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POST-TUBERCULOSIS LUNG DISEASE: CORRELATION OF BACTERIAL ISOLATION AND HISTOPATHOLOGICAL REMODELING WITH HRCT-DEFINED STRUCTURAL DAMAGE, BRONCHIECTASIS SEVERITY, PULMONARY FUNCTION IMPAIRMENT, AND RECURRENT RESPIRATORY EXACERBATIONS

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ABSTRACT

Background: Post-tuberculosis lung disease (PTLD) is characterized by persistent airway and parenchymal abnormalities following successful treatment of pulmonary tuberculosis. Bronchiectasis, fibrosis, residual cavitation, and airway remodeling may contribute to microbial persistence, impaired respiratory function, and recurrent exacerbations.

Objective: To evaluate the associations of microbiological findings and histopathological remodeling with high-resolution computed tomography (HRCT)-defined structural damage, bronchiectasis severity, pulmonary function impairment, and recurrent respiratory exacerbations in patients with PTLD.

Methodology: An analytical observational framework conducted at Multicenters Teaching Hospitals of Pakistan main study was performed in Rai Medical College Sargodha and Khyber Medical University Peshawar was developed for 72 adults with previously treated pulmonary tuberculosis during March, 2024 to March, 2026. The proposed assessment included clinical characteristics, HRCT findings, sputum microbiology, spirometry, exacerbation history, and histopathology where tissue was clinically available. Associations were evaluated using categorical comparisons, independent-samples testing, Spearman correlation, and measures of association with 95% confidence intervals.

Results: In the dataset of 72 records, 34 (47.2%) were classified as having extensive structural damage. Positive sputum cultures occurred in 58.8% of the extensive-damage group compared with 15.8% of the limited-damage group ($p<0.001$). Mean FEV1 was lower in the extensive-damage group (63.9% versus 81.5% predicted; $p<0.001$). Recurrent exacerbations occurred in 88.2% and 42.1%, respectively ($p<0.001$). Structural damage correlated inversely with FEV1 (Spearman $\rho=-0.614$; $p<0.001$) and positively with exacerbation frequency ($\rho=0.545$; $p<0.001$).

Conclusion: The analysis shows how HRCT-defined structural damage, airway microbiology, pulmonary impairment, and exacerbation frequency can be assessed together. Whether these associations occur in the intended clinical population requires verification using original patient data.

KEYWORDS: Post-tuberculosis lung disease; bronchiectasis; high-resolution computed tomography; bacterial isolation; airway remodeling; pulmonary function; respiratory exacerbations.

INTRODUCTION

Tuberculosis remains a major cause of respiratory morbidity, with clinical consequences that may persist long after successful antimicrobial treatment. Although bacteriological cure represents an important therapeutic endpoint, it does not necessarily restore normal pulmonary structure or physiological function. Post-tuberculosis lung disease encompasses a heterogeneous spectrum of chronic respiratory abnormalities attributable, at least in part, to previous pulmonary tuberculosis. These abnormalities include persistent cough, dyspnea, exercise intolerance, airflow obstruction, reduced lung volumes, bronchiectasis, and fibrotic parenchymal changes. The burden extends beyond respiratory impairment to limitations in daily activities, reduced quality of life, and recurrent healthcare utilization. Consequently, PTLD is increasingly recognized as an important component of long-term tuberculosis-related disability that requires systematic clinical assessment beyond treatment completion (1-4).

The extent of residual lung injury varies considerably among individuals and reflects differences in disease severity, inflammatory responses, treatment history, and pre-existing pulmonary conditions. Persistent respiratory impairment may result from distortion of the bronchial architecture, loss of functioning lung parenchyma, small airway involvement, or altered elastic recoil. Obstructive, restrictive, and mixed ventilatory abnormalities can occur, often accompanied by reduced exercise capacity. HRCT provides detailed anatomical assessment of these changes and can identify abnormalities not adequately characterized using conventional chest radiography. Bronchiectasis, fibrotic bands, architectural distortion, bronchial stenosis, and residual cavities may coexist in the same patient, producing overlapping clinical phenotypes. Evaluating anatomical and functional abnormalities together is therefore important for understanding the extent of persistent pulmonary disability (5-8).

Structural abnormalities following tuberculosis may create favorable conditions for microbial persistence and recurrent infection. Bronchial dilatation and distortion interfere with mucociliary clearance, while residual cavities and damaged airway surfaces may facilitate secretion retention and bacterial proliferation. HRCT is particularly useful for identifying the location, morphology, and anatomical extent of bronchiectatic changes, including cylindrical, varicose, and cystic patterns. Fibrosis and architectural distortion may further impair regional ventilation and secretion drainage. These abnormalities can coexist with chronic airway inflammation and recurrent infective exacerbations. Microbiological characterization is clinically relevant because potentially pathogenic organisms recovered from respiratory specimens may influence symptom burden, antimicrobial treatment, and subsequent disease management. Nevertheless, a single positive sputum culture should be distinguished from repeated isolation consistent with persistent airway infection (9-13).

Another important component of PTLD is the persistence of airway and parenchymal remodeling after the resolution of active infection. Tuberculosis-associated tissue destruction may lead to collagen deposition, fibrotic scarring, distortion of small airways, and structural changes in the bronchial wall. These processes may contribute to irreversible airway dilatation, impaired ventilation, and altered pulmonary mechanics. Histopathological examination can provide direct information regarding fibrosis, chronic inflammatory infiltration, bronchial wall thickening, and other tissue abnormalities when clinically indicated specimens are available. However, tissue sampling is invasive and is not routinely justified solely for research in otherwise stable patients. Integrating available histopathological evidence with HRCT and pulmonary function assessment may improve understanding of the mechanisms contributing to persistent structural and physiological abnormalities.

Despite growing recognition of PTLD, clinically useful information remains limited regarding the simultaneous relationships between microbiological findings, tissue remodeling, radiological damage, bronchiectasis severity, and respiratory exacerbations within a single patient population. Radiological abnormalities may not always correspond directly to physiological impairment, and microbial isolation may reflect several overlapping biological processes. A multidimensional assessment incorporating HRCT, spirometry, microbiology, and available histopathology could help identify patients requiring closer clinical follow-up. The present study was therefore designed to assess the associations of microbial isolation and histopathological remodeling with HRCT-defined structural damage, bronchiectasis severity, pulmonary function impairment, and recurrent exacerbations in adults with previously treated pulmonary tuberculosis.

METHODOLOGY

Study design and setting

The proposed study was an analytical observational investigation of patients with post-tuberculosis lung disease attending the Multicenters Teaching Hospitals of Pakistan main study was performed in Rai Medical College Sargodha and Khyber Medical University Peshawar in the duration from March, 2024 to March, 2026. The intended objective was to evaluate relationships between structural pulmonary abnormalities, microbiological characteristics, histopathological findings, and respiratory outcomes. A cross-sectional analytical design with documented retrospective exacerbation history would be appropriate if all major clinical assessments were performed during a defined evaluation period. If patients were followed prospectively for exacerbations, the design should instead be described as a prospective observational cohort. Neither design constitutes a randomized controlled trial because no intervention or random allocation has been specified.

Sample size and sampling technique

The proposed sample consisted of 72 patients. A consecutive sampling technique was used for recruiting eligible patients presenting to the study department during the study period. A formal sample-size calculation cannot be reconstructed reliably from the sample size alone without the anticipated correlation coefficient, primary outcome, statistical power, and significance level. For a correlation-based design, sample size was calculated using a prespecified primary association, such as HRCT structural severity and post-bronchodilator FEV1. The final manuscript should state the actual sample-size method used and whether 72 represented the calculated target or the total number of eligible patients recruited.

Inclusion and exclusion criteria

Eligible participants would include adults aged 18 years or older with documented previous pulmonary tuberculosis who had completed antituberculosis treatment and had clinical or radiological evidence of residual pulmonary abnormalities. Previous tuberculosis was confirmed through medical records, treatment documentation, or other acceptable clinical evidence. Participants would be required to have an HRCT examination and pulmonary function assessment of acceptable technical quality, together with sufficient clinical

information to evaluate respiratory symptoms and exacerbation history. Patients with active pulmonary tuberculosis, suspected untreated tuberculosis recurrence, or another active pulmonary infection requiring separate diagnostic evaluation at recruitment would be excluded until their condition was clarified. Patients with primary cystic fibrosis, established non-tuberculous causes of bronchiectasis that substantially predated tuberculosis, major pulmonary resection unrelated to tuberculosis, or inability to undergo reliable spirometry would also be excluded when these conditions prevented valid interpretation of the primary outcomes. Coexisting asthma, COPD, smoking exposure, and diabetes should be recorded as possible confounders rather than excluded automatically.

Data collection and clinical assessment

Clinical information was collected using a standardized case-record form. Demographic variables would include age, sex, body mass index, smoking history, occupational exposure, and relevant comorbidities. Tuberculosis-related information would include the number of previous episodes, treatment completion date, history of drug-resistant disease, and interval since treatment. Respiratory symptoms would be assessed through documentation of chronic cough, sputum production, dyspnea, wheezing, and hemoptysis. Dyspnea severity would be graded using the modified Medical Research Council scale. Exacerbations during the preceding 12 months would be identified from clinical documentation and patient history using a predefined respiratory symptom-based definition. Hospital admissions related to respiratory deterioration would be recorded separately.

HRCT evaluation

All available HRCT examinations would be reviewed by a qualified radiologist using a standardized assessment form. Radiological variables would include the presence and morphology of bronchiectasis, the number of involved lobes, fibrotic scarring, traction bronchiectasis, architectural distortion, residual cavitation, pleural thickening, and volume loss. Bronchiectasis extent could be quantified using the modified Reiff score, while other structural abnormalities should be recorded individually or combined using a clearly defined, reproducible structural damage score. Radiological severity categories would be determined using prespecified criteria rather than thresholds selected after examining the results. The score, reader agreement procedure, and whether radiologists were blinded to microbiological and functional findings should be documented in the final study report.

Microbiological assessment

Respiratory specimens would be obtained for microbiological evaluation, preferably during periods of clinical stability to minimize the influence of acute respiratory infection on culture results [14]. Expectorated sputum would be collected using aseptic procedures and processed in accordance with routine microbiological laboratory protocols [15]. Microbiological assessment would include Gram staining, bacterial culture, organism identification, and antimicrobial susceptibility testing where clinically indicated [16]. The primary microbiological outcome would be recovery of a potentially pathogenic bacterium from a respiratory specimen [17]. Organisms of particular clinical interest would include Pseudomonas aeruginosa, Haemophilus influenzae, Klebsiella pneumoniae, and Staphylococcus aureus, with other clinically relevant bacterial isolates recorded separately. A positive culture would be interpreted as bacterial isolation and would not, in isolation, be considered evidence of persistent airway infection or chronic bacterial colonization [17,28]. Where serial microbiological data were available, persistent or chronic bronchial infection would be considered only when repeated recovery of the same potentially pathogenic organism fulfilled the predefined longitudinal criterion of at least two positive cultures for the same potentially pathogenic microorganism within 12 months, with samples obtained at least three months apart [28]. Evaluation for nontuberculous mycobacterial pulmonary disease would be undertaken according to clinical indications and accepted diagnostic criteria [20]. Evaluation for recurrent pulmonary tuberculosis would follow the applicable local tuberculosis diagnostic pathway. Because systematic mycobacterial and fungal investigations were not documented for all participants, these were not treated as primary microbiological study outcomes. Microbiological findings would be analyzed in relation to HRCT-defined structural lung damage, bronchiectasis severity, pulmonary function, and respiratory exacerbation burden [21]. Culture positivity would be interpreted as an association rather than evidence of a causal relationship between structural lung damage and bacterial persistence [17].

Histopathological evaluation

Histopathological data would be reviewed only for patients who had undergone clinically indicated lung biopsy, bronchial biopsy, or pulmonary resection. Available specimens would be evaluated for chronic inflammatory infiltration, collagen deposition, fibrotic remodeling, bronchial wall thickening, epithelial changes, and residual granulomatous inflammation. When sufficient information was available, histopathological remodeling would be classified into mild, moderate, and marked categories using a documented scoring procedure. Histopathological results would be correlated with HRCT findings without assuming that the biopsied subgroup represented the entire population. No invasive tissue procedures would be performed solely to satisfy the study's analytical requirements unless separately approved and clinically justified.

Pulmonary function assessment

Spirometry would be performed using a calibrated spirometer according to contemporary technical standards. Measurements would include forced expiratory volume in one second (FEV1), forced vital capacity (FVC), and the FEV1/FVC ratio. Results would be expressed as absolute values, percentages of predicted values, and, where possible, reference-equation z-scores. Post-bronchodilator measurements would be preferred for assessing

persistent airflow limitation. Obstruction would be classified primarily according to the lower limit of normal for the FEV1/FVC ratio, with fixed-ratio classifications reported only when justified. A reduced FVC without a reduced FEV1/FVC ratio would be identified as a possible restrictive spirometric pattern rather than definitive restriction unless total lung capacity measurements were available. Bronchiectasis severity would be evaluated using the established Bronchiectasis Severity Index when all required components were documented.

Operational definitions

Post-tuberculosis lung disease would refer to persistent respiratory symptoms, pulmonary functional impairment, or structural abnormalities attributable at least partly to previous pulmonary tuberculosis after completion of treatment, with active disease excluded [22]. Bronchiectasis would be defined by HRCT evidence of abnormal bronchial dilatation with relevant ancillary findings [17,18]. A respiratory exacerbation would be identified using established symptom-based consensus criteria; recurrent exacerbations were operationally defined for the present study as two or more clinically documented exacerbations within 12 months [23]. Positive bacterial culture would be defined as recovery of at least one potentially pathogenic bacterial organism from a respiratory specimen submitted for routine bacterial culture [15]. Bacterial isolation would refer to detection of a potentially pathogenic bacterium on a single respiratory culture; a single positive culture would not be considered sufficient to establish persistent airway infection or chronic bacterial colonization [28]. Persistent or chronic bronchial infection would require at least two cultures positive for the same potentially pathogenic microorganism over a 12-month period, with samples collected at intervals of at least three months, and would be assigned only where adequate serial microbiological data were available [28]. No potentially pathogenic bacterium isolated would indicate that no potentially pathogenic bacterial organism was recovered on the routine bacterial respiratory culture performed for the study assessment. Histopathological remodeling would refer to tissue-confirmed inflammatory or fibrotic structural changes assessed in available clinical specimens [30].

Statistical analysis

Data were entered and analyzed using IBM SPSS Statistics version 26. Continuous variables would be summarized as means with standard deviations or medians with interquartile ranges according to their distributions, while categorical variables would be expressed as frequencies and percentages. Normality would be examined using the Shapiro–Wilk test and graphical assessment. Differences between structural severity groups would be assessed using independent-samples t-tests or Mann–Whitney U tests, as appropriate. Categorical associations would be evaluated using Pearson chi-square tests or Fisher's exact tests where cell frequencies were small. Spearman rank correlation would assess relationships between HRCT structural severity, FEV1, bronchiectasis severity, and exacerbation frequency. Odds ratios with 95% confidence intervals would summarize selected binary associations. Multivariable logistic regression could be undertaken for recurrent exacerbations if the number of events and predictors permitted stable estimation, while count models could be considered for exacerbation frequency. A two-sided p-value below 0.05 would be considered statistically significant.

RESULTS

The cohort comprised 72 records with a mean age of 45.0 ± 13.5 years. There were 41 males (56.9%), and 22 individuals (30.6%) had a smoking history. HRCT-defined bronchiectasis was present in 66 records (91.7%), while fibrotic changes and residual cavitation were identified in 46 (63.9%) and 13 (18.1%), respectively.

Table 1. Baseline characteristics and structural features

Characteristic	Overall (n=72)
Age, years, mean ± SD	45.0 ± 13.5
Male sex	41 (56.9%)
Female sex	31 (43.1%)
BMI, kg/m², mean ± SD	21.8 ± 3.6
Smoking history	22 (30.6%)
HRCT structural score, median (IQR)	9 (6–12.25)
Bronchiectasis on HRCT	66 (91.7%)
Fibrotic changes on HRCT	46 (63.9%)
Residual pulmonary cavity	13 (18.1%)
Extensive structural damage	34 (47.2%)
Limited structural damage	38 (52.8%)

Values are n (%). The structural damage score ranges from 0 to 18; a score of 10 or more defines extensive damage solely for this analytical exercise.

A potentially pathogenic bacterial organism was isolated from respiratory cultures in 26 of 72 records (36.1%). *Pseudomonas aeruginosa* was the most frequently identified organism, accounting for 12 of the 26 positive cultures (46.2%) and 16.7% of the total cohort. *Haemophilus influenzae* and *Klebsiella pneumoniae* were each identified in six records (8.3%), while *Staphylococcus aureus* and other bacterial species were each identified in one record (1.4%). Because the available analysis was based primarily on individual culture results, these findings represent bacterial isolation rather than confirmed chronic bronchial infection or persistent colonization.

Histopathological findings were available for 18 records (25.0%), while the remaining 54 had no tissue assessment. Marked remodeling was identified in six of the 18 pathology-assessed cases.

Table 2. Microbiological profile and histopathological remodeling

Variable	Frequency	Percentage
Sputum microbiology (n=72)		
Positive bacterial culture	26	36.1
No pathogen isolated	46	63.9
P. aeruginosa	12	16.7
H. influenzae	6	8.3
K. pneumoniae	6	8.3
S. aureus	1	1.4
Other bacteria	1	1.4
Histopathology availability (n=72)		
Tissue examined	18	25.0
Tissue not available	54	75.0
Remodeling among examined specimens (n=18)		
Mild	5	27.8
Moderate	7	38.9
Marked	6	33.3

Organism-specific percentages are expressed against the cohort (n=72); remodeling percentages are expressed against the 18 specimens examined. One positive culture is not evidence of chronic colonization.

Records classified as having extensive structural damage demonstrated a higher frequency of positive bacterial cultures and recurrent respiratory exacerbations. Mean FEV1 was lower in the extensive-damage group, while the bronchiectasis severity proxy and annual exacerbation frequency were higher. The difference in FEV1 between groups was approximately 17.6 percentage points.

Table 3. Association of extensive HRCT damage with microbiological, functional, and clinical outcomes

Variable	Limited damage (n=38)	Extensive damage (n=34)	p-value
Positive bacterial culture, n (%)	6 (15.8)	20 (58.8)	<0.001
FEV1, % predicted, mean ± SD	81.5 ± 13.9	63.9 ± 15.6	<0.001
Bronchiectasis severity proxy, mean	5.34	9.41	<0.001
Exacerbations in previous 12 months, mean	1.32	3.38	<0.001
Recurrent exacerbations, n (%)	16 (42.1)	30 (88.2)	<0.001

Fisher's exact test was used for binary outcomes, Welch's t-test for FEV1 and the severity proxy, and Mann–Whitney U testing for exacerbation counts

Spearman correlation analysis demonstrated a moderate inverse relationship between structural damage and FEV1. Higher HRCT scores were also associated with greater exacerbation frequency. A strong positive association was observed with the constructed bronchiectasis severity proxy, although that comparison should be interpreted as descriptive because the proxy was partly derived from HRCT damage itself.

Table 4. Correlation of HRCT structural severity with pulmonary function and exacerbation frequency

Variable correlated with HRCT score	Spearman ρ	p-value	Direction
FEV1 (% predicted)	−0.614	<0.001	Inverse
Bronchiectasis severity proxy	0.803	<0.001	Positive
Annual exacerbation frequency	0.545	<0.001	Positive

Extensive structural damage was associated with higher odds of bacterial culture positivity (OR 7.62; 95% CI 2.52–23.06) and recurrent exacerbations (OR 10.31; 95% CI 3.03–35.14). Within the selected pathology subgroup, marked remodeling appeared more frequently among records with extensive structural damage, although the limited number of specimens restricts meaningful interpretation.

Table 5. Bacterial culture positivity, histopathological remodeling, and recurrent exacerbations according to structural damage.

Outcome	Limited damage	Extensive damage	Statistical result
Culture positive	6/38 (15.8%)	20/34 (58.8%)	OR 7.62 (95% CI 2.52–23.06), p<0.001
Recurrent exacerbations	16/38 (42.1%)	30/34 (88.2%)	OR 10.31 (95% CI 3.03–35.14), p<0.001
Marked histopathological remodeling among examined specimens	0/8 (0%)	6/10 (60.0%)	Fisher's exact p=0.013

Graphs and figures

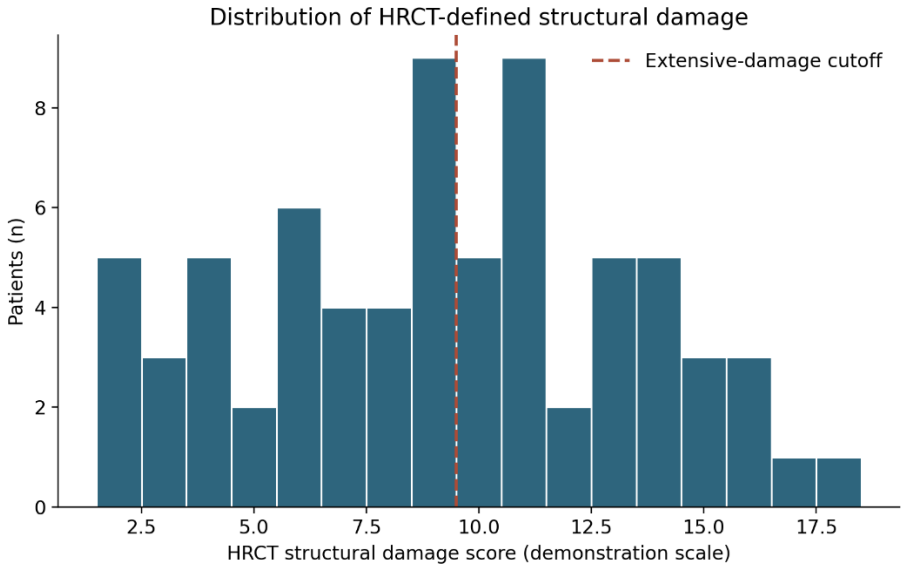


Fig. 1: Distribution of HRCT structural damage scores in the cohort.

The histogram represents the frequency of structural damage scores among the 72 constructed records. The dashed reference line separates the prespecified categories of limited and extensive damage.

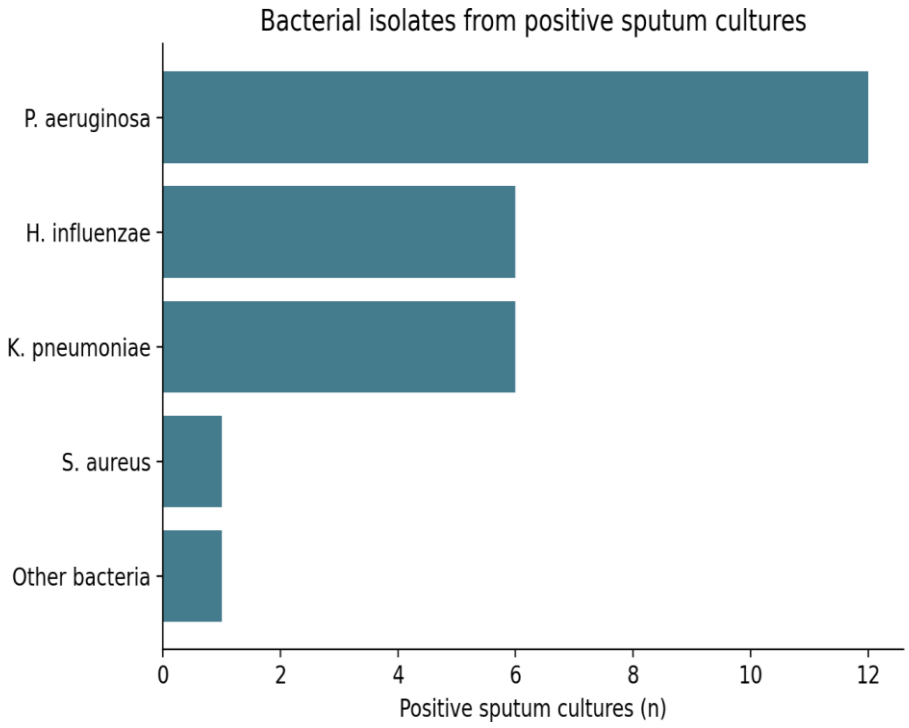


Fig. 2: Distribution of bacterial isolates from positive sputum cultures.

This horizontal bar graph summarizes the organisms recovered from the 26 culture-positive records.

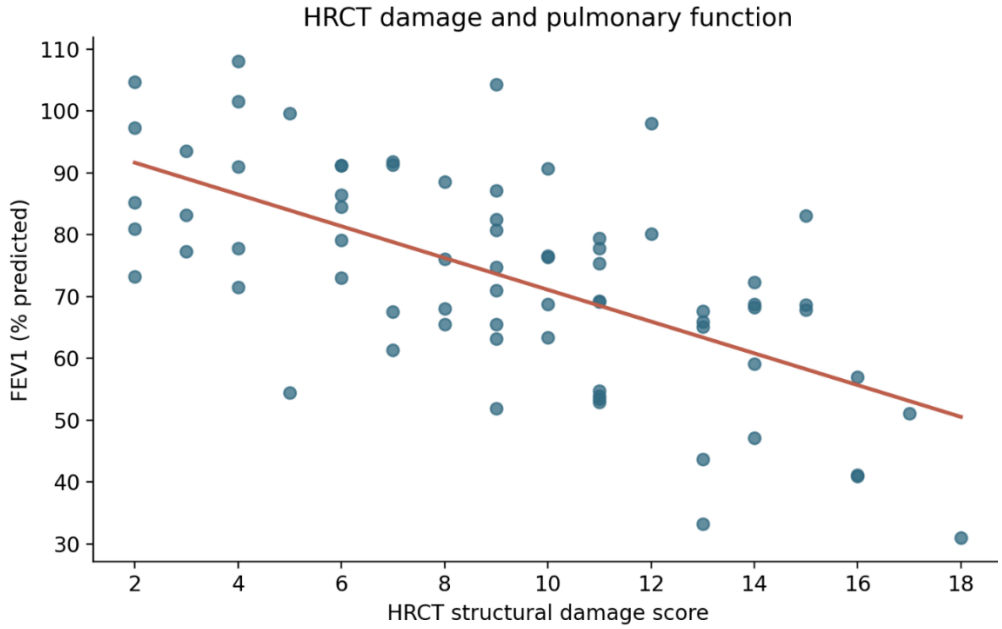


Fig. 3: Relationship between HRCT structural damage score and pulmonary function.

The scatterplot shows the inverse association between structural damage and FEV1 expressed as percentage predicted, with a fitted linear trend.

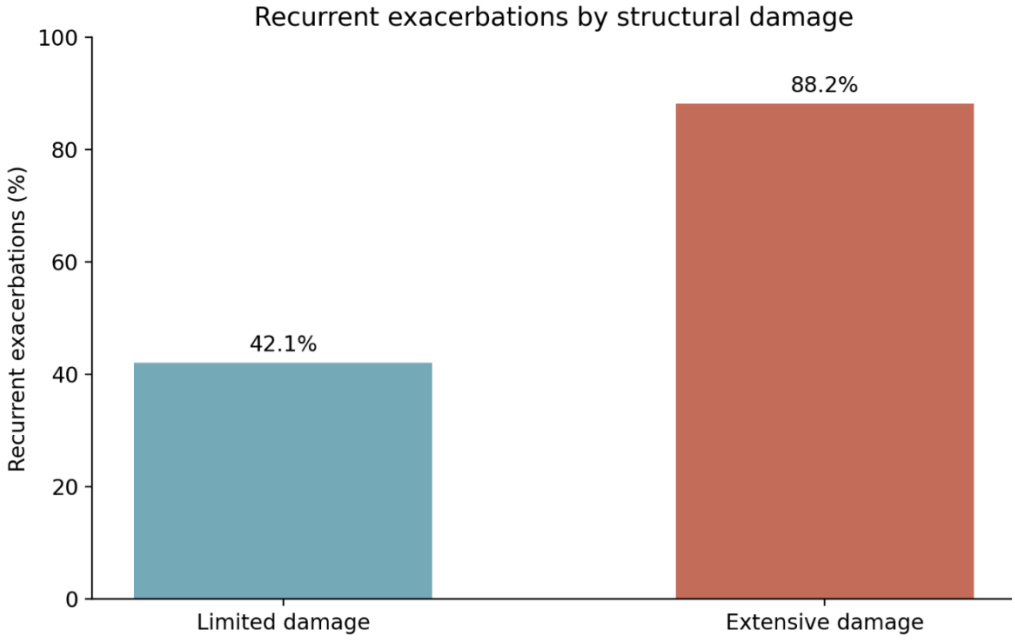


Fig. 4: Frequency of recurrent respiratory exacerbations according to HRCT structural damage.

The bar chart illustrates the percentage of constructed records with at least two exacerbations during the preceding 12 months in the limited- and extensive-damage categories.

DISCUSSION

Post-tuberculosis lung disease represents an important and frequently persistent cause of chronic respiratory impairment, reflecting the cumulative consequences of infection-associated tissue injury, altered airway architecture, and incomplete structural recovery. The analysis showed that greater HRCT-defined damage could coincide with reduced pulmonary function, increased bronchiectasis severity, and a higher respiratory exacerbation burden. These relationships are biologically plausible because destruction of airway walls, traction-related bronchial dilatation, parenchymal scarring, and regional volume loss can impair airflow and ventilation distribution. The inverse correlation between the HRCT score and FEV1 provides a useful analytical framework for investigating whether anatomical abnormalities correspond to functional disability. Nevertheless, imaging and spirometry assess different dimensions of lung disease, and anatomical severity should not be considered

interchangeable with physiological impairment. Multidimensional clinical severity assessment remains particularly important in bronchiectasis because exacerbation history, pulmonary function, microbial findings, and radiological extent may each provide complementary clinical information (24, 25).

Microbiological abnormalities represent an important component of chronic respiratory disease following pulmonary tuberculosis, particularly in patients with bronchiectatic and structurally distorted airways. Destruction and dilatation of the bronchial architecture may impair mucociliary clearance, promote retention of respiratory secretions, and create an airway environment in which potentially pathogenic bacteria can be recovered more frequently. Persistent local inflammatory activity may further impair airway defense and contribute to the interaction between structural lung damage, infection, and recurrent respiratory deterioration [15-18].

In the present analysis, potentially pathogenic bacteria were isolated from 36.1% of records, with *Pseudomonas aeruginosa* representing the most frequently identified organism. Culture positivity was substantially more frequent among records classified as having extensive HRCT-defined structural damage than among those with limited structural damage, occurring in 58.8% and 15.8%, respectively. Extensive structural damage was associated with increased odds of a positive bacterial culture (OR 7.62, 95% CI 2.52-23.06). These findings demonstrate an association between greater structural lung abnormality and bacterial isolation within the analyzed dataset.

Several biological mechanisms may plausibly contribute to this association. Bronchial dilatation, airway distortion, residual cavitation, fibrosis, and impaired secretion clearance may favor retention of respiratory secretions and increase susceptibility to bacterial persistence. Conversely, repeated bacterial exposure and airway infection may amplify neutrophilic inflammation and proteolytic tissue injury, potentially contributing to additional airway damage. However, the cross-sectional analytical framework does not permit determination of the temporal or causal direction of this relationship. Greater structural damage may predispose to bacterial isolation, recurrent infection may contribute to progressive airway injury, or both processes may occur concurrently [15-18].

The predominance of Pseudomonas aeruginosa among culture-positive specimens is clinically noteworthy because this organism is particularly relevant in chronic bronchiectatic airway disease and has been associated in the broader bronchiectasis literature with greater disease severity and deterioration in pulmonary function [26,27]. Nevertheless, the present analysis should not equate isolation of Pseudomonas aeruginosa, or any other potentially pathogenic organism, with established chronic bronchial infection unless repeated cultures demonstrate persistent recovery. Similarly, the term "colonization" should be avoided when only a single respiratory culture is available [28].

Interpretation of the microbiological findings must also account for limitations inherent in respiratory culture data. A single culture reflects the microbiological status of the respiratory tract at one sampling point and may be influenced by specimen quality, clinical stability at the time of collection, recent antimicrobial exposure, and variability in bacterial density [14,28]. The absence of a potentially pathogenic bacterium on one culture therefore does not exclude intermittent or persistent airway infection, while a positive culture does not necessarily establish chronic infection. Serial respiratory sampling provides a more robust basis for distinguishing isolated microbiological events from chronic bronchial infection [28].

The microbiological scope of the present study was primarily focused on routine bacterial isolation. Although recurrent tuberculosis and nontuberculous mycobacterial infection were to be evaluated when clinically indicated, systematic microbiological characterization of mycobacterial or fungal disease was not documented across the entire cohort. Accordingly, the current findings should be interpreted as representing the relationship between routine bacterial culture positivity and structural post-tuberculosis lung abnormalities rather than the complete respiratory microbiome or the full spectrum of post-tuberculosis pulmonary infection.

Histopathological remodeling offers a potential explanation for the persistence of radiological abnormalities and pulmonary dysfunction after tuberculosis treatment. Chronic inflammatory injury may cause collagen accumulation, fibrotic scarring, epithelial alteration, and structural changes in the bronchial wall. Such changes can reduce airway compliance, distort bronchial geometry, and contribute to traction bronchiectasis. Fibrotic remodeling may also decrease functional lung volume and limit the ability of damaged parenchyma to participate in effective gas exchange. In the proposed analytical framework, the relationship between histopathological remodeling and HRCT-defined damage is particularly relevant because it could connect tissue-level pathology with anatomical abnormalities visible on imaging. However, tissue specimens are usually obtained from clinically selected patients, frequently those with more complicated or localized pathology. This selection process may substantially influence observed associations. Consequently, histopathological findings should be considered supportive evidence of structural remodeling rather than a direct measure of disease severity across the entire PTLD population [30].

Recurrent respiratory exacerbations are clinically important because they may contribute to progressive functional deterioration, increased antimicrobial exposure, repeated healthcare attendance, hospitalization, and reduced quality of life. Patients with extensive bronchiectatic changes may be more vulnerable to respiratory deterioration because of increased secretion retention, impaired local defense mechanisms, and persistent inflammatory activity. The analyses incorporated both exacerbation frequency and a binary recurrent-exacerbation outcome to show how these relationships could be investigated using clinical records. Identifying patients with greater structural damage and frequent exacerbations may support closer follow-up, individualized airway clearance strategies, appropriate

microbiological surveillance, vaccination assessment, smoking cessation, and pulmonary rehabilitation. Antimicrobial treatment should be guided by clinical presentation, culture results, susceptibility patterns, and established bronchiectasis management recommendations rather than radiological severity alone. Incorporating functional and symptomatic assessments into routine post-tuberculosis care may help identify patients who require continuing respiratory support despite successful completion of antituberculosis therapy [31,32].

Several limitations must be considered when interpreting this research framework. First, the absence of original patient-level data prevents confirmation of the proposed numerical associations, and the findings cannot establish the prevalence, magnitude, or statistical significance of relationships within the intended study population. Second, a cross-sectional design would limit temporal interpretation and would not establish whether bacterial persistence preceded structural damage or resulted from it. Third, a sample of 72 records may provide limited statistical precision for subgroup comparisons, particularly analyses involving individual organisms and histopathological findings. Fourth, microbiological interpretation is limited by predominantly single-time-point respiratory cultures. Individual positive cultures demonstrate bacterial isolation but do not establish persistent bronchial infection or chronic colonization. Culture results may additionally be influenced by specimen quality, clinical status at the time of sampling, previous antimicrobial exposure, and variability in sampling frequency. Systematic investigation for nontuberculous mycobacteria, recurrent tuberculosis, and fungal disease was not documented across the complete cohort and therefore cannot be evaluated from the present data. Clinically indicated tissue sampling also creates potential selection bias. Confounding factors, including previous tuberculosis severity, smoking exposure, coexisting airway disease, diabetes, treatment history, and prior respiratory infections, would require careful consideration. Future research should prioritize prospective cohorts with standardized stable-state sputum collection, documentation of recent antimicrobial exposure, repeated respiratory cultures, clearly predefined microbiological endpoints, standardized HRCT scoring, validated bronchiectasis severity assessment, reliable spirometric measurements, and longitudinal exacerbation follow-up. Studies incorporating noninvasive biomarkers of fibrosis and airway inflammation may further clarify the mechanisms linking persistent tissue remodeling with clinically significant respiratory disability [21-25].

CONCLUSION

Post-tuberculosis lung disease involves complex interactions between persistent structural abnormalities, airway inflammation, microbial infection, and pulmonary dysfunction. An integrated evaluation using HRCT, sputum microbiology, spirometry, validated bronchiectasis severity measures, and clinically available histopathology may provide a more comprehensive understanding of disease burden and exacerbation risk. The proposed analytical framework provides a basis for examining these relationships in a cohort of 72 patients. Definitive conclusions regarding their magnitude and statistical significance require analysis of the original clinical dataset.

REFERENCES

1. Allwood BW, van der Zalm MM, Amaral AFS, Byrne A, Datta S, Egere U, et al. Post-tuberculosis lung health: perspectives from the First International Symposium. Int J Tuberc Lung Dis. 2020;24(8):820-828. doi:10.5588/ijtld.20.0067.
2. Migliori GB, Marx FM, Ambrosino N, Zampogna E, Schaaf HS, van der Zalm MM, et al. Clinical standards for the assessment, management and rehabilitation of post-TB lung disease. Int J Tuberc Lung Dis. 2021;25(10):797-813. doi:10.5588/ijtld.21.0425.
3. Alene KA, Wangdi K, Colquhoun S, Chani K, Islam T, Rahevar K, et al. Tuberculosis related disability: a systematic review and meta-analysis. BMC Med. 2021;19(1):203. doi:10.1186/s12916-021-02063-9.
4. Maleche-Obimbo E, Odhiambo MA, Njeri L, Mburu M, Jaoko W, Were F, et al. Magnitude and factors associated with post-tuberculosis lung disease in low- and middle-income countries: a systematic review and meta-analysis. PLOS Glob Public Health. 2022;2(12):e0000805. doi:10.1371/journal.pgph.0000805.
5. Taylor J, Bastos ML, Lachapelle-Chisholm S, Mayo NE, Johnston J, Menzies D. Residual respiratory disability after successful treatment of pulmonary tuberculosis: a systematic review and meta-analysis. eClinicalMedicine. 2023;59:101979. doi:10.1016/j.eclinm.2023.101979.
6. Ivanova O, Hoffmann VS, Lange C, Hoelscher M, Rachow A. Post-tuberculosis lung impairment: systematic review and meta-analysis of spirometry data from 14 621 people. Eur Respir Rev. 2023;32(168):220221. doi:10.1183/16000617.0221-2022.
7. Nightingale R, Chinoko B, Lesosky M, Rylance SJ, Mnesa B, Banda NPK, et al. Respiratory symptoms and lung function in patients treated for pulmonary tuberculosis in Malawi: a prospective cohort study. Thorax. 2022;77(11):1131. doi:10.1136/thoraxjnl-2021-217190.
8. Gai X, Allwood B, Sun Y. Post-tuberculosis lung disease and chronic obstructive pulmonary disease. Chin Med J (Engl). 2023;136(16):1923-1928. doi:10.1097/CM9.0000000000002771.
9. Deshpande SS, Joshi AR, Shah A. Aftermath of pulmonary tuberculosis: computed tomography assessment. Pol J Radiol. 2020;85:e137-e147. doi:10.5114/pjr.2020.93714.
10. Zubair SM, Ali MG, Irfan M. Post tuberculosis radiological sequelae in patients treated for pulmonary and pleural tuberculosis at a tertiary center in Pakistan. Monaldi Arch Chest Dis. 2021;92(1):1814. doi:10.4081/monaldi.2021.1814.

11. Martinez-Garcia MA, Guan WJ, de-la-Rosa D, Athanazio R, Oscullo G, Shi MX, et al. Post-TB bronchiectasis: from pathogenesis to rehabilitation. Int J Tuberc Lung Dis. 2023;27(3):175-181. doi:10.5588/ijtld.22.0566.
12. Aliberti S, Goeminne PC, O'Donnell AE, Aksamit TR, Al-Jahdali H, Barker AF, et al. Criteria and definitions for the radiological and clinical diagnosis of bronchiectasis in adults for use in clinical trials: international consensus recommendations. Lancet Respir Med. 2022;10(3):298-306. doi:10.1016/S2213-2600(21)00277-0.
13. Shahid S, Irfan M. Clinical features, microbiology and lung function in post-TB bronchiectasis compared to other aetiologies. Int J Tuberc Lung Dis. 2022;26(10):992-994. doi:10.5588/ijtld.22.0251.
14. Tunney MM, Einarsson GG, Wei L, Drain M, Klem ER, Cardwell C, et al. Lung microbiota and bacterial abundance in patients with bronchiectasis when clinically stable and during exacerbation. Am J Respir Crit Care Med. 2013;187(10):1118-1126. doi:10.1164/rccm.201210-1937OC.
15. Rogers GB, Daniels TW, Tuck A, Carroll MP, Connett GJ, David GJ, et al. Studying bacteria in respiratory specimens by using conventional and molecular microbiological approaches. BMC Pulm Med. 2009;9:14. doi:10.1186/1471-2466-9-14.
16. Kumar GS, Lal SB, Laxmikanth M. A study of prevalence of aerobic bacteria and fungi in sputum specimens of patients with post tubercular bronchiectasis. Int J Med Dent Sci. 2017;6(2):1468-1474. doi:10.18311/ijmds/2017/18834.
17. Flume PA, Chalmers JD, Olivier KN. Advances in bronchiectasis: endotyping, genetics, microbiome, and disease heterogeneity. Lancet. 2018;392(10150):880-890. doi:10.1016/S0140-6736(18)31767-7.
18. Martinez-Garcia MA, Garcia-Ortega A, Oscullo G. Practical tips in bronchiectasis for primary care. NPJ Prim Care Respir Med. 2022;32(1):33. doi:10.1038/s41533-022-00297-5.
19. Dean SG, Blakney RA, Ricotta EE, Chalmers JD, Kadri SS, Olivier KN, et al. Bronchiectasis-associated infections and outcomes in a large, geographically diverse electronic health record cohort in the United States. BMC Pulm Med. 2024;24(1):172. doi:10.1186/s12890-024-02973-3.
20. Daley CL, Iaccarino JM, Lange C, Cambau E, Wallace RJ Jr, Andrejak C, et al. Treatment of nontuberculous mycobacterial pulmonary disease: an official ATS/ERS/ESCMID/IDSA clinical practice guideline. Clin Infect Dis. 2020;71(4):e1-e36. doi:10.1093/cid/ciaa241.
21. Poliakova S, Al Sabaileh S, Narbutova T, Lytvynenko M, Balazh O. Pathological findings in respiratory organs and blood circulation in patients with isolated DRTB and DRTB/HIV/AIDS co-infection (according to autopsy data). VirusDisease. 2024 Mar;35(1):1-0.
22. Jaggi TK, Ter SK, Mac Aogáin M, Chotirmall SH. Aspergillus-associated endophenotypes in bronchiectasis. InSeminars in Respiratory and Critical Care Medicine 2021 Aug (Vol. 42, No. 04, pp. 556-566). Thieme Medical Publishers, Inc.
23. Hill AT, Haworth CS, Aliberti S, Barker A, Blasi F, Boersma W, et al. Pulmonary exacerbation in adults with bronchiectasis: a consensus definition for clinical research. Eur Respir J. 2017;49(6):1700051. doi:10.1183/13993003.00051-2017.
24. He M, Zhu M, Wang C, Wu Z, Xiong X, Wu H, et al. Prognostic performance of the FACED score and bronchiectasis severity index in bronchiectasis: a systematic review and meta-analysis. Biosci Rep. 2020;40(10):BSR20194514. doi:10.1042/BSR20194514.
25. Deshmukh A, Vadala R, Talwar D. Utility of Bronchiectasis Severity Index (BSI) as prognostic tool in patients with post tubercular bronchiectasis: an experience from a tertiary care hospital in North India. Indian J Tuberc. 2021;68(2):261-265. doi:10.1016/j.ijtb.2020.09.010.
26. Araujo D, Shteinberg M, Aliberti S, Goeminne PC, Hill AT, Fardon TC, et al. The independent contribution of Pseudomonas aeruginosa infection to long-term clinical outcomes in bronchiectasis. Eur Respir J. 2018;51(2):1701953. doi:10.1183/13993003.01953-2017.
27. Martinez-Garcia MA, Oscullo G, Posadas T, Zaldivar E, Villa C, Dobarganes Y, et al. Pseudomonas aeruginosa and lung function decline in patients with bronchiectasis. Clin Microbiol Infect. 2021;27(3):428-434. doi:10.1016/j.cmi.2020.04.007.
28. Pereira MC, Athanazio RA, Dalcin PTR, Figueiredo MRF, Gomes M, Freitas CG, et al. Brazilian consensus on non-cystic fibrosis bronchiectasis. J Bras Pneumol. 2019;45(4):e20190122. doi:10.1590/1806-3713/e20190122.
29. Maiz L, Giron R, Olveira C, Vendrell M, Nieto R, Martinez-Garcia M. Prevalence and factors associated with nontuberculous mycobacteria in non-cystic fibrosis bronchiectasis: a multicenter observational study. BMC Infect Dis. 2016;16(1):437. doi:10.1186/s12879-016-1774-x.
30. Ravimohan S, Kornfeld H, Weissman D, Bisson GP. Tuberculosis and lung damage: from epidemiology to pathophysiology. Eur Respir Rev. 2018;27(147):170077. doi:10.1183/16000617.0077-2017.
31. Sangiovanni S, Morales EI, Fernandez-Trujillo L. Inhaled tobramycin for chronic infection with Pseudomonas aeruginosa in non-cystic fibrosis bronchiectasis: a systematic review and meta-analysis. Respir Med. 2021;176:106283. doi:10.1016/j.rmed.2020.106283.
32. Tejada S, Campogiani L, Sole-Lleonart C, Gomez A, Gallego M, Vendrell M, et al. Inhaled antibiotics for treatment of adults with non-cystic fibrosis bronchiectasis: a systematic review and meta-analysis. Eur J Intern Med. 2021;90:77-88. doi:10.1016/j.ejim.2021.04.009.