Innovations

# Comparison of Respiratory Function in Smokers and Non-Smokers after Treated Pulmonary Tuberculosis Patients

**[1]Dr Gaddam Venkata Mohan; [2]Dr. Berikutti Muniraju; [3]Dr Vadde Vijaya Lakshmi; [4]Dr Ravella Madhuri; [5]Dr Senapathi Lavanya; [6]Dr Lakhinena Anusha**

[1,4,5,6] Assistant Professor, [2]Junior Resident, [3]Senior Resident

[1,2,3,4] Department of Respiratory Medicine,
Great Eastern Medical School, Ragolu, Srikakulam
[5] Department of Respiratory Medicine, NRI medical college ,Tagarapuvalasa
[6]Civil assistant surgeon, PHC Tadivalasa

Corresponding Author: **Dr Gaddam Venkata Mohan**

***Abstract:***
***Background:*** *Pulmonary tuberculosis (TB), even after successful treatment, often leaves behind structural lung damage known as post-TB sequelae. These changes can lead to chronic respiratory symptoms and long-term functional impairment. Smoking is known to further compromise lung function but its specific impact on patients with post-TB sequelae has not been fully explored.* ***Objectives:*** *This study aimed to compare respiratory function and exercise capacity between smokers and non-smokers who had been treated for pulmonary TB and now presented with radiological sequelae.* ***Methods:*** *A cross-sectional study was conducted over 18 months in the Department of Respiratory Medicine, Great Eastern Medical School, Srikakulam. A total of 100 patients with post-TB sequelae were enrolled, divided equally into smokers and non-smokers. All participants underwent clinical evaluation, chest X-ray, spirometry, and six-minute walk test (6MWT). Spirometric patterns, lung volumes, and exercise tolerance were compared between the groups. The Smoking Index (SI) was used to classify the severity of smoking exposure.* ***Results:*** *The most common spirometric pattern among smokers was mixed (56%), while 38% of non-smokers had normal spirometry (p<0.001). Mean $FEV_1$ was significantly lower in smokers (1.19 ± 0.46 L) compared to non-smokers (1.68 ± 0.51 L). The 6MWT distance was also significantly reduced in smokers (326.45 ± 34.21 m) versus non-smokers (369.47 ± 30.39 m) (p=0.012). A strong negative correlation was observed between the smoking index and all functional parameters including FVC, $FEV_1$, $FEV_1$/FVC, PEF, and 6MWD (p<0.001). Patients with bilateral radiological lesions had significantly worse functional outcomes than those with unilateral involvement.* ***Conclusion:*** *Both lung function and exercise capacity were significantly compromised in smokers with post-tuberculosis sequelae compared to non-smokers. Spirometry and 6MWT serve as effective tools to assess the extent of impairment and can help guide rehabilitation strategies. These findings highlight the importance of smoking cessation in improving long-term respiratory outcomes among TB survivors.*

***Keywords:*** *Pulmonary tuberculosis, post-TB sequelae, spirometry, six-minute walk test, smoking, respiratory function, Smoking Index, chronic lung disease, pulmonary rehabilitation*.

**Introduction**

Tuberculosis (TB) remains a pressing global public health challenge. India alone accounts for nearly one-fourth of the global TB burden, with an estimated 28 lakh new cases annually and 4.8 lakh deaths attributed to the disease [1]. Caused by *Mycobacterium tuberculosis*, TB is a highly infectious airborne disease transmitted via droplet nuclei. Even after completion of anti-tubercular therapy (ATT), residual damage to the lungs frequently persists.

Despite proper treatment, healing from TB often leads to long-term pulmonary sequelae such as fibrosis, cavitations, bronchiectasis, bulla formation, and calcification [2–4]. These sequelae can compromise pulmonary function and result in persistent symptoms including cough with sputum production, dyspnoea, wheezing, fever, chest pain, and haemoptysis.

To assess functional impairment due to these post-TB changes, tools such as spirometry and the six-minute walk test (6MWT) are widely used. Spirometry provides objective quantification of lung function, while the 6MWT evaluates exercise tolerance and correlates closely with a patient's ability to perform daily activities. These tests are particularly valuable in assessing the degree of disability and tailoring pulmonary rehabilitation, thereby improving the patient’s quality of life.

TB-related structural damage contributes to poor ventilation, impaired gas exchange, and reduced physical performance. Compared to laboratory-based tests, the 6MWT offers a practical, patient-friendly method for evaluating functional limitation and endurance. Smoking—an independent risk factor for both respiratory and cardiovascular conditions—can further deteriorate lung function. It exacerbates respiratory symptoms and adversely affects test outcomes, including both spirometry and 6MWT.

In this context, it becomes imperative to understand the additive or synergistic impact of smoking on pulmonary function in patients with TB sequelae. Exploring this relationship can provide valuable insights into disease progression and highlight the critical importance of smoking cessation.

**Post-Tuberculosis Sequelae**

TB may result in chronic structural damage affecting the pleura, pulmonary parenchyma, airways, mediastinum, and pulmonary vasculature, which can be visualized radiologically. As described by Kim et al., thin-walled cavities, fibrosis, lung collapse or destruction, aspergilloma, bronchiectasis, and bulla are frequently encountered in treated TB patients [3–6]. A combination of these morphological changes is often responsible for persistent respiratory dysfunction in post-TB patients.

**Impact of Smoking on Tuberculosis Pathogenesis**

Tobacco smoke contains over 4,000 harmful chemicals, many of which directly impair respiratory health. The particulate matter in smoke deposits in alveoli and airways, leading to cilia damage, epithelial irritation, and impaired mucociliary clearance. Beedi smoke, due to its unprocessed nature, is considered even more hazardous than cigarette smoke.

Prolonged exposure to tobacco and other pollutants compromises tracheobronchial clearance, facilitating *M. tuberculosis* invasion of the alveoli [7]. Smoking also alters alveolar surfactant function [8] and interferes with immune mechanisms. Notably, nicotine binds to acetylcholine receptors on macrophages, suppressing intracellular TNF-α production, which is vital for mycobacterial clearance [9]. Studies have consistently shown that smoking correlates with higher TB incidence, increased disease severity, and delayed radiological resolution [10–14].

Deepti Rathee et al. reported that only 80% of smokers achieved full radiographic clearance post-treatment, compared to 93.3% of non-smokers. Persistent cavitations were more common among smokers and ex-smokers than in non-smokers [15].

Common post-TB radiological abnormalities include:

1. Fibrosis
2. Cavitation
3. Bronchiectasis
4. Calcification
5. Bulla
6. Lung collapse/destruction
7. Mixed lesions

**Tuberculosis and Immunology**

TB pathogenesis involves intricate immunological responses. Macrophages, the key immune cells, not only phagocytose *M. tuberculosis* but also initiate tissue remodelling, contributing to airflow obstruction. Uncontrolled matrix metalloproteinase (MMP) activity can cause extensive tissue damage.

Granuloma formation is the hallmark of TB, consisting of macrophages, lymphocytes, neutrophils, and multinucleated giant cells, with a central core of caseous necrosis [16–18]. Over time, granulomas may calcify, fibrose, or cavitate, each with different implications for lung function. Proteolytic enzymes released by neutrophils and macrophages promote liquefaction and cavity formation.

Stages of Pulmonary Tuberculosis[19,20]

1. Stage 1: No bacillary growth – Alveolar macrophages destroy bacilli.
2. Stage 2: Symbiotic phase – Bacilli multiply within immature macrophages.
3. Stage 3: Caseous necrosis – Host response restricts bacillary growth.
4. Stage 4: Cell-mediated immunity – Determines containment or progression.
5. Stage 5: Liquefaction – Leads to cavity formation due to necrosis.

Common symptoms include:

- Cough
- Breathlessness
- Sputum production
- Chest pain
- Haemoptysis
- Wheeze

**Inflammatory Mediators in TB and Sequelae**

Pulmonary fibrosis and airway distortion in TB arise from abnormal healing, involving inflammatory mediators like:

- TNF-α
- IL-1β, IL-6, IL-12, IL-18
- Interferon-γ
- Matrix Metalloproteinases (MMPs) [21,24]

**Key Risk Factors for Post-TB Sequelae**

1. Extensive pulmonary involvement
2. Delay in diagnosis
3. Incomplete or inadequate treatment
4. Immunocompromised states (e.g., HIV, CKD)
5. Smoking
6. Diabetes mellitus

**Spirometry Overview**

Spirometry quantifies lung function, especially in evaluating forced vital capacity (FVC) and forced expiratory volume in 1 second ($FEV_1$). These measurements aid in identifying obstructive, restrictive, or mixed defects and are particularly useful for early diagnosis of airflow limitations.

Common Spirometry Devices:

- Flow-measurement spirometers: Pneumotachograph, turbine, ultrasonic sensors
- Volume-measurement spirometers: Water seal, bellows, rolling seal

**Smoking and Spirometry**

Smoking significantly impairs lung function. A study by Sunita Nighute and Abhijit Awari found that among 50 smokers, 36% had obstructive, 8% restrictive, and 4% mixed patterns, whereas 98% of non-smokers had normal spirometry [25]. Bano et al. and others concluded that smokers were over 17 times more likely to develop obstructive lung disease [26,27]. Boskabady et al. observed more frequent respiratory symptoms and lower spirometry values among smokers [28].

**Spirometry in Post-TB Patients**

Several studies underscore the prevalence of persistent pulmonary dysfunction after TB. Ananya Panda et al. observed that the most common defect was restrictive (39.6%), followed by mixed (34.7%), and obstructive in only a few cases [29]. Manji et al. noted 74% of their TB patients had impaired lung function, with obstructive patterns in 42%, restrictive in 13%, and mixed in 19% [30].

Other notable studies:

- Meyyappan D. reported mixed defects in 39% and reduced exercise tolerance in 98% of patients[31].
- Singh B. found obstructive patterns to be most common [32].
- Agarwala A. found 52.7% obstructive, 13.8% restrictive, and 16.6% mixed defects [33].

These findings support the notion that TB is a key risk factor for chronic obstructive pulmonary disease and long-term functional decline.

**Six-Minute Walk Test (6MWT)**

The 6MWT is a simple, low-cost test to evaluate functional status and exercise capacity, widely applicable even in peripheral settings. It reflects the ability to perform daily activities and helps assess the impact of pulmonary or cardiac disease, both pre- and post-treatment

[34].

It is especially useful for:

- Baseline functional assessment
- Monitoring response to therapy
- Predicting morbidity and mortality
- Guiding rehabilitation programs

**Need for the Study**

Pulmonary tuberculosis (TB), despite successful treatment, often leaves behind significant structural and functional lung impairments known as post-tuberculosis sequelae. These sequelae—such as fibrosis, cavitation, bronchiectasis, and collapse—result in persistent respiratory symptoms and impaired pulmonary function. In India, which bears nearly a quarter of the global TB burden, the long-term impact of TB on respiratory health is a growing concern, especially given the high incidence of both active TB and smoking.

While spirometry and the six-minute walk test (6MWT) are established tools for assessing lung function and exercise tolerance, there is a scarcity of studies comparing the functional outcomes in smokers and non-smokers among patients with post-TB sequelae. Smoking is known to worsen respiratory symptoms and accelerate lung function decline; however, its specific contribution to the deterioration of pulmonary function in the context of TB sequelae remains underexplored in the Indian population.

Understanding these differences is crucial for:

- Identifying high-risk patients (e.g., smokers with TB sequelae)
- Planning individualized rehabilitation strategies
- Promoting smoking cessation as part of TB management
- Enhancing long-term outcomes and quality of life in TB survivors

Therefore, this study is needed to fill the existing gap by comparing the respiratory function and functional capacity of smokers and non-smokers with treated pulmonary tuberculosis and radiological sequelae, using objective assessments like spirometry and 6MWT. The findings may help inform clinical decisions and public health strategies targeted at post-TB care and smoking cessation efforts.

**Aim**

To compare the respiratory function among treated pulmonary tuberculosis patients with sequelae between smokers and non-smokers.

**Objectives**

1. To compare the spirometric parameters between smokers and non-smokers among patients treated for pulmonary tuberculosis.
2. To compare the six-minute walk distance (6MWD) between smokers and non-smokers in the same patient population.
3. To evaluate the overall functional status, including both spirometry and exercise capacity, in treated pulmonary tuberculosis patients with sequelae, stratified by smoking status.

**Methodology**

**Study Setting and Design**

This prospective, cross-sectional study was conducted over a period of 18 months in the Department of Respiratory Medicine, Great Eastern Medical School, Srikakulam, after obtaining ethical clearance from the Institutional Ethics Committee.

**Study Population**

Participants were recruited from the outpatient department of the institution. All eligible patients were those previously treated for sputum-positive pulmonary tuberculosis and now presenting with post-TB sequelae.

**Inclusion Criteria**

1. Patients previously treated for sputum-positive tuberculosis in accordance with RNTCP guidelines.
2. Currently sputum smear-negative for acid-fast bacilli (AFB).
3. Chest X-ray showing radiological evidence of tuberculosis sequelae.

**Exclusion Criteria**

1. Resting blood pressure >180/120 mmHg.
2. Resting heart rate >120 beats per minute.
3. History of recent chest pain or cardiovascular compromise.
4. Musculoskeletal or vascular abnormalities of the lower limbs affecting mobility.
5. Known cases of respiratory failure.
6. History of recent abdominal or cardiac surgery (within the last 6 months).

**Ethical considerations**

This study was reviewed and approved by the Institutional Ethics Committee (IEC) of Great Eastern Medical School and Hospital, Srikakulam, prior to its commencement (IEC Approval Number: **921/IEC/GEMS&H/202**). The research was conducted in accordance with the ethical principles outlined in the Declaration of Helsinki (2013 revision)and theIndian Council of Medical Research (ICMR) guidelines for biomedical research involving human participants (2017)**.**

Informed written consent was obtained from all participants following a detailed explanation of the study objectives, procedures, and potential risks. While the study posed minimal risk, some participants may have experienced temporary symptoms such as dizziness or dyspnea during testing (e.g., spirometry or 6-minute walk test).
Patient confidentiality was strictly maintained, with all collected data anonymized and used exclusively for research purposes. Participants indirectly benefited from increased awareness of their pulmonary status and were provided guidance regarding possible rehabilitation interventions to improve quality of life.

**Clinical Assessment and Grouping**

All participants underwent a detailed clinical evaluation, including history of presenting symptoms, prior anti-tubercular treatment (ATT) details, and smoking history. Based on smoking status, patients were categorized as smokers and non-smokers.

**Smoking Index**

The Smoking Index (SI) was calculated as:
SI = (Number of cigarettes or beedis smoked per day) × (Number of years smoked)
Smokers were further classified as [35]:

- Mild smokers: SI < 100
- Moderate smokers: SI = 100–300
- Heavy smokers: SI > 300

**Anthropometric Measurements**

Height (in centimetres) and weight (in kilograms) were recorded for each participant. Body Mass Index (BMI) was calculated and categorized based on NICE guidelines:

- Underweight: BMI < 18.5
- Normal: BMI 18.5–24.9
- Overweight: BMI 25.0–29.9
- Obese: BMI ≥ 30

**Anti-Tubercular Treatment (ATT) History**

Detailed ATT history was documented, including regimen type (government or private), treatment duration, drugs administered, and sputum AFB status at initiation.

**Radiological Assessment**

Chest radiographs were evaluated to assess TB sequelae. The lung fields were divided into six anatomical zones:

- Upper zone: Up to the lower border of the 2nd rib
- Middle zone: Between the lower borders of the 2nd and 4th ribs

- Lower zone: Below the 4th rib

**Spirometry Assessment**

Pulmonary function testing was performed using the Minispir II spirometer with Winspiro PRO software v5.7. Patients were instructed in their local language and tested in a seated position using disposable mouthpieces.

Parameters Recorded

- Forced Vital Capacity (FVC)
- Forced Expiratory Volume in 1 second ($FEV_1$)
- $FEV_1$/FVC ratio
- Peak Expiratory Flow Rate (PEFR)

Both pre- and post-bronchodilator values were measured.

**Pattern Classification (ATS Guidelines)**[14]

- Normal: $FEV_1$/FVC >70% and FVC >80% predicted
- Obstructive: $FEV_1$/FVC <70%, FVC >80% predicted
- Restrictive: $FEV_1$/FVC >70%, FVC <80% predicted
- Mixed: $FEV_1$/FVC <70%, FVC <80% predicted

**Severity Grading (ATS/ERS Standards)**[6]

- Obstruction (based on % predicted $FEV_1$):
    - Mild: 70–79%, Moderate: 60–69%, Moderately Severe: 50–59%, Severe: 35–49%, Very Severe: <35%
- Restriction (based on % predicted FVC):
    - Mild: 70–80%, Moderate: 60–69%, Moderately Severe: 50–59%, Severe: <50%

**Six-Minute Walk Test (6MWT)**

The 6MWT was conducted in accordance with ATS guidelines. A 30-meter corridor with floor markings was used. Patients were instructed to walk back and forth at their own pace for six minutes. No encouragement was provided, and time announcements were made every minute.

**Protocol Details**

- Patients were allowed to pause if they experienced chest pain, giddiness, or cramps.
- The test resumed if the patient recovered.
- Distance was recorded at 2, 4, and 6 minutes.
- Pre- and post-test measurements included:
    - Heart Rate (HR)
    - Blood Pressure (BP)
    - Oxygen Saturation ($SpO_2$)
    - Borg Dyspnoea Score

**Borg Dyspnoea Scale**

- 0: No breathlessness
- 0.5: Very, very slight

- Progressively increasing scores reflected greater breathlessness

**Statistical Analysis**

All data were compiled using Microsoft Excel and analyzed using SPSS software. Continuous variables such as spirometric parameters and six-minute walk distance were expressed as mean ± standard deviation (SD), while categorical variables such as spirometric patterns, BMI categories, and symptom distribution were presented as frequencies and percentages. To compare mean values between smokers and non-smokers, the Independent Samples t-test was applied when data followed a normal distribution, and the Mann–Whitney U test was used for non-normally distributed variables. For comparison of categorical variables between groups, the Chi-square test was utilized. To assess the relationship between the Smoking Index and functional parameters including spirometry values and 6MWD, Spearman's rank correlation coefficient was used. A p-value less than 0.05 was considered statistically significant throughout the analysis.

**Results**

The baseline characteristics (Table 1) showed that smokers were, on average, older than non-smokers, with a mean age of 58.22 years compared to 53.06 years. A majority of smokers were male and had normal BMI, whereas a higher proportion of non-smokers were underweighted. Most smokers had a high smoking index (>300), with 40% smoking for over 20 years and 80% using beedis. Table 2 compared spirometry patterns, revealing that mixed ventilatory defects were most common among smokers (56%), while the majority of non-smokers (38%) exhibited normal lung function. Table 3 further detailed spirometric parameters among smokers, showing significantly reduced mean FVC (1.88 L), FEV1 (1.19 L), and FEV1/FVC ratio (62.18%), indicating obstructive and mixed defects.

Functional capacity, assessed through the six-minute walk test (Table 4), was significantly impaired in smokers, who walked a mean distance of 326.45 meters compared to 369.47 meters in non-smokers ($p = 0.012$). Hemodynamic parameters post-walk (Table 5) also reflected compromised function in smokers, with significantly lower post-test SPO2 and elevated heart rate, systolic and diastolic blood pressure, and mean arterial pressure. Table 6 demonstrated a strong and statistically significant negative correlation between the smoking index and all key pulmonary function parameters (FVC, FEV1, FEV1/FVC, PEF) as well as walk distance, indicating that higher smoking burden was associated with worse respiratory outcomes. Lastly, Table 7 showed that patients with bilateral radiological lesions had significantly poorer spirometric values and walked shorter distances than those with unilateral lesions, confirming the impact of structural lung damage on functional impairment.

**Table 1. Baseline Characteristics of Study Participants (n=100)**

| Characteristic | Smokers (n = 50) | Non-Smokers (n = 50) | *p*-value |
|---|---|---|---|
| **Age (mean ± SD)** | 58.22 ± 10.15 | 53.06 ± 12.06 | 0.690 |
| **Sex** | | | |
| Male | 34 (68%) | 28 (56%) | — |
| Female | 16 (32%) | 22 (44%) | — |
| **BMI Category** | | | — |
| Underweight (<18.5) | 11 (22%) | 23 (46%) | — |
| Normal (18.5–24.9) | 30 (60%) | 23 (46%) | — |
| Overweight (≥25) | 9 (18%) | 4 (8%) | — |
| **Smoking Index** | — | — | — |
| <100 (Mild) | 1 (2%) | — | — |
| 100–300 (Moderate) | 10 (20%) | — | — |
| >300 (Heavy) | 34 (68%) | — | — |
| **Duration of Smoking** | | | — |
| <10 years | 8 (16%) | — | — |
| 11–15 years | 12 (24%) | — | — |
| 16–20 years | 10 (20%) | — | — |
| >20 years | 20 (40%) | — | — |
| **Type of Smoking** | | — | — |
| **Beedi only** | 40 (80%) | — | — |
| **Cigarette only** | 5 (10%) | — | — |
| **Both** | 5 (10%) | — | — |
| **Smokes per Day** | | — | — |
| **<10** | 20 (40%) | — | — |
| **11–20** | 16 (32%) | — | — |
| **21–30** | 14 (28%) | — | — |

**Table 2. Comparison of Spirometry Patterns Between Smokers and Non-Smokers**

| Spirometry Pattern | Smokers (n=50) | Non-Smokers (n=50) | *p*-value |
|---|---|---|---|
| **Mixed** | 28 (56%) | 5 (10%) | <0.001 |
| **Obstructive** | 14 (28%) | 16 (32%) | ns |

| Spirometry Pattern | Smokers (n=50) | Non-Smokers (n=50) | *p*-value |
|---|---|---|---|
| Restrictive | 5 (10%) | 10 (20%) | ns |
| Normal | 3 (6%) | 19 (38%) | <0.001 |

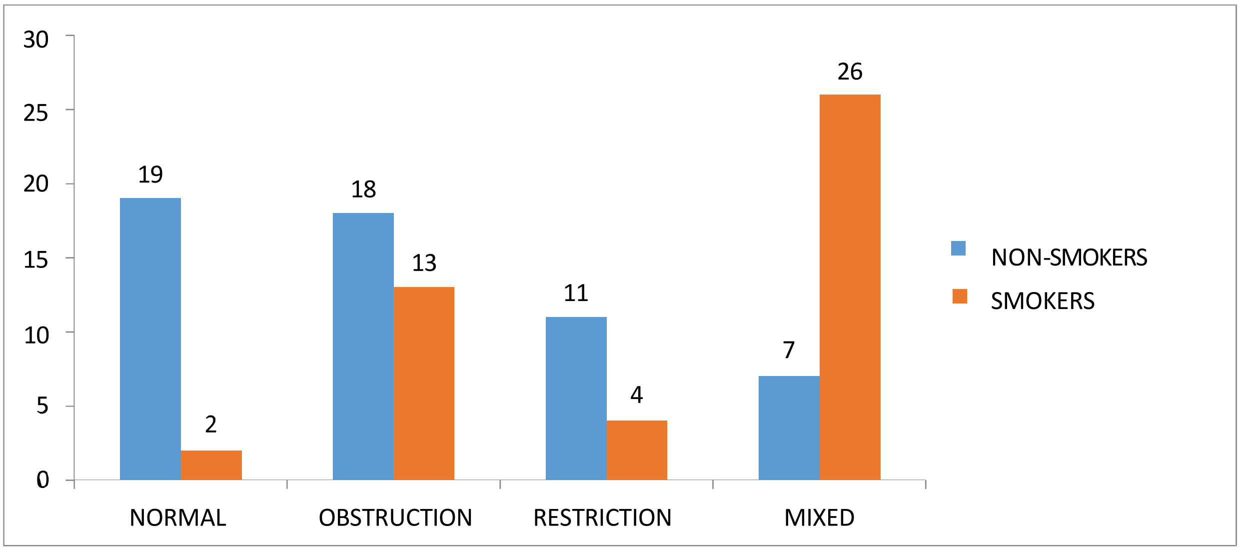


**Table 3. Spirometry Parameters in Smokers**

| Parameter | Mean ± SD |
|---|---|
| FVC (L) | 1.88 ± 0.53 |
| FEV1 (L) | 1.19 ± 0.46 |
| FEV1/FVC (%) | 62.18 ± 11.77 |
| PEF (L/sec) | 3.09 ± 5.62 |

**Table 4. Six-Minute Walk Distance Comparison**

| Group | Mean Distance (m) ± SD | *p*-value |
|---|---|---|
| Smokers | 326.45 ± 34.21 | 0.012 |

| **Group** | **Mean Distance (m) ± SD** | ***p*-value** |
|---|---|---|
| **Non-Smokers** | 369.47 ± 30.39 | |

**Table 5. Hemodynamic Parameters Pre- and Post-6MWT**

| **Parameter** | **Group** | **Pre-Test (Mean ± SD)** | **Post-Test (Mean ± SD)** | **p-value** |
|---|---|---|---|---|
| **$SpO_2$ (%)** | **Smokers** | 96.26 ± 1.24 | 92.74 ± 2.66 | <0.001 |
| | **Non-Smokers** | 97.55 ± 1.10 | 95.82 ± 1.69 | 0.065 |
| **Heart Rate (bpm)** | **Smokers** | 86.96 ± 7.48 | 103.44 ± 13.89 | <0.001 |
| | **Non-Smokers** | 82.42 ± 5.89 | 90.53 ± 8.08 | 0.076 |
| **SBP (mmHg)** | **Smokers** | 119.64 ± 8.44 | 127.68 ± 9.80 | <0.001 |
| | **Non-Smokers** | 117.71 ± 9.51 | 122.91 ± 9.42 | 0.004 |
| **DBP (mmHg)** | **Smokers** | 77.40 ± 6.44 | 82.32 ± 6.04 | 0.034 |
| | **Non-Smokers** | 77.18 ± 6.09 | 78.98 ± 6.28 | 0.087 |
| **MAP (mmHg)** | **Smokers** | 90.42 ± 5.85 | 97.08 ± 6.13 | <0.001 |
| | **Non-Smokers** | 90.67 ± 6.50 | 93.58 ± 6.56 | 0.098 |

**Table 6. Correlation Between Smoking Index and Functional Parameters**

| **Parameter** | **Spearman's rho** | ***p*-value** |
|---|---|---|
| **FVC** | -0.450 | <0.001 |
| **FEV1** | -0.687 | <0.001 |
| **FEV1/FVC** | -0.585 | <0.001 |
| **PEF** | -0.604 | <0.001 |
| **6MWD** | -0.691 | <0.001 |

**Table 7. Radiological Lesion Extent vs Spirometry and 6MWT**

| Lesion (X-ray) | FVC (L) | FEV1 (L) | FEV1/FVC (%) | PEF (L/s) | 6MWD (m) |
|---|---|---|---|---|---|
| **Unilateral** | 2.18 | 1.55 | 72.75 | 3.22 | 358.47 |
| **Bilateral** | 1.62 | 0.98 | 60.63 | 1.32 | 296.79 |
| ***p*-value** | <0.001 | <0.001 | <0.001 | <0.001 | <0.001 |

**Discussion:**

Pulmonary tuberculosis causes a variety of long-term lung problems, including pulmonary fibrosis, bronchiectasis, aspergilloma, airway stenosis, and chronic airflow obstruction [36], and has also been linked to lung cancer [37]. These consequences frequently result in complications such as recurrent respiratory infections, haemoptysis, pulmonary hypertension, and cor pulmonale. They also interfere with daily activities, resulting in poor quality of life, increased financial burden, and psychological distress.

In our study, a total of 100 treated pulmonary tuberculosis patients with sequelae were included and categorized into two equal groups: Group I – smokers, and Group II – non-smokers. In the smokers' group, 34 were male and 16 were female; in the non-smokers' group, 28 were male and 22 were female. The most common age group was 51–60 years, with a mean age of approximately 51 years. Among smokers, one patient was a mild smoker, 10 were moderate smokers, and 34 were heavy smokers, as defined by their smoking index.

Consistent with earlier studies, the most common symptoms observed in our cohort were cough (86%), breathlessness (66%), and sputum production (86%), closely matching reported figures in the literature where cough, breathlessness, and sputum production were seen in 90%, 80%, and 86% of patients, respectively. Long R conducted a prospective study in 25 patients with post-TB sequelae and reported emphysematous changes (36%), bronchiectasis (40%), bronchial distortion (56%), and fibrosis (64%) as the most common radiological abnormalities [16]. In our investigation, bronchiectasis was observed in 27%, fibrosis in 25%, and mixed radiological lesions in 43% of patients.

Racilet et al. found that smokers had a higher residual radiological severity score than non-smokers, with more extensive lobar involvement [38]. This aligns with our study findings where 71% of non-smokers had only one lung zone involved, compared to just 24% in smokers. Conversely, 16% of smokers had involvement of four or more zones, while no non-smokers exhibited this extent of radiological spread.

**Spirometry**

Among smokers, the mixed pattern predominated (56%), followed by obstruction (14%), restriction (5%), and only 3% had normal spirometry. In contrast, the non-smoker group showed normal spirometry in 38%, followed by obstruction (32%),

restriction (20%), and mixed pattern (10%). These differences were statistically significant ($p$< 0.0001).
Spearman correlation analysis showed a significant negative correlation between smoking index and spirometric parameters (FVC, $FEV_1$, $FEV_1$/FVC, PEF), as well as the six-minute walk distance (6MWD) ($p$< 0.0001). These findings are similar to those reported by Avradip Santra et al., who found obstructive patterns in 27.54% and mixed patterns in 72.46% of patients [39]. Nimit V. Khara et al. found mixed ventilatory defects in 47%, restrictive defects in 37%, and obstructive defects in 9% [37]. Neeta Singh et al., in a study of 51 multidrug-resistant TB patients' post-treatment, found that 96% had ventilatory defects: 66% mixed, 19% restrictive, and 11% obstructive [40].
However, other studies have shown different patterns. Verma et al., in a study of 92 post-TB patients, found 37 had restrictive defects and 21 had mixed patterns [38]. Bhola Singh et al. observed that obstructive defects were predominant (56.25%), with restrictive impairment in only 10.42% [32]. Manji et al. reported obstructive, restrictive, and mixed impairments in 42%, 13%, and 19% of patients, respectively [30,41]. Santhosh Kumar et al. noted obstructive defects in 45.1%, restrictive in 25.6%, and mixed in 29.3%. Patil et al. found that obstructive defects were most common (42%), followed by mixed (14%) and normal spirometry (46%) [42].
Tuberculosis acts as an independent risk factor for the development of airflow obstruction, possibly due to ventilation–perfusion mismatch, structural airway abnormalities, vasoconstriction, hypoxemia, and vascular damage by the bacilli. Additional changes such as pleural thickening, fibrosis, and atelectasis may explain the high prevalence of mixed patterns observed in our cohort [4,16].

**Effect of Smoking on PTB**

Smoking compounds the pulmonary damage caused by TB. Nicotine suppresses tumour necrosis factor-alpha (TNF-α), which is essential for macrophage-mediated immune response, increasing susceptibility to lung structural damage [43]. Furthermore, mycobacterial antigens, combined with smoking and environmental pollutants, perpetuate chronic airway inflammation and bronchial narrowing. Smoking alters normal tissue repair mechanisms and promotes protease activity, particularly matrix metalloproteinases (MMPs), which degrade lung tissue and lead to airflow obstruction and fibrosis [37].
Anup Banur et al. found that beedi smokers had significantly lower FVC, $FEV_1$, $FEV_1$/FVC, PEFR, and MEF75 values compared to non-smokers [44]. Similar results were reported by Padmavathy KM and Bano R et al., who demonstrated a greater prevalence of obstructive ventilatory defects among smokers than non-smokers [45,46].

**Six-Minute Walk Test (6MWT)**

The six-minute walk test, used to evaluate functional capacity, revealed significantly poorer performance among smokers. In our study, 8 out of 45 smokers were unable to complete the test due to breathlessness and palpitations, while all non-smokers completed it. The mean distance walked by non-smokers was 369.47 ± 30.39 meters, compared to 326.45 ± 34.21 meters in smokers—a significant difference of 43 meters ($p < 0.0001$).

These findings are consistent with studies by S. Sivaranjini et al., who found significantly lower 6MWD among smokers [47], and Karanth et al., who showed that post-TB patients had significant functional impairment and lower walk distances [48]. Mikhail Chushkin et al. reported a strong correlation between 6MWD, spirometry, and patient symptoms [43]. Similarly, Marcos DP et al., in drug-resistant TB patients, showed reduced distances in the six-minute walk test [50].

Reduced 6MWD in smokers may be due to several factors, including chronic hypoxemia, carbon monoxide-induced functional anaemia, and impaired cardiovascular and muscular responses to exercise. Smoking has also been shown to diminish peripheral muscle efficiency and cardiac reserve, all of which contribute to poor exercise tolerance and recovery.

**Limitations**

Mixed ventilatory defects are difficult to confirm using spirometry alone. A definitive diagnosis of a mixed disorder requires both spirometry and lung volume measurements. A mixed pattern is suspected when spirometry shows an obstructive pattern (low FEV1/FVC ratio) accompanied by a reduction in total lung capacity (TLC). In our study, only spirometry was used to assess restrictive defects; thus, some mixed disorders may have been misclassified. Future studies incorporating lung volume testing and diffusion capacity assessments are recommended to improve diagnostic accuracy.

**Conclusion:**

This study was conducted to compare the respiratory function of treated pulmonary tuberculosis patients with sequelae among smokers and non-smokers. The most common spirometric pattern among smokers was the mixed type (56%), followed by obstructive (14%), restrictive (5%), and only 3% had normal lung function. In contrast, non-smokers most frequently exhibited a normal pattern (38%), with obstructive, restrictive, and mixed patterns observed in 32%, 20%, and 10% of cases, respectively. The mean FEV1 was significantly lower in smokers (1.09 L) compared to non-smokers (1.68 L), indicating compromised lung function. Additionally, the mean distance walked in the six-minute walk test (6MWT) was significantly reduced in smokers (326.45 ± 34.21 meters) compared to non-smokers (369.47 ± 30.39 meters), reflecting reduced exercise capacity. These findings highlight that both spirometric values and functional capacity were significantly impaired in smokers with post-tuberculosis sequelae. Spirometry and 6MWT served as effective tools to assess the functional status and quality of life in these patients and may aid in planning appropriate pulmonary rehabilitation. Most importantly, this study reinforces the need for strong smoking cessation advocacy in tuberculosis management, as continued tobacco use is associated with worsened long-term respiratory outcomes and diminished recovery.

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**Supplementary Tables**

**Supplementary Table 1. Radiological Side Involvement in Chest X-ray**

| Side of Lesion | Smokers (n=50) | Non-Smokers (n=50) | *p*-value |
|---|---|---|---|
| **Unilateral** | 28 (56%) | 31 (62%) | 0.374 |
| **Bilateral** | 22 (44%) | 19 (38%) | |

**Supplementary Table 2. Distribution of Radiological Side Effects**

| Side Effect | Smokers (n=50) | Non-Smokers (n=50) | *p*-value |
|---|---|---|---|
| **Collapse** | 8 (16%) | 0 (0%) | — |
| **Cavitation** | 15 (30%) | 6 (12%) | 0.048 |
| **Bronchiectasis** | 28 (56%) | 23 (46%) | 0.682 |
| **Bulla** | 5 (10%) | 2 (4%) | 0.992 |
| **Calcification** | 6 (12%) | 3 (6%) | 0.137 |
| **Combined Lesions** | 28 (56%) | 12 (24%) | <0.001 |

**Supplementary Table 3. Distribution of Number of Lung Zones Involved**

| No. of Zones Involved | Smokers (n=50) | Non-Smokers (n=50) | *p*-value |
|---|---|---|---|
| **1 Zone** | 11 (22%) | 39 (71%) | <0.001 |
| **2 Zones** | 17 (38%) | 15 (27%) | <0.001 |
| **3 Zones** | 10 (20%) | 1 (2%) | <0.001 |
| **4 or more Zones** | 7 (16%) | 0 (0%) | <0.001 |

**Supplementary Table 4. Spirometry and 6MWD by Number of Zones Involved**

| Zones Involved | FVC (L) | FEV1 (L) | FEV1/FVC (%) | PEF (L/s) | 6MWD (m) | *p*-value |
|---|---|---|---|---|---|---|
| **1 Zone** | 2.23 | 1.68 | 78.17 | 3.60 | 370.84 | <0.001 |
| **2 Zones** | 2.09 | 1.35 | 64.95 | 1.66 | 338.34 | |
| **3 Zones** | 1.58 | 0.89 | 57.75 | 1.27 | 287.82 | |

| **Zones Involved** | **FVC (L)** | **FEV1 (L)** | **FEV1/FVC (%)** | **PEF (L/s)** | **6MWD (m)** | ***p*-value** |
|---|---|---|---|---|---|---|
| **4 Zones** | 1.28 | 0.63 | 51.66 | 1.01 | 261.71 | |

**Supplementary Table 5. Smoking Type and Frequency**

| **Characteristic** | **Smokers (n=50)** |
|---|---|
| **Type of Smoking** | |
| **Beedi only** | 40 (80%) |
| **Cigarette only** | 5 (10%) |
| **Both** | 5 (10%) |
| **Smokes per Day** | |
| **<10** | 20 (40%) |
| **11–20** | 16 (32%) |
| **21–30** | 14 (28%) |

In the supplementary analysis, radiological patterns and smoking behaviours were further explored to understand their relationship with pulmonary function. Bilateral radiological involvement was observed more frequently in smokers (44%) than in non-smokers (38%), although this difference was not statistically significant (Supplementary Table 1). Specific radiological complications such as cavitation and collapse were notably more prevalent among smokers, with cavitation present in 30% of smokers versus 12% of non-smokers ($p$ = 0.048), and collapse exclusively found in the smoking group. Additionally, 56% of smokers exhibited combined radiological lesions compared to 24% in non-smokers, which was statistically significant ($p$< 0.001) (Supplementary Table 2).

The number of lung zones involved also differed significantly between groups, with 71% of non-smokers having only one affected zone, while smokers more frequently had involvement of two or more zones (Supplementary Table 3). A progressive decline in spirometric parameters and 6-minute walk distance (6MWD) was observed with increasing zonal involvement, indicating that radiological disease burden strongly influences both lung function and exercise capacity (Supplementary Table 4). Regarding smoking patterns, the vast majority of smokers (80%) used beedis, and 60% smoked more than 10 beedis per day, with 28% smoking over 20 per day (Supplementary Table 5). These findings further highlight the structural and functional pulmonary consequences of chronic smoking, particularly in individuals with a history of pulmonary tuberculosis.