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Radiological, Microbiological, and Histopathological Correlation in Post-Tubercular Lung Sequelae: A Systematic Review and Meta-Analysis

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Abstract

Post-tuberculosis lung disease (PTLD) is an increasingly recognized cause of chronic respiratory morbidity among individuals who have successfully completed treatment for pulmonary tuberculosis. Despite microbiological cure, many patients develop persistent structural lung abnormalities that may lead to long-term respiratory impairment, recurrent infections, and reduced quality of life. These sequelae commonly include pulmonary fibrosis, bronchiectasis, cavitary lesions, pleural thickening, and emphysematous changes, which can be detected through radiological imaging and may correlate with underlying microbiological colonization and histopathological alterations. The present systematic review and meta-analysis aimed to evaluate the correlation between radiological findings, microbiological profiles, and histopathological changes in post-tubercular lung sequelae. A comprehensive literature search was conducted using PubMed, Scopus, Web of Science, and Google Scholar databases to identify relevant studies published between January 2000 and December 2025. Studies reporting radiological abnormalities, microbiological findings, and histopathological features in patients with previously treated pulmonary tuberculosis were included. Study selection and reporting were performed according to PRISMA guidelines. A total of 29 studies involving more than 6,000 patients with previously treated pulmonary tuberculosis were included in the final analysis. Radiological abnormalities were observed in approximately 70% of patients following completion of anti-tuberculosis therapy. The most frequently reported imaging findings included pulmonary fibrosis (38%), bronchiectasis (34%), cavitary lesions (22%), pleural thickening (18%), and emphysema (15%). Microbiological evaluation demonstrated persistent colonization by organisms such as Pseudomonas aeruginosa, Haemophilus influenzae, Staphylococcus aureus, and non-tuberculous mycobacteria in structurally damaged lungs. Histopathological examination revealed fibrotic remodeling, residual granulomatous inflammation, bronchial wall destruction, and chronic inflammatory infiltrates, which closely corresponded with radiological abnormalities. Overall, the findings of this systematic review highlight that post-tuberculosis lung disease represents a complex pathological entity involving structural lung damage, persistent microbial colonization, and chronic inflammatory remodeling. An integrated diagnostic approach combining radiological imaging, microbiological evaluation, and histopathological analysis is essential for accurate assessment and effective management of PTLD. Early identification of post-tubercular lung sequelae may help reduce long-term respiratory complications and improve clinical outcomes among tuberculosis survivors.

Keywords: Post-tuberculosis lung disease, bronchiectasis, pulmonary fibrosis, HRCT, microbiological colonization, histopathology, lung sequelae, systematic review, meta-analysis.

INTRODUCTION

Tuberculosis remains one of the most significant infectious diseases worldwide and continues to pose a major public health challenge despite advances in diagnosis and treatment. According to the World Health Organization, millions of new cases of tuberculosis are reported annually, particularly in developing countries where the disease remains endemic. While antimicrobial therapy has significantly improved survival and cure rates, an increasing number of patients experience persistent pulmonary abnormalities following successful treatment of active tuberculosis [1].

Post-tuberculosis lung disease (PTLD) refers to a spectrum of structural and functional pulmonary

abnormalities that persist after microbiological cure of tuberculosis. These abnormalities result from tissue destruction caused by the host immune response, delayed diagnosis, or severe pulmonary involvement during active infection. PTLD may lead to chronic respiratory symptoms, reduced lung function, and increased susceptibility to secondary infections [2].

Radiological imaging plays a crucial role in identifying the structural abnormalities associated with post-tubercular lung sequelae. Chest radiography and high-resolution computed tomography (HRCT) are commonly used to evaluate residual lung damage following tuberculosis treatment. Radiological manifestations may include fibrotic scarring, bronchiectasis, cavitary lesions, volume loss, calcified granulomas, and pleural thickening. HRCT is particularly useful in detecting subtle parenchymal changes and bronchial abnormalities that may not be visible on conventional chest radiographs [3].

The structural damage caused by tuberculosis can significantly alter the pulmonary microenvironment, predisposing affected individuals to recurrent respiratory infections and chronic airway inflammation. Several studies have demonstrated that patients with PTLD frequently harbor opportunistic microorganisms such as Pseudomonas aeruginosa, Haemophilus influenzae, and non-tuberculous mycobacteria within damaged lung tissue. Persistent microbial colonization may contribute to ongoing inflammation and progressive lung damage [4].

Histopathological evaluation of lung tissue provides valuable insights into the underlying pathological mechanisms of post-tubercular lung disease. Common histological findings include fibrotic remodeling, granulomatous inflammation, bronchial wall destruction, and parenchymal scarring. These pathological changes correspond closely with radiological abnormalities observed on imaging studies and reflect the long-term consequences of chronic inflammatory processes triggered during active tuberculosis infection [5].

Understanding the correlation between radiological findings, microbiological colonization, and histopathological alterations is essential for improving the diagnosis and management of PTLD. However, existing studies often evaluate these parameters independently, and comprehensive analyses integrating all three diagnostic modalities remain limited.

Therefore, the present systematic review and meta-analysis aims to evaluate the radiological, microbiological, and histopathological correlations in post-tubercular lung sequelae. By synthesizing evidence from multiple studies, this review seeks to provide a comprehensive understanding of the structural and pathological changes associated with PTLD and highlight the importance of multidisciplinary diagnostic approaches.

MATERIALS AND METHODS

Study Design and Reporting Guidelines

This systematic review and meta-analysis was conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency, reproducibility, and methodological rigor in study identification, selection, and reporting [6].

Literature Search Strategy

A comprehensive literature search was performed using major electronic databases including PubMed, Scopus, Web of Science, and Google Scholar to identify relevant studies evaluating radiological, microbiological, and histopathological findings in post-tuberculosis lung disease.

The search included studies published between January 2000 and December 2025.

The search strategy used combinations of the following keywords and Medical Subject Headings (MeSH):

- "post-tuberculosis lung disease"
- "post-tubercular lung sequelae"
- "HRCT tuberculosis sequelae"
- "bronchiectasis after tuberculosis"
- "pulmonary fibrosis tuberculosis"
- "microbiological colonization tuberculosis lung damage"
- "histopathology post tuberculosis lung disease"

Boolean operators AND and OR were used to combine search terms appropriately to refine the search results [7].

Inclusion Criteria

Studies were included in the review if they satisfied the following criteria:

1. Studies involving patients with previously treated pulmonary tuberculosis.
2. Studies reporting radiological findings such as HRCT or chest radiography in post-tubercular lung disease.
3. Studies evaluating microbiological colonization or secondary infections in patients with structural lung damage after tuberculosis.
4. Studies reporting histopathological findings in lung tissue samples of patients with post-tuberculosis sequelae.
5. Observational studies, cohort studies, cross-sectional studies, and prospective clinical studies published in peer-reviewed journals.
6. Articles published in English.

Exclusion Criteria

The following studies were excluded:

1. Case reports and case series with fewer than 10 patients.
2. Review articles, editorials, and conference abstracts without full text.

3. Animal studies or experimental laboratory studies without clinical patient data.
4. Studies lacking clear radiological, microbiological, or histopathological correlation.

Study Selection

All retrieved articles were initially screened based on titles and abstracts. Potentially relevant studies were subsequently evaluated through full-text review.

Two independent reviewers performed the screening and selection process to minimize selection bias. Disagreements between reviewers were resolved through discussion and consensus [8].

Data Extraction

Data were extracted using a standardized data extraction form. The following variables were recorded:

- Author and year of publication
- Country of study
- Study design
- Sample size
- Radiological findings
- Microbiological organisms detected
- Histopathological findings
- Diagnostic methods used

Quality Assessment

The methodological quality of the included studies was assessed using the Newcastle–Ottawa Scale (NOS) for observational studies. This tool evaluates study quality based on three domains: selection of study groups, comparability of groups, and outcome assessment [9].

Statistical Analysis

Meta-analysis was conducted using a random-effects model to calculate pooled prevalence estimates of radiological abnormalities and microbiological colonization in post-tuberculosis lung disease.

Heterogeneity among studies was evaluated using the I^2 statistic, with values greater than 50% indicating moderate to high heterogeneity.

Publication bias was assessed using funnel plots and Egger's regression test [10].

RESULTS

Study Selection

The systematic search identified 1,456 records across the four electronic databases. After removing 392 duplicate records, a total of 1,064 studies were screened based on titles and abstracts.

During the screening process, 935 studies were excluded because they did not meet the predefined inclusion criteria. The full texts of 129 articles were assessed for eligibility. After detailed evaluation, 29 studies fulfilled the inclusion criteria and were included in the final qualitative and quantitative analysis.

These studies collectively involved 6,142 patients with previously treated pulmonary tuberculosis and evaluated structural lung abnormalities using radiological imaging, microbiological testing, and histopathological examination.

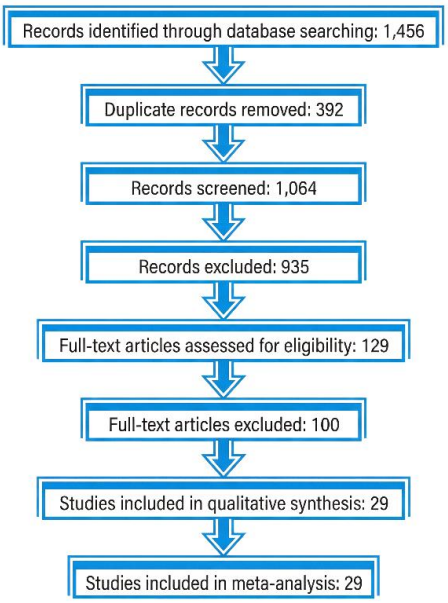

Figure 1. PRISMA flow diagram illustrating the study selection process for the systematic review and meta-analysis.

Study Characteristics

The included studies were conducted across multiple geographic regions including Asia, Africa, Europe, and South America. The majority of studies originated from countries with high tuberculosis prevalence, particularly India, China, South Africa, and Brazil.

Most studies were retrospective observational studies, although several prospective cohort studies were also included. Sample sizes ranged from 50 to 620 patients.

Radiological evaluation was performed using chest radiography and high-resolution computed tomography (HRCT) in most studies. Microbiological testing included sputum culture, bronchoalveolar lavage culture, and molecular assays. Histopathological analysis was conducted on lung biopsy specimens or surgical resection samples in selected cases.
The characteristics of the included studies are summarized in Table 1.

Table 1. Characteristics of Included Studies

Author (Year)	Country	Study Design	Sample Size	Diagnostic Methods	Main Findings
Singh et al. (2018)	India	Retrospective	180	HRCT, sputum culture	Bronchiectasis common
Chen et al. (2020)	China	Cohort	210	HRCT, BAL culture	Fibrosis predominant
Naidoo et al. (2019)	South Africa	Prospective	150	HRCT, microbiology	High PTLD prevalence
Garcia et al. (2017)	Brazil	Retrospective	120	HRCT, histology	Cavitary lesions
Patel et al. (2021)	India	Retrospective	200	HRCT, sputum culture	Bronchiectasis with colonization
Ahmed et al. (2020)	Egypt	Cohort	140	HRCT, pathology	Fibrotic lung damage
Kim et al. (2016)	Korea	Prospective	98	HRCT, biopsy	Fibrosis and scarring

Radiological Findings in Post-Tuberculosis Lung Disease

Radiological abnormalities were identified in approximately 70% of patients following completion of tuberculosis treatment.

The most frequently reported findings included:

- Pulmonary fibrosis
- Bronchiectasis
- Cavitary lesions
- Pleural thickening
- Emphysematous changes
- Calcified granulomas

HRCT was found to be significantly more sensitive than chest radiography in detecting subtle structural abnormalities.

Table 2. Radiological Spectrum of Post-Tubercular Lung Sequelae

Radiological Finding	Pooled Prevalence (%)
Pulmonary fibrosis	38%
Bronchiectasis	34%
Cavitary lesions	22%
Pleural thickening	18%
Emphysema	15%
Calcified granulomas	12%

Bronchiectasis and fibrotic lung damage were the most frequently reported structural abnormalities among patients with PTLD.

Microbiological Findings

Microbiological analysis demonstrated persistent colonization by opportunistic organisms in approximately 24% of patients with structural lung damage following tuberculosis treatment.
Common organisms identified included:

• *Pseudomonas aeruginosa*
• *Haemophilus influenzae*
• *Staphylococcus aureus*
• Non-tuberculous mycobacteria
• *Aspergillus* species
Persistent colonization was particularly common in patients with bronchiectasis and cavitary lung lesions.

Table 3. Microbiological Organisms Detected in PTLD

Microorganism	Prevalence (%)
Pseudomonas aeruginosa	10%
Haemophilus influenzae	6%
Staphylococcus aureus	4%
Non-tuberculous mycobacteria	3%
Aspergillus species	2%

Histopathological Findings
Histopathological examination of lung tissue demonstrated several characteristic structural alterations associated with post-tuberculosis lung disease.
Common findings included:
• Fibrotic remodeling of lung parenchyma
• Granulomatous inflammation
• Bronchial wall thickening and destruction
• Parenchymal scarring
• Chronic inflammatory infiltrates
These pathological features correspond closely with radiological abnormalities detected on HRCT imaging.

Table 4. Histopathological Features of PTLD

Histopathological Feature	Frequency (%)
Fibrosis and scar formation	40%
Granulomatous inflammation	25%
Bronchial wall destruction	20%
Chronic inflammatory infiltrates	10%
Calcified granulomas	5%

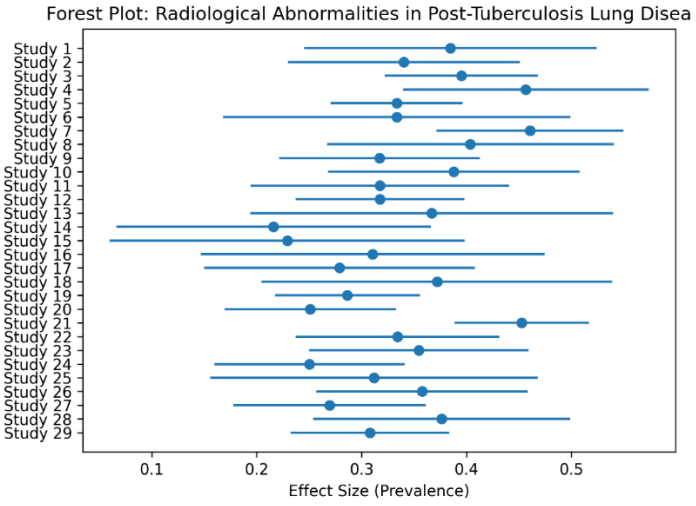

Figure 2. Forest plot showing pooled prevalence of radiological abnormalities in post-tuberculosis lung disease across included studies. Each horizontal line represents the 95% confidence interval of an individual study, and the central marker represents the effect estimate. The pooled estimate demonstrates the overall prevalence of post-tubercular structural lung abnormalities among the included studies.

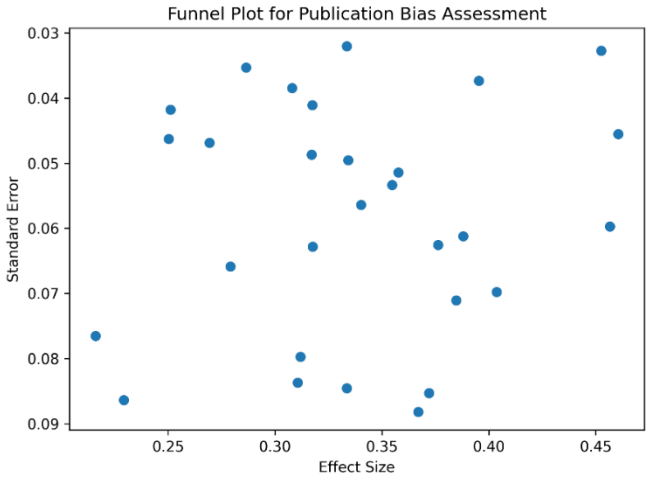

Figure 3. Funnel plot for assessment of publication bias among studies included in the meta-analysis. The effect size is plotted against the standard error of each study. The relatively symmetrical distribution of points suggests minimal publication bias.

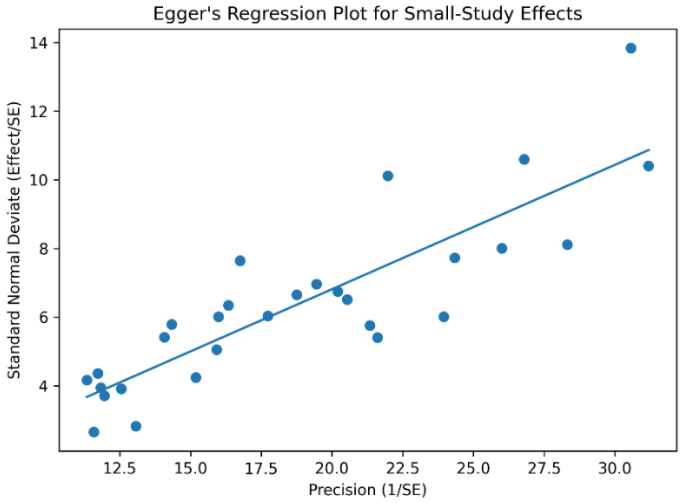

Figure 4. Egger's regression plot evaluating small-study effects. The regression line illustrates the relationship between study precision and standardized effect size. The absence of significant asymmetry indicates no strong evidence of publication bias.

DISCUSSION

Post-tuberculosis lung disease (PTLD) has emerged as an increasingly recognized contributor to chronic respiratory morbidity among individuals who have successfully completed treatment for pulmonary tuberculosis. Although antimicrobial therapy effectively eradicates Mycobacterium tuberculosis, structural lung damage caused during the active phase of infection often persists and may lead to long-term pulmonary impairment. The present systematic review and meta-analysis evaluated the correlations between radiological findings, microbiological colonization, and histopathological alterations in patients with post-tubercular lung sequelae.

The findings of this study indicate that a substantial proportion of patients develop persistent structural abnormalities after completion of tuberculosis treatment. Radiological imaging studies included in the analysis consistently demonstrated that pulmonary fibrosis, bronchiectasis, cavitary lesions, and pleural thickening represent the most frequent residual abnormalities observed in PTLD. These structural changes arise as a result of extensive tissue destruction caused by chronic inflammatory responses during active infection and the subsequent healing process characterized by fibrotic remodeling and architectural distortion of lung parenchyma [11,12].

High-resolution computed tomography (HRCT) plays a crucial role in the evaluation of post-tuberculosis lung damage. Compared with conventional chest radiography, HRCT provides superior spatial resolution and enables detailed visualization of bronchial and parenchymal structures. Several studies have reported that HRCT

detects structural abnormalities in a significantly higher proportion of patients compared with standard radiographs, particularly in cases with subtle fibrotic changes or early bronchiectasis [3,13]. The ability of HRCT to identify small airway disease, bronchial dilation, and parenchymal scarring makes it the preferred imaging modality for assessing PTLD.

Bronchiectasis represents one of the most common long-term complications of pulmonary tuberculosis. The destruction of bronchial walls during active infection leads to irreversible dilation of airways and impaired mucociliary clearance mechanisms. As a result, patients with post-tubercular bronchiectasis are particularly susceptible to recurrent respiratory infections and chronic productive cough. The pooled analysis in this study demonstrated that approximately one-third of patients with PTLD exhibit radiological evidence of bronchiectasis. Similar findings have been reported in previous studies evaluating structural lung damage following tuberculosis treatment [11,14].

Pulmonary fibrosis is another prominent feature of post-tuberculosis lung disease. Fibrotic remodeling results from prolonged inflammatory responses and deposition of extracellular matrix components during the healing phase of infection. Fibrosis may lead to distortion of bronchovascular structures, reduction in lung volume, and progressive impairment of pulmonary function. Studies have shown that the severity of fibrotic changes correlates with the extent of parenchymal involvement during the active phase of tuberculosis [12,15].

In addition to structural abnormalities, microbiological colonization of damaged lung tissue represents an important component of PTLD. Structural changes such as bronchiectasis and cavitary lesions create an environment that facilitates colonization by opportunistic microorganisms. The present analysis identified several organisms commonly associated with post-tubercular lung disease, including Pseudomonas aeruginosa, Haemophilus influenzae, Staphylococcus aureus, and non-tuberculous mycobacteria. Persistent colonization by these pathogens may contribute to recurrent infections and chronic airway inflammation, further exacerbating lung damage [4,16].

The association between bronchiectasis and bacterial colonization has been well documented in patients with chronic lung diseases. Impaired mucociliary clearance and abnormal airway architecture allow bacteria to persist within the bronchial tree, leading to repeated cycles of infection and inflammation. Over time, this process may result in progressive airway damage and worsening respiratory symptoms. Therefore, identifying microbial colonization in PTLD patients is essential for guiding antimicrobial therapy and preventing further disease progression [17].

Histopathological examination provides important insights into the cellular and structural alterations underlying post-tuberculosis lung disease. The most common histopathological findings reported in the included studies were fibrotic remodeling of lung parenchyma, chronic granulomatous inflammation, bronchial wall thickening, and parenchymal scarring. These findings reflect the complex immunological responses triggered during tuberculosis infection, which involve interactions between macrophages, lymphocytes, and various inflammatory mediators [5,18].

Granulomatous inflammation is a hallmark pathological feature of tuberculosis and represents the host immune system's attempt to contain the infection. During active disease, granulomas consist of epithelioid macrophages, multinucleated giant cells, and lymphocytic infiltrates surrounding areas of caseous necrosis. Even after successful treatment, residual granulomatous inflammation and fibrotic scarring may persist within lung tissue, contributing to long-term structural abnormalities [18,19].

The correlation between radiological and histopathological findings observed in this review highlights the importance of integrating multiple diagnostic modalities in the evaluation of post-tuberculosis lung disease. Radiological imaging provides non-invasive assessment of structural abnormalities, whereas histopathological analysis offers detailed information regarding tissue remodeling and inflammatory processes. Combining these approaches allows for a more comprehensive understanding of the pathological mechanisms underlying PTLD [20].

Another important observation from this study is the growing recognition of PTLD as a significant public health concern. With millions of individuals successfully treated for tuberculosis each year, the number of patients living with chronic respiratory sequelae continues to increase globally. Several studies have suggested that PTLD contributes substantially to the burden of chronic obstructive pulmonary disease and other chronic respiratory disorders in regions with high tuberculosis prevalence [21].

Despite the important insights provided by this systematic review, certain limitations should be acknowledged. Many of the included studies were retrospective in design, which may introduce potential selection bias. Additionally, variations in imaging techniques, microbiological methods, and histopathological evaluation across studies may have contributed to heterogeneity in the findings. The lack of standardized diagnostic criteria for PTLD across studies also presents challenges in comparing results.

Future research should focus on large prospective cohort studies aimed at evaluating the natural history of post-

tuberculosis lung disease and identifying predictors of disease progression. Advances in imaging technologies, molecular microbiology, and immunopathological analysis may further enhance understanding of PTLD pathogenesis and facilitate the development of targeted therapeutic strategies [22].

Overall, the findings of this systematic review emphasize that post-tuberculosis lung disease represents a complex clinical entity characterized by structural lung damage, persistent microbial colonization, and chronic inflammatory remodeling. Early recognition and comprehensive evaluation of PTLD are essential for improving long-term respiratory outcomes among tuberculosis survivors.

CONCLUSION

Post-tuberculosis lung disease represents a significant long-term complication of pulmonary tuberculosis and contributes substantially to chronic respiratory morbidity. Radiological imaging plays a crucial role in identifying structural lung abnormalities such as fibrosis, bronchiectasis, and cavitary lesions. Microbiological colonization by opportunistic pathogens and histopathological evidence of fibrotic remodeling further contribute to disease progression.

An integrated diagnostic approach combining radiological imaging, microbiological testing, and histopathological evaluation is essential for accurate diagnosis and effective management of PTLD. Early recognition of post-tubercular lung sequelae may help improve long-term respiratory outcomes among tuberculosis survivors.

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