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Research Article

Assessment of Pulmonary Tuberculosis Treatment Response Using Serial Chest Computed Tomography

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ABSTRACT
Background: Pulmonary tuberculosis (PTB) remains a major global health challenge despite the availability of effective antimicrobial therapy. Accurate assessment of treatment response is essential for ensuring cure, detecting treatment failure, and preventing drug resistance. While sputum-based microbiological tests remain the reference standard, imaging plays a critical complementary role, particularly in patients with negative sputum results or persistent symptoms. Chest computed tomography (CT) offers superior sensitivity compared to chest radiography in detecting parenchymal and airway abnormalities associated with PTB. This article reviews the role of serial chest CT in evaluating treatment response in pulmonary tuberculosis, describing characteristic imaging findings, temporal changes during therapy, quantitative and qualitative assessment methods, clinical utility, and limitations. Pulmonary tuberculosis (TB) remains a major global health challenge, and despite the availability of standardized treatment regimens, timely assessment of therapeutic response continues to be a clinical priority. Conventional sputum-based methods and chest radiography have limitations in sensitivity and temporal resolution, particularly in detecting subtle parenchymal changes. Chest computed tomography (CT), with its superior ability to characterize lung architecture, offers potential advantages in evaluating disease trajectory and guiding clinical decision-making.
Aim: To evaluate treatment response in patients with pulmonary tuberculosis using serial chest CT scans and determine the characteristic imaging changes associated with successful therapy.
Material and Methods: This retrospective observational study included patients with microbiologically confirmed pulmonary TB who underwent baseline and follow-up chest CT imaging during the course of standard anti-tubercular therapy. CT scans were reviewed independently by two experienced thoracic radiologists. Key imaging parameters assessed included the presence and extent of cavitation, nodules, consolidations, tree-in-bud opacities, lymphadenopathy, and pleural involvement. Changes in these features were compared across serial examinations to determine patterns of radiological improvement or persistence. Clinical and microbiological treatment response indicators were correlated with CT findings to strengthen interpretative validity.
Results: Serial CT evaluation demonstrated consistent radiologic trends in patients responding to treatment. The most notable improvements included reduction in cavity size, decreased nodular burden, resolution of consolidations, and marked regression of tree-in-bud opacities. Lymph node enlargement and pleural abnormalities also showed significant interval improvement in many cases. In contrast, a subset of patients with persistent or worsening CT abnormalities exhibited delayed microbiological conversion or clinical non-response. CT findings provided earlier detection of treatment failure compared to conventional radiography and often preceded sputum conversion in several clinically improving patients.
Conclusion: Serial chest CT is a valuable adjunct in monitoring therapeutic response in pulmonary tuberculosis, offering enhanced sensitivity in detecting parenchymal and airway changes. Its use can support earlier recognition of inadequate treatment response and help optimize individualized patient management.

Keywords: Pulmonary tuberculosis, Computed tomography, Treatment response, Serial imaging, Cavitation.

INTRODUCTION

Pulmonary tuberculosis (TB) remains one of the most significant infectious diseases worldwide, continuing to pose major diagnostic, therapeutic, and public health challenges despite substantial progress in global control programs. It is caused by Mycobacterium tuberculosis and primarily affects the lungs,

though its systemic implications and potential for dissemination make it a disease of considerable complexity. Globally, TB accounts for millions of new cases each year and remains a leading cause of morbidity and mortality, particularly in regions with socioeconomic disadvantages or high burdens of HIV co-infection.[1] Although the incidence has declined in many high-income nations, TB persists as a critical health problem in low- and middle-income countries, illustrating continued disparities in access to prevention, early diagnosis, and timely treatment.[2] Effective management of pulmonary TB relies on accurate diagnosis and, equally important, reliable evaluation of treatment response. Traditionally, clinical assessment and sputum microbiology—particularly smear microscopy and culture—have been the cornerstone of monitoring therapeutic efficacy. While sputum culture conversion is considered a robust indicator of treatment success, it is not without limitations. Culture results require weeks for completion, and sputum smear results may not always correlate with disease activity, especially in smear-negative, HIV-positive, or early-disease presentations.[3] Moreover, microbiologic negativity does not always equate to complete radiologic resolution or the absence of residual pathological activity, which may influence long-term outcomes and risk of relapse. These limitations highlight the need for adjunct tools capable of providing detailed, temporal insights into pulmonary structural changes during therapy.Chest radiography has been widely used to monitor treatment progress, but it lacks sensitivity in detecting subtle parenchymal, airway, and mediastinal changes. Overlapping structures and limited spatial resolution reduce its ability to fully characterize patterns such as early cavitation, bronchiectasis, or endobronchial spread. As a result, radiographic assessment may underestimate disease burden or misclassify therapeutic response in certain patients.[4] Advanced imaging modalities have therefore become increasingly valuable in the comprehensive evaluation of pulmonary TB. Computed tomography (CT), particularly high-resolution chest CT, offers superior detail in assessing parenchymal, airway, and pleural abnormalities compared with conventional radiography. Features such as cavitary lesions, tree-in-bud nodularity, bronchial wall thickening, ground-glass opacities, and bronchiectasis can be detected with greater accuracy and precision. CT can also reveal abnormalities even in patients with normal or minimally abnormal chest radiographs, making it a powerful tool for early disease recognition.[5] Moreover, CT provides an opportunity to dynamically assess temporal changes in disease morphology, allowing clinicians to observe the degree and speed of structural improvement following the initiation of anti-tuberculous therapy. Monitoring treatment response with serial CT imaging offers potential advantages. First, CT allows quantification of lesion resolution, such as decreases in consolidation, nodularity, or cavity size—changes that may reflect microbial clearance and tissue healing. Second, serial CT can identify complications such as persistent cavities, fibrosis, bronchiectasis, or paradoxical worsening, which may influence long-term outcomes or require tailored management strategies. Third, CT can assist in early identification of inadequate treatment response, which is particularly important in regions with drug-resistant TB or in patients with adherence challenges.[6] By identifying nonresponders earlier, clinicians can adjust therapy promptly, improving the likelihood of success and reducing the risk of transmission. Despite these advantages, routine use of CT in TB management remains controversial due to concerns regarding cost, radiation exposure, and variable availability in resource-limited settings. Nevertheless, for selected patient populations, including those with extensive disease, atypical presentations, co-existing immunosuppression, or suspected complications, CT may provide clinically actionable insights that are not obtainable through traditional methods alone. This has led to growing interest in understanding how CT findings evolve over the course of therapy and whether their temporal progression correlates with clinical and microbiologic outcomes. Serial CT studies have demonstrated that certain radiologic patterns may serve as markers of active disease or indicators of therapeutic response. For example, tree-in-bud opacities typically decrease as airway infection clears, while cavity closure may lag behind other healing processes, especially in patients with extensive tissue destruction at baseline.[7] additionally, some structural abnormalities such as bronchiectasis may improve partially but often represent irreversible sequelae of chronic inflammation. Understanding the natural evolution of such findings on CT is essential for interpreting imaging results and avoiding misclassification of treatment failure in cases where residual structural abnormalities persist despite microbiologic cure.

MATERIALS AND METHODS

This study was designed as a prospective observational investigation conducted at American International Institute of Medical Sciences, Udaipur. The aim was to evaluate treatment response in patients with pulmonary tuberculosis using serial chest computed tomography (CT). All imaging and clinical evaluations were performed under standardized institutional protocols, with multidisciplinary input from radiologists, pulmonologists, and infectious disease specialists. A total of 78 consecutive patients diagnosed with pulmonary tuberculosis were enrolled. Patients were referred from outpatient clinics, inpatient wards, and specialized tuberculosis units. Inclusion criteria consisted of confirmed pulmonary tuberculosis based on sputum smear microscopy, GeneXpert MTB/RIF assay, or culture positivity, along with the ability to undergo serial chest CT examinations. Exclusion criteria included patients with multidrug-resistant tuberculosis, co-existing lung malignancy, prior thoracic surgery, severe renal impairment contraindicating contrast administration, or incomplete follow-up imaging. Written informed consent was obtained from all participants before inclusion.

METHODOLOGY

Baseline demographic and clinical data—including age, sex, smoking status, HIV status, comorbidities, symptom duration, and previous tuberculosis history—were recorded. Laboratory parameters such as sputum smear grading, GeneXpert results, erythrocyte sedimentation rate (ESR), C-reactive protein (CRP), and complete blood counts were documented at baseline and during follow-up whenever available. All patients were treated according to national tuberculosis treatment guidelines under directly observed therapy.

CT Imaging Protocol

Serial chest CT examinations were performed using a multidetector CT scanner with standardized acquisition parameters. Scans included high-resolution axial reconstructions at 1–1.25 mm slice thickness, with lung and mediastinal windows evaluated for detailed parenchymal assessment. Intravenous contrast was administered when clinically indicated. CT scans were obtained at baseline (prior to initiation of therapy) and subsequently at predetermined treatment intervals to monitor radiological changes. Parameters assessed included extent of consolidation, cavitary lesions (size, wall thickness, and number), nodular opacities, tree-in-bud patterns, ground-glass opacities, bronchial wall thickening, bronchiectasis, lymphadenopathy, and pleural involvement. Total extent of lung involvement was quantified using a semi-quantitative scoring system for each lobe.

Image Interpretation

All CT images were independently reviewed by two experienced thoracic radiologists who were blinded to clinical status and treatment progress. Discrepancies were resolved by consensus. Each radiological parameter was recorded systematically using a structured proforma. Changes in lesion morphology, reduction in parenchymal involvement, resolution of cavitation, and improvement in airway abnormalities were noted to determine radiological response. Radiological improvement was categorized as complete, partial, stable, or progressive disease based on predefined criteria. Patients were followed throughout the treatment course with repeated clinical assessment and serial CT imaging. Clinical improvement was documented based on symptom resolution, sputum conversion, and weight gain. Radiological response was correlated with clinical outcomes. Any complications such as paradoxical worsening, new cavitations, drug-related lung injury, or treatment failure were recorded. Patients with incomplete imaging or loss to follow-up were excluded from final outcome analysis.

Statistical Analysis

All collected data were entered into a structured database and analyzed using SPSS version 16.0. Continuous variables were expressed as mean ± standard deviation, and categorical variables as frequencies and percentages. Pre- and post-treatment CT parameters were compared using paired t-test or Wilcoxon signed-rank test depending on data distribution. Associations between radiological response and clinical outcomes were analyzed using chi-square test or Fisher's exact test where appropriate. A p-value < 0.05 was considered statistically significant.

RESULTS

Table 1: Baseline Demographic and Clinical Characteristics

The baseline characteristics of the 78 enrolled patients demonstrate that pulmonary tuberculosis affected a relatively young to middle-aged population, with a mean age of 42.68 ± 13.42 years. A male predominance was

observed, with 61.54% males and 38.46% females, indicating higher susceptibility or greater healthcare-seeking behavior among men. Most patients (66.67%) were non-smokers, while 33.33% reported a history of smoking, suggesting that smoking was not a predominant risk factor in this cohort but may still influence disease severity in some cases. Regarding HIV status, a small proportion (8.97%) were HIV-positive, consistent with known associations between immunosuppression and tuberculosis. A history of previous tuberculosis was present in 23.08% of patients, indicating that nearly one-fourth had recurrent or reactivated disease, while the majority (76.92%) were newly diagnosed cases.

Table 2: Baseline CT Findings Before Treatment

The baseline CT findings reveal extensive radiological abnormalities consistent with active pulmonary tuberculosis. Consolidation was the most frequent finding, present in 79.49% of patients, indicating widespread alveolar involvement at the time of diagnosis. Nodular opacities were also common, detected in 74.36%, reflecting endobronchial spread and granulomatous inflammation. Cavitary lesions were present in over half the patients (56.41%), signifying advanced disease with significant tissue destruction. The tree-in-bud pattern was seen in 62.82%, further supporting active infectious bronchogenic dissemination. Bronchial wall thickening (65.38%) and bronchiectasis (41.03%) indicated chronic inflammatory airway damage. Ground-glass opacities (46.15%) suggested concurrent interstitial involvement. Lymphadenopathy was noted in 34.62%, representing nodal immune response, while pleural effusion occurred in 23.08%, indicating pleural inflammation in nearly a quarter of the cohort.

Table 3: Comparison of CT Findings before and After Treatment

A significant reduction in nearly all CT abnormalities was observed following treatment. Consolidation decreased from 79.49% at baseline to 23.08% after therapy, with a highly significant p-value (<0.001), demonstrating substantial resolution of alveolar disease. Similarly, cavitary lesions declined sharply from 56.41% to 19.23% ($p < 0.001$), indicating effective control of destructive pulmonary pathology. Nodular opacities and tree-in-bud patterns also showed marked improvement, decreasing to 43.59% and 26.92%, respectively (both $p < 0.001$), reflecting reduced endobronchial spread. Ground-glass opacities reduced significantly from 46.15% to 15.38% ($p < 0.001$). Bronchial wall thickening decreased from 65.38% to 28.21% ($p < 0.001$), suggesting diminished airway inflammation. Bronchiectasis showed a modest but significant decline from 41.03% to 25.64% ($p = 0.041$), consistent with partial reversibility of chronic changes. Pleural effusion diminished from 23.08% to 7.69% ($p = 0.012$).

Table 4: Radiological Treatment Response Categories

Analysis of radiological treatment response revealed that 37.18% of patients achieved a complete response, showing near-total resolution of radiological abnormalities. Partial response was the most common outcome, observed in 44.87%, indicating substantial but incomplete radiological improvement. Stable disease was noted in 11.54%, reflecting minimal radiological change despite therapy, possibly due to chronic fibrosis or incomplete healing. Progressive disease occurred in 6.41%, representing patients who showed worsening radiological abnormalities, potentially due to treatment failure, drug resistance, or paradoxical reactions.

Table 5: Correlation of Radiological Response with Clinical Improvement

A strong correlation was observed between radiological response and clinical improvement. Patients with complete radiological response predominantly experienced clinical improvement, with 42.86% showing favorable clinical outcomes compared to only 13.33% who did not improve ($p = 0.018$), indicating a statistically significant relationship. Among patients with partial response, clinical improvement was common (46.03%), although the association was not statistically significant ($p = 0.642$), suggesting that partial radiological improvement may not always translate proportionally into clinical benefit. Stable disease was associated with poorer clinical outcomes, as 26.67% of clinically non-improved patients fell into this category compared to 7.94% who improved ($p = 0.047$), indicating a significant correlation. Progressive disease showed a strong association with lack of clinical improvement, with 20.00% showing no improvement versus 3.17% who improved ($p = 0.011$), confirming that radiological worsening predicts negative clinical outcomes.

Table 1. Baseline Demographic and Clinical Characteristics of Patients (n = 78)

Variable	Category / Mean ± SD	Frequency (n)	Percentage (%)
Age (years)	42.68 ± 13.42	—	—
Sex	Male	48	61.54%
	Female	30	38.46%
Smoking Status	Smoker	26	33.33%
	Non-smoker	52	66.67%
HIV Status	Positive	7	8.97%
	Negative	71	91.03%
History of Previous TB	Yes	18	23.08%
	No	60	76.92%

Table 2. Baseline CT Findings before Treatment Initiation (n = 78)

CT Parameter	Present (n)	Percentage (%)
Consolidation	62	79.49%
Cavitary Lesions	44	56.41%
Nodular Opacities	58	74.36%
Tree-in-Bud Pattern	49	62.82%
Ground-Glass Opacities	36	46.15%
Bronchial Wall Thickening	51	65.38%
Bronchiectasis	32	41.03%
Lymphadenopathy	27	34.62%
Pleural Effusion	18	23.08%

Table 3. Comparison of CT Findings before and After Treatment (n = 78)

CT Parameter	Baseline n (%)	After Treatment n (%)	p-value
Consolidation	62 (79.49%)	18 (23.08%)	<0.001*
Cavitary Lesions	44 (56.41%)	15 (19.23%)	<0.001*
Nodular Opacities	58 (74.36%)	34 (43.59%)	<0.001*
Tree-in-Bud Pattern	49 (62.82%)	21 (26.92%)	<0.001*
Ground-Glass Opacities	36 (46.15%)	12 (15.38%)	<0.001*
Bronchial Wall Thickening	51 (65.38%)	22 (28.21%)	<0.001*
Bronchiectasis	32 (41.03%)	20 (25.64%)	0.041*
Pleural Effusion	18 (23.08%)	6 (7.69%)	0.012*

***Statistically significant ($p < 0.05$)**

Table 4. Radiological Treatment Response Categories (n = 78)

Response Category	Frequency (n)	Percentage (%)
Complete Response	29	37.18%
Partial Response	35	44.87%
Stable Disease	9	11.54%
Progressive Disease	5	6.41%

Table 5. Correlation of Radiological Response with Clinical Improvement (n = 78)

Radiological Response	Clinical Improvement (n = 63)	No Improvement (n = 15)	p-value
Complete Response	27 (42.86%)	2 (13.33%)	0.018*
Partial Response	29 (46.03%)	6 (40.00%)	0.642

Stable Disease	5 (7.94%)	4 (26.67%)	0.047*
Progressive Disease	2 (3.17%)	3 (20.00%)	0.011*

***Statistically significant**

DISCUSSION

This study found centrilobular/nodular patterns and tree-in-bud consistent with endobronchial spread (nodular opacities 74.36%, tree-in-bud 62.82%), and most of these findings improved after treatment (nodules → 43.59%, tree-in-bud → 26.92%). Im et al. (1993) described centrilobular lesions as the most common CT feature of early active pulmonary TB and reported centrilobular lesions in ~95% of cases, with most such lesions disappearing within ~5 months of therapy.^8 The present cohort shows the same predominant small-airway pattern but at a lower baseline proportion (74.4% nodules / 62.8% tree-in-bud vs Im's 95% centrilobular lesions), and the observed marked post-treatment decline here mirrors Im et al.'s observation of rapid resolution of airway-centered disease with effective therapy, supporting the interpretation that nodular/tree-in-bud patterns largely represent active, reversible endobronchial disease.[8] The "tree-in-bud" appearance is a recognized marker of bronchiolar impaction and infectious bronchogenic spread. Eisenhuber (2002) emphasized the tree-in-bud sign as a hallmark of bronchiolar plugging and infectious spread on thin-section CT, explaining its pathologic basis.9 Our baseline tree-in-bud prevalence (62.82%) is concordant with the notion that this sign is common in active pulmonary TB, and the reduction to 26.92% after treatment in our data corroborates Eisenhuber's mechanistic point that tree-in-bud reflects luminal impaction that frequently resolves when infection is controlled.[9] Cavitation was present in 56.41% at baseline and fell to 19.23% after treatment in our cohort. Jeong and Lee's AJR review (2008) summarized that cavitation is a frequent feature of post-primary/reactivation TB and reported literature ranges for cavitary disease commonly between roughly 30–60% in adult reactivation TB (reviewing multiple series) and stressed that cavities often decrease in size or resolve with treatment but can persist in some patients.10 Our baseline cavitation (56.4%) sits at the high end of Jeong et al.'s reported range and the marked post-treatment drop to 19.2% is consistent with their summary that many cavities shrink or close but a sizeable minority may persist — matching the review's clinical teaching that cavitary burden tends to fall with adequate therapy.[10] Imaging modalities that are more sensitive than CXR can detect earlier/greater radiologic burden and can help monitor response. Liu et al. (2007) used serial lung Gallium-67 scintigraphy and reported that functional imaging detected disease activity and that tracer uptake generally declined with successful therapy; they highlighted that imaging changes may precede clinical or simple radiographic readouts.11 Our study's quantitative radiologic reductions (e.g., consolidation 79.49% → 23.08%; cavitation 56.41% → 19.23%) echo Liu et al.'s finding that objective imaging metrics fall substantially with effective treatment, and the close correlation we observed between radiological and clinical improvement supports the view that imaging (CT or functional imaging) is a reliable monitor of therapeutic response.[11] Host factors alter radiographic phenotype. Geng et al. (2005) in a molecular-epidemiology cohort (1990–1999, n hundreds) showed that HIV infection was strongly associated with atypical radiographic appearances (increased adenopathy/effusion, less cavitation) and concluded that immune status, not simply time since infection, predicts radiographic pattern.^12 In our cohort HIV-positivity was 8.97%, a relatively small subgroup; nevertheless our overall pattern—high cavitation (56.4%) and upper-lung-type findings—fits with predominance of immunocompetent presentations as Geng et al. describe. Where our HIV patients existed, we would expect a relatively higher proportion of atypical features (adenopathy/effusion), consistent with the literature.[12] Cavitary TB often associates with more severe presentations and different complications. Lee et al. (2006) compared cavitary TB with tuberculous pneumonia and reported that cavitary disease comprised a substantial fraction of adult reactivation TB series (their series included 40 patients with cavitary TB vs 16 with tuberculous pneumonia) and that cavitary TB more commonly produced hemoptysis and radiographic chronicity.13 Our cohort's cavitation rate (56.4%) and the observed strong correlation between persistent radiologic disease/progression and poor clinical outcome (progressive disease 6.41% and associated lack of clinical improvement, p=0.011) mirror Lee et al.'s clinical message that cavitary disease implies a higher risk clinical phenotype and slower radiologic/clinical

recovery.[13] Radiographic extent and predictors of radiographic improvement have been quantified in prior series. Heo et al. (2009) prospectively measured radiographic lesion extent and reported a decrease in mean radiographic lesion extent from 22.8% at diagnosis to 10.5% after 6 months in 135 pts, and identified prior TB, cavitation and fibrotic changes as predictors of poorer radiographic clearance.14 In our work consolidation decreased from 79.49%→23.08% and bronchiectasis only modestly declined (41.03%→25.64%, p=0.041). The larger absolute percentages in our CT-based measures versus Heo's plain-film percentages reflect CT's greater sensitivity (CT detects more abnormalities than CXR) and support Heo et al.'s finding that cavities and prior disease hamper full radiographic recovery — a pattern we also observed (past TB 23.08% and slower resolution of bronchiectasis).[14] Bronchial wall thickening and bronchiectasis were common (65.38% and 41.03% at baseline) in our cohort, with bronchiectasis decreasing only modestly after treatment (to 25.64%). Wei et al. (2004) and similar CT-series emphasized that bronchiectatic and fibrotic sequelae may persist after microbiologic cure and that airway wall changes and traction bronchiectasis are often long-term sequelae of destructive TB.[15] The partial reversibility we saw (bronchiectasis fell from 41.0% to 25.6%) is consistent with the concept that some bronchial inflammation reverses while structural bronchiectasis (especially chronic traction) often remains, aligning with the CT-pathology correlation literature. Comprehensive imaging reviews show that CT is the reference for delineating active vs. chronic/residual lesions and for defining patterns (nodules, consolidation, cavities, tree-in-bud, bronchiectasis, lymphadenopathy). Skoura et al.'s review (2015) summarized imaging patterns across many series and emphasized that CT detects more bronchiectasis, nodules and cavities than CXR and is most useful for assessing treatment response and complications.^16 That matches our high baseline detection rates (e.g., nodules 74.4%, consolidation 79.5%) and the sizable post-treatment declines; CT therefore both inflates baseline prevalence compared with older CXR series and more sensitively demonstrates the degree of resolution — exactly the behaviorSkoura et al. describes .[16] Finally, several targeted CT-pattern papers underlined that imaging features predict disease activity and treatment trajectory. Gosset et al. (2009) (AJR) discussed the tree-in-bud/nodular complex as a strong imaging correlate of active endobronchial spread, and emphasized that centrilobular nodules and branching linear opacities generally decline with treatment when disease is microbiologically controlled. Our observed concomitant large falls in nodular/tree-in-bud frequency (nodules 74.4%→43.6%; tree-in-bud 62.8%→26.9%, both $p<0.001$) echo that principle and bolster the clinical-radiologic message that these CT signs are dynamic biomarkers of active infection and response. [17]

CONCLUSION

In conclusion, serial chest CT emerges as a valuable tool for monitoring treatment response in pulmonary tuberculosis, providing detailed visualization of disease evolution beyond what conventional radiography can offer. Progressive reduction in active parenchymal lesions, cavity resolution, and decreased airway involvement on follow-up CT scans can help clinicians identify early therapeutic success or detect suboptimal response. Incorporating CT-based assessment into clinical decision-making may therefore enhance timely treatment adjustments and improve patient outcomes. However, standardized CT-evaluation criteria and judicious use considering radiation exposure remain essential for optimizing its role in tuberculosis management.

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