuals ($p = 0.312$), the relationship was not statistically significant. Recurrent hospitalization due to PTLD exacerbations did not correlate with reduced QoL scores ($p = 0.472$). The findings suggest that QoL impairment in PTLD is multifactorial, influenced by factors such as structural lung damage, chronic inflammation, psychological stress, and socioeconomic conditions, beyond conventional clinical variables (Table 6).

Table 6. Multi-variable logistic regression study and prevalence estimates of indices associated with poor Quality-of-life among TB survivors with PTLD.

Variable	Prevalence n (%)	95% confidence interval	Adjusted odds ratio (95% CI)	p-value	Interpretation
Smoking	15 (25.0%)	15.30%–37.90%	2.89 (1.18–7.08)	0.020*	Significant predictor of poor QoL
Radiological fibrosis	32 (53.33%)	40.13%–66.25%	4.56 (1.83–11.34)	0.001**	Strongest independent predictor
Recurrent hospital admissions (≥3/year)	16 (26.67%)	16.04%–39.48%	3.21 (1.29–7.98)	0.012*	Associated with increased disease burden
Diabetes mellitus	14 (23.33%)	13.98%–35.75%	2.17 (0.87–5.40)	0.097	Not statistically significant

3.7. Association between clinical variables and Quality-of-life in patients with post-tuberculosis lung disease

The correlation among the overall Quality-of-life index score and certain clinical factors is provided in Table 6. The mean Quality-of-life score for males (66.12 ± 6.24) and females (67.53 ± 6.59) was similar ($p = 0.428$). Likewise, there was no association noted between the Quality-of-life score and smoking ($p = 0.521$), alcohol intake ($p = 0.604$) or body mass index ($p = 0.312$). Moreover, there was no important association between the number of quality-of-life and hospitalization cases ($p = 0.472$). It can be stated that the studied factors did not significantly affect the quality-of-life in patients with post-tuberculosis sequelae (Table 7).

Table 7. Evaluation of total quality-of-life scores across demographic and clinical variables among TB survivors with PTLD following successful completion of anti-tuberculosis therapy. Statistically significant examination involved an independent t-test, with $p < 0.05$ value.

Clinical Variable	Category	Mean QoL score ± SD	95% confidence interval	p-value
Gender	Male	66.12 ± 6.24	64.08–68.16	0.428
	Female	67.53 ± 6.59	64.61–70.45	
Smoking Status	Smoker	65.80 ± 6.41	62.25–69.35	0.521
	Non-smoker	67.14 ± 6.38	65.12–69.16	
Alcohol Consumption	Alcohol user	65.92 ± 6.55	62.21–69.63	0.604
	Non-alcohol user	67.01 ± 6.36	64.95–69.07	
Body Mass Index (BMI)	<18.5 kg/m²	65.33 ± 6.20	62.43–68.23	0.312
	≥18.5 kg/m²	67.82 ± 6.47	65.74–69.90	
Hospital Admissions	<2 admissions	66.01 ± 6.12	63.98–68.04	0.472
	≥2 admissions	67.45 ± 6.74	64.78–70.12	

3.8. Advanced statistical analysis of determinants of Quality-of-life in PTLD patients

Advanced statistical analysis was conducted to identify the causes of quality-of-life in patients with post-transplant lymphoproliferative disorders. This study utilized various statistical methods to evaluate factors influencing patient outcomes, highlighting important variables that affect their overall well-being and quality-of-life after treatment (Table 8; Fig. 5).

3.8.1. Correlation analysis

Pearson correlation analysis highlighted significant relationships among pulmonary function, nutritional status, hospitalization burden, and Quality-of-life in patients with PTLD. A positive correlation was observed among FEV_1 (% predicted) and QoL scores ($r = 0.62$, $p < 0.001$), indicating that better pulmonary function correlates with improved QoL, Body mass index (BMI) also showed a moderate positive correlation with QoL ($r = 0.41$, $p = 0.002$). Conversely, the number of hospital admissions negatively correlated with QoL ($r = –0.55$, $p < 0.001$), suggesting that frequent hospitalizations adversely affect QoL in PTLD patients.

3.8.2. Logistic regression analysis

Binary logistic regression identified independent predictors of poor QoL in PTLD patients. Key findings include radiological fibrosis as the strongest predictor (Adjusted Odds Ratio [AOR]: 4.56; $p = 0.001$), followed by smoking (AOR: 2.89; $p = 0.020$) and recurrent hospital admissions (≥3 per year; AOR: 3.21; $p = 0.012$). Diabetes mellitus was positively associated with poor QoL but not statistically significant (AOR: 2.17; $p = 0.097$). The model exhibited good fit (Nagelkerke R^2: 0.48) and classification accuracy of 81.7%, indicating moderate predictive performance.

3.8.3. Prevalence estimates with 95% confidence intervals

Prevalence estimates indicate that restrictive ventilatory defects are the most common pulmonary function abnormality, affecting 53.33% of patients, followed by obstructive defects (26.67%) and mixed defects (13.33%). Normal spirometry was rare, observed in 6.67%. In terms of radiological abnormalities, fibrotic changes occurred in 53.33% of patients, while bronchiectasis was seen in 16.67%. Additionally, 26.67% of participants experienced recurrent hospital admissions. These

findings highlight the significant impact of pulmonary function impairment, fibrotic lung damage, and respiratory morbidity on the Quality-of-life of tuberculosis survivors with PTLD.

Table 8. Multivariable analysis of clinical and radiological predictors associated with poor Quality-of-life among TB survivors with PTLD.

Variable	PTLD Severity / Clinical Impact	Association with Poor QoL	Adjusted Odds Ratio (95% CI)	p-value
Smoking	Increased respiratory impairment	Significant	2.89 (1.18–7.08)	0.020*
Radiological fibrosis	Severe structural lung damage	Highly significant	4.56 (1.83–11.34)	0.001**
Recurrent hospital admissions (≥3/year)	Increased disease burden	Significant	3.21 (1.29–7.98)	0.012*
Diabetes mellitus	Moderate clinical impact	Not statistically significant	2.17 (0.87–5.40)	0.097

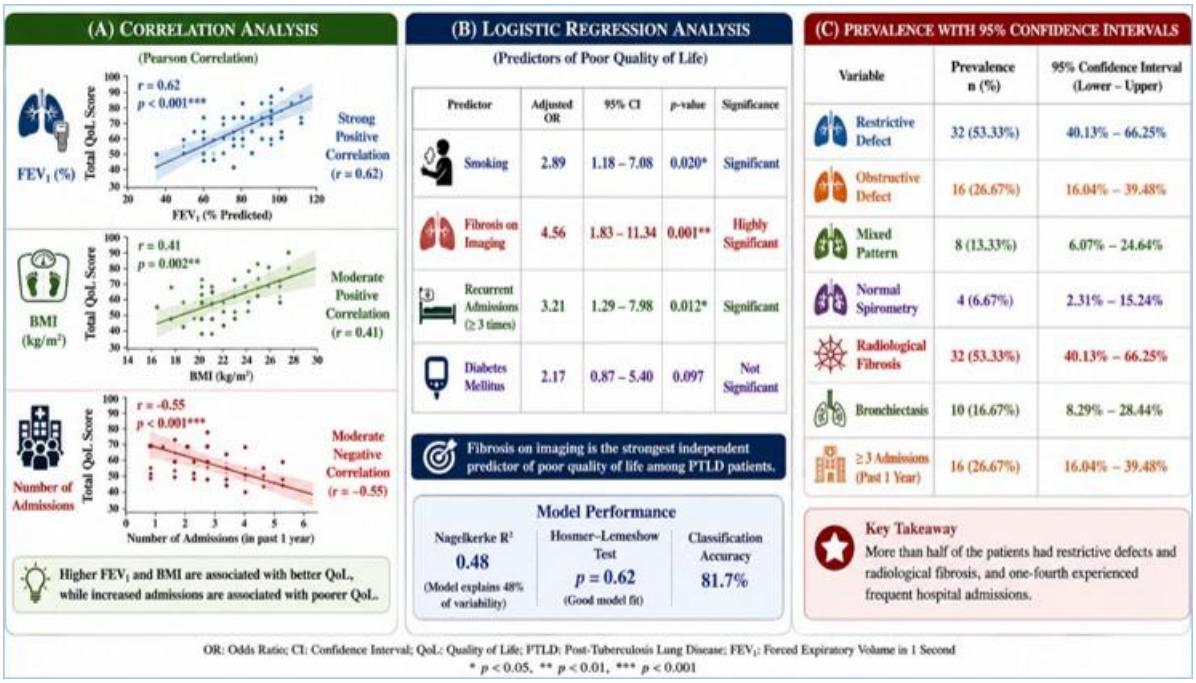

Fig. 6. Integrated statistical visualization illustrates correlation analysis and multivariable logistic regression regarding determinants of impaired Quality-of-life in TB survivors with PTLD.

4. DISCUSSION

The study emphasizes the significant burden of PTLD (post-tuberculosis lung disease) in survivors of respiratory tuberculosis, highlighting that microbiological cure does not guarantee recovery of lung health. Traditionally, tuberculosis control programs have focused on bacteriological eradication, but evidence shows many survivors face chronic respiratory issues after treatment. PTLD is identified as a major form of chronic respiratory disease linked to ongoing symptoms, increased healthcare needs, reduced pulmonic function, and lower Quality-of-life, especially in high TB burden countries like India [20–23]. In recent years, TB survivorship has emerged as a key focus in TB care, emphasizing the long-term effects on individuals after treatment. Research indicates that lung damage from Mycobacterium tuberculosis can persist or even worsen post-clearance, attributed to factors like ongoing inflammation, immune-mediated damage, and fibrosis [24, 25]. Consequently, PTLD requires long-term follow-up, pulmonary rehabilitation, and multidisciplinary management, rather than being treated as a standalone post-infection

issue [26]. The study highlights the essential for enhanced post-treatment care in tuberculosis control policies in India, highlighting the inadequacies of current programs that focus on diagnosis and treatment while neglecting respiratory assessment and rehabilitation. As PTLD burdens increase, it is crucial to integrate spirometric screening, pulmonary rehabilitation, smoking cessation, vaccinations, nutritional support, and chronic disease management into care plans [22, 27]. The research evaluated hospitalized patients with post-tuberculosis sequelae in South India, revealing persistent respiratory and functional issues even after cure. The mean age of participants was 54.82 years, indicating that post-TB lung disease predominantly affects middle-aged and older adults [25, 28]. The male predominance in the cohort aligns with global trends linked to smoking exposure and delayed healthcare-seeking behavior among men [20, 29].

A considerable number of TB survivors showed underweight or low-normal BMI, highlighting ongoing nutritional vulnerability. Malnutrition is both a risk index and a significance of tuberculosis, adversely affecting pulmonary recovery through weakened immune function, respiratory muscles, and impaired tissue healing [22, 30, 31]. The study found dyspnea as the maximum predominant symptom, followed by chronic cough and wheezing, consistent with previous research on persistent respiratory issues linked to post-tuberculosis lung disease [32, 33]. Factors like chronic airflow limitation and bronchial hyperresponsiveness contribute to these ongoing symptoms, indicating chronic airway involvement and postinfectious obstructive lung disease in this population [34]. Frequent exacerbations and hospital admissions in patients highlight the chronic and progressive nature of PTLD, similar to other chronic pulmonary disorders [35]. The consistent use of inhaler therapy among participants indicates a significant burden of chronic airway disease, aligning with evidence that links PTLD to COPD-like pathology [36].

Pulmonary function assessment revealed restrictive ventilatory defects as the most prevalent spirometric abnormality, followed by obstructive and mixed patterns. This aligns with previous findings indicating that fibrosis and other factors lead to restrictive impairment post-tuberculosis [37]. Obstructive defects are also noted in patients with conditions such as bronchial stenosis and emphysema. Variability in spirometric patterns may stem from differences in disease severity, smoking history, and assessment timing after treatment [22, 24, 36]. Fibrotic abnormalities were the main radiological finding in our study population, with significant occurrences of fibrotic strands, parenchymal fibrosis, and architectural distortion. These results support prior studies linking fibrosis to PTLD [22]. Additionally, bronchiectasis was commonly noted, indicating chronic airway inflammation and irreversible bronchial damage due to postinfectious remodeling [24]. These structural lung abnormalities are crucial as they correlate with chronic respiratory symptoms, recurrent infections, reduced exercise tolerance, and worsening pulmonary function [23]. Examination of health-related Quality-of-life revealed moderate-to-severe impairments in patients, particularly affecting physical activity and functional domains more than symptom domains. This aligns with prior research indicating that chronic respiratory issues significantly diminish QoL for TB survivors [38]. Factors such as persistent dyspnea, fatigue, reduced exercise tolerance, social restrictions, and psychological distress contribute to the overall decline in both physical and psychosocial well-being in PTLD patients, highlighting that impairment extends beyond respiratory symptoms and reflects the multifaceted impact of chronic pulmonary disability [39].

In the current study, no significant association was observed among QoL scores and variables such as gender, alcohol use, smoking status, and body mass index, or hospitalization history. While some prior research linked smoking to lower QoL in PTLD patients, results have been inconsistent [38, 40]. The lack of significance may stem from the study's limited sample size, the homogeneity of participants, or the complex, multidimensional nature of QoL, which includes various determinants beyond isolated clinical variables [41]. This study highlights that post-TB lung disease (PTLD) plays a important role in chronic respiratory issues and reduces the QoL in TB survivors, even after treatment. It stresses the necessity for early detection and thorough management of post-TB respiratory conditions. Current international guidelines recommend integrating pulmonary rehabilitation, long-term monitoring, smoking cessation, nutrition, vaccination, and psychosocial support into post-TB care [24, 26, 42]. Findings highlight the necessity of broadening TB control strategies to include long-term survivorship care and chronic respiratory disease prevention. Strengthening post-treatment follow-up, raising PTLD awareness among clinicians, and establishing dedicated post-TB respiratory clinics can improve patient outcomes and reduce healthcare burdens in TB-endemic regions. Given the high number of TB survivors in India, PTLD may emerge as a major chronic respiratory issue, underscoring the urgent need for integrating post-TB care into national respiratory health policies and TB elimination initiatives.

5. Conclusion

The present study highlights the substantial clinical and functional burden of PTLD among previously treated pulmonary TB patients. Persistent pulmonary symptoms, restrictive ventilatory impairment, and fibrotic radiological abnormalities were highly

prevalent despite successful completion of anti-tuberculosis therapy. Importantly, PTLD significantly compromised patients Quality-of-life, particularly physical functioning and daily activity. These findings reinforce the growing recognition that microbiological treatment does not necessarily associate to renovation of respiratory related health. PTLD should therefore be considered a major component of TB-associated chronic respiratory disease and integrated into long-term TB care strategies. Early identification of pulmonary impairment, routine spirometric evaluation, pulmonary rehabilitation, nutritional optimization, smoking cessation, vaccination, and multidisciplinary follow-up may help reduce long-term disability among TB survivors. Imminent longitudinal multi-center studies with greater cohorts are acceptable to better define disease progression, identify predictors of severe PTLD, and develop evidence-based rehabilitation protocols tailored to high TB burden settings such as India.

6. FUTURE DIRECTIONS

Future research on PTLD should prioritize the long-term significances of tuberculosis survivorship, as successful treatment does not eliminate chronic pulmonary disability. There is a crucial necessity for large-scale studies to investigate PTLD's natural history, long-term outcomes, and effective rehabilitation strategies. Evaluating biomarkers associated with PTLD progression is critical for targeted interventions, while advancements in imaging and digital health technologies will enhance care accessibility. The development of standardized diagnostic criteria and management protocols is essential, along with a focus on the psychosocial and socioeconomic impacts faced by survivors. Integrating tuberculosis programs with chronic respiratory care services may significantly improve outcomes for TB survivors globally.

Declaration of generative AI

During this work's preparation, the author(s) utilized ChatGPT and Grammarly to enhance the article's English writing. Post-tool use, they reviewed and edited the content and take full responsibility for the published article's content.

Data availability statement

The datasets from the study can be requested from the corresponding author, following institutional ethical guidelines and regulations on patient confidentiality.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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