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Original Article

HRCT Patterns of Pulmonary Tuberculosis and Their Correlation with Sputum Smear Positivity

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ABSTRACT

Background: Pulmonary tuberculosis remains a major public health concern, particularly in high-burden settings where sputum smear microscopy is still widely used despite limited sensitivity in early and paucibacillary disease. High-resolution computed tomography may provide complementary information by identifying radiological patterns associated with disease activity and bacillary burden. Objective: To determine the frequency of HRCT patterns in clinically suspected pulmonary tuberculosis and assess their association with sputum smear positivity. Methods: This cross-sectional observational study included 150 patients with clinically suspected pulmonary tuberculosis who underwent HRCT chest and sputum smear microscopy using Ziehl-Neelsen staining. HRCT findings, including consolidation, cavitation, tree-in-bud pattern, centrilobular nodules, ground-glass opacity, fibrosis, lymphadenopathy, laterality, and lobar extent, were compared between smear-positive and smear-negative groups using Chi-square testing, with odds ratios and 95% confidence intervals calculated for key associations. Results: Of 150 patients, 88 (58.7%) were smear-positive and 62 (41.3%) were smear-negative. Consolidation was the most frequent HRCT finding (72.0%), followed by tree-in-bud pattern (66.7%), centrilobular nodules (60.0%), and cavitation (48.7%). Cavitation showed the strongest association with smear positivity (OR 8.08, 95% CI 3.78-17.24), followed by tree-in-bud pattern (OR 4.15, 95% CI 2.02-8.51). Bilateral and multilobar involvement were also significantly associated with smear positivity, whereas ground-glass opacity was more frequent in smear-negative patients. Conclusion: Cavitation, tree-in-bud pattern, and greater disease extent on HRCT were strongly associated with sputum smear positivity, supporting the complementary role of HRCT in evaluating suspected pulmonary tuberculosis. Keywords: Pulmonary tuberculosis; HRCT; sputum smear positivity; cavitation; tree-in-bud pattern; Ziehl-Neelsen staining.

INTRODUCTION

Pulmonary tuberculosis remains one of the most persistent infectious disease challenges worldwide, with a disproportionate burden in low- and middle-income countries where delayed diagnosis, limited access to advanced testing, and ongoing community transmission continue to sustain disease incidence (1). Despite major advances in tuberculosis control, active pulmonary disease remains clinically important because untreated or late-treated cases contribute not only to individual morbidity but also to household and community spread, particularly when bacillary burden is high and patients remain undiagnosed during the infectious phase (2). Early recognition of active pulmonary tuberculosis is

therefore essential for timely initiation of anti-tuberculous therapy, infection-control measures, contact tracing, and reduction of transmission-related morbidity (3).

Sputum smear microscopy for acid-fast bacilli has historically remained a widely used diagnostic method because it is inexpensive, rapid, technically simple, and feasible in resource-constrained settings (4). However, smear microscopy has important diagnostic limitations, particularly in patients with early disease, low bacillary load, poor sputum production, atypical clinical presentation, or immunocompromised status, where microbiological yield may be reduced despite clinically active pulmonary tuberculosis (5). This limitation is clinically relevant because smear-negative patients may still have radiologically active disease and may experience diagnostic delay when sputum microscopy is interpreted in isolation (6). In this context, imaging has an important complementary role in evaluating suspected pulmonary tuberculosis, especially when microbiological confirmation is delayed, unavailable, or discordant with clinical suspicion (7).

Chest radiography is commonly used as an initial imaging modality, but its ability to characterize subtle parenchymal abnormalities, early bronchogenic spread, small nodular disease, and disease extent is limited. High-resolution computed tomography provides more detailed visualization of lung parenchyma and airways, allowing detection of radiological patterns that may reflect the underlying pathological processes of pulmonary tuberculosis, including granulomatous inflammation, caseous necrosis, endobronchial spread, and post-inflammatory fibrotic change (8). Typical HRCT findings described in active or previous pulmonary tuberculosis include consolidation, cavitation, centrilobular nodules, tree-in-bud pattern, ground-glass opacity, fibrosis, and mediastinal lymphadenopathy (9). Among these findings, the tree-in-bud pattern is particularly important because it represents centrilobular branching opacities caused by impacted and inflamed bronchioles, and in the setting of tuberculosis it is commonly interpreted as a marker of endobronchial dissemination and active disease (10).

Cavitation has additional clinical significance because it is closely linked with advanced parenchymal destruction and high mycobacterial burden. Cavitary lesions provide an oxygen-rich environment that favors multiplication of Mycobacterium tuberculosis, increasing the likelihood that bacilli will be expectorated and detected on sputum smear microscopy (11). Previous clinical and radiological studies have therefore identified cavitation as one of the strongest imaging correlates of smear positivity and infectiousness in pulmonary tuberculosis (12). Other HRCT patterns, including consolidation and centrilobular nodules, may also be observed in active disease, although their association with smear positivity may vary according to disease stage, bacillary load, immune status, and population characteristics (13). In contrast, ground-glass opacity may be seen in early, subtle, or paucibacillary disease, where sputum smear results may remain negative despite radiological evidence of pulmonary involvement (14).

The relationship between HRCT patterns and sputum smear positivity is clinically relevant because radiological features may help estimate disease activity, bacillary burden, and potential infectivity before or alongside microbiological confirmation. This is particularly important in high-burden or resource-limited settings where culture and molecular tests may not be consistently available and where clinical decisions often depend on integration of symptoms, microscopy, and imaging findings (15). Although molecular diagnostic methods have improved tuberculosis detection, smear microscopy continues to be widely used in many settings because of cost, availability, and operational feasibility (16). HRCT may therefore help identify patients who require closer microbiological evaluation, respiratory isolation, or urgent treatment consideration when smear findings and clinical suspicion are discordant (17).

Existing literature supports the value of radiological assessment in pulmonary tuberculosis, but reported associations between individual HRCT patterns and sputum smear positivity vary across studies because of differences in study populations, diagnostic criteria, imaging protocols, disease severity, and microbiological methods (18). Some studies have emphasized the role of radiological patterns in

identifying active pulmonary tuberculosis and predicting higher bacterial load, whereas others have shown overlap between smear-positive and smear-negative disease, indicating that imaging findings should be interpreted as supportive rather than definitive diagnostic evidence (19). This variability highlights the need for additional local evidence evaluating which HRCT patterns are most strongly associated with smear positivity in clinically suspected pulmonary tuberculosis (20). Understanding these associations may improve radiology-supported clinical decision-making, particularly when smear microscopy is negative or when rapid estimation of disease activity is required (21).

Accordingly, this study was conducted to determine the frequency of HRCT patterns among patients with clinically suspected pulmonary tuberculosis and to assess their association with sputum smear positivity. The study specifically evaluated whether cavitation, tree-in-bud pattern, consolidation, centrilobular nodules, ground-glass opacity, and the extent of pulmonary involvement differed between smear-positive and smear-negative patients, with the objective of identifying imaging features that may support assessment of active and potentially infectious pulmonary tuberculosis in routine clinical practice (22).

MATERIALS AND METHODS

This cross-sectional observational study was conducted at a tertiary care hospital from January 2024 to December 2024 to evaluate HRCT patterns in patients with clinically suspected pulmonary tuberculosis and to determine their association with sputum smear positivity. The cross-sectional design was selected because the objective was to assess radiological findings and sputum smear status at the time of diagnostic evaluation rather than to measure incidence, prognosis, or treatment response. The study population comprised patients referred for evaluation of suspected pulmonary tuberculosis on the basis of clinical features such as persistent cough, fever, weight loss, and hemoptysis, and all enrolled participants underwent both high-resolution computed tomography of the chest and sputum smear examination as part of the diagnostic workup.

A non-probability consecutive sampling technique was used to enroll 150 eligible patients during the study period. Consecutive recruitment was used to reduce selection bias by including all patients who fulfilled the eligibility criteria during the defined period of data collection. Male and female patients aged 15 years or older were included if they had clinical suspicion of pulmonary tuberculosis and underwent both HRCT chest and sputum smear microscopy. Patients were excluded if they had a previous history of treated pulmonary tuberculosis, known chronic lung disease, suspected or known lung malignancy, or poor-quality, incomplete, motion-degraded, or non-diagnostic HRCT images that could interfere with reliable interpretation of pulmonary findings. These exclusions were applied to reduce confounding from pre-existing structural lung abnormalities and to improve the validity of radiological interpretation.

After eligibility assessment, informed consent was obtained from all participants before inclusion. Demographic and clinical information was recorded using a structured proforma, including age, sex, presenting clinical suspicion, sputum smear result, and HRCT findings. Each participant underwent HRCT chest using a multidetector computed tomography scanner in the supine position during full inspiration. Thin-section images were acquired with a slice thickness of approximately 1–1.5 mm and reconstructed using a high-spatial-frequency algorithm to optimize visualization of lung parenchyma and small airway abnormalities. Images were evaluated in lung window settings by experienced radiologists using a predefined assessment approach focused on the presence or absence of consolidation, cavitation, centrilobular nodules, tree-in-bud pattern, ground-glass opacity, fibrosis, and mediastinal lymphadenopathy. The distribution and extent of disease were also recorded, including unilateral or bilateral involvement and single-lobe or multilobar disease.

Sputum specimens were examined for acid-fast bacilli using Ziehl-Neelsen staining. Based on sputum smear microscopy results, patients were categorized into smear-positive and smear-negative groups. The

primary outcome variable was sputum smear positivity. The principal explanatory variables were HRCT findings, including cavitation, tree-in-bud pattern, consolidation, centrilobular nodules, ground-glass opacity, lymphadenopathy, fibrosis, laterality of involvement, and lobar extent of disease. Cavitation was operationally defined as a gas-containing space within an area of pulmonary consolidation, nodule, or mass-like lesion. Tree-in-bud pattern was defined as centrilobular branching linear and nodular opacities suggestive of bronchiolar impaction or endobronchial spread. Consolidation was defined as increased parenchymal attenuation obscuring underlying vessels, while ground-glass opacity was defined as increased pulmonary attenuation without complete obscuration of bronchovascular structures. Multilobar disease was defined as involvement of more than one pulmonary lobe on HRCT.

Several procedural steps were used to improve data quality and reduce bias. Consecutive sampling minimized selective enrollment of clinically severe or radiologically obvious cases. Uniform inclusion and exclusion criteria were applied before data analysis. HRCT assessment was performed using a structured checklist to ensure consistent documentation of predefined imaging findings. Patients with previously treated tuberculosis, chronic lung disease, lung malignancy, or non-diagnostic imaging were excluded to reduce misclassification and confounding from residual fibrotic, malignant, or chronic inflammatory changes. Data were entered into a structured database, checked for completeness and internal consistency, and reviewed for denominator accuracy before statistical analysis.

The sample size was 150 patients, enrolled consecutively during the one-year study period, which provided an adequate descriptive sample for estimating the frequency of common HRCT patterns and comparing their distribution between smear-positive and smear-negative groups. Data were analyzed using Statistical Package for the Social Sciences version 25. Quantitative variables were summarized as mean and standard deviation, while categorical variables were summarized as frequencies and percentages. The distribution of HRCT findings was first described in the overall study population and then compared between smear-positive and smear-negative groups. The Chi-square test was used to assess associations between categorical HRCT findings and sputum smear status, with Fisher's exact test considered when expected cell counts were small. A p-value of less than 0.05 was considered statistically significant. For stronger clinical interpretation, comparative analysis should report effect estimates such as odds ratios with 95% confidence intervals for key HRCT findings, including cavitation, tree-in-bud pattern, ground-glass opacity, bilateral involvement, and multilobar disease. Missing or incomplete records were reviewed before analysis, and variables with incomplete documentation were excluded from the relevant variable-specific analysis rather than changing the total study denominator.

The study was conducted after approval from the institutional review board of the hospital. Written informed consent was obtained from participants before data collection. Patient confidentiality was maintained by using anonymized study records, restricting access to study data, and reporting results only in aggregate form. The study followed ethical principles for observational clinical research and did not alter the diagnostic or therapeutic management of enrolled patients.

RESULTS

A total of 150 patients with clinically suspected pulmonary tuberculosis were included in the analysis. The mean age of the study population was 38.6 ± 14.2 years. The largest age group was 31–45 years, comprising 51 patients (34.0%), followed by 15–30 years in 42 patients (28.0%), 46–60 years in 36 patients (24.0%), and >60 years in 21 patients (14.0%). Male patients were more frequent than female patients, with 92 males (61.3%) and 58 females (38.7%). On sputum smear microscopy, 88 patients (58.7%) were smear-positive and 62 patients (41.3%) were smear-negative.

HRCT demonstrated multiple overlapping radiological patterns among the included patients. Consolidation was the most frequent finding and was observed in 108 patients (72.0%), followed by tree-in-bud pattern in 100 patients (66.7%), centrilobular nodules in 90 patients (60.0%), and cavitation in 73 patients (48.7%). Ground-glass opacity was present in 58 patients (38.7%), lymphadenopathy in 46

patients (30.7%), and fibrosis in 34 patients (22.7%). These findings indicate that inflammatory air-space involvement and bronchiolar spread were the dominant HRCT patterns in this cohort, while fibrotic and nodal findings were comparatively less frequent.

When HRCT findings were compared according to sputum smear status, cavitation showed the strongest association with smear positivity. Cavitation was present in 60 of 88 smear-positive patients (68.2%) compared with 13 of 62 smear-negative patients (21.0%), corresponding to approximately eight-fold higher odds of smear positivity among patients with cavitation (OR = 8.08, 95% CI: 3.78–17.24; $p < 0.001$). Tree-in-bud pattern was also significantly associated with smear positivity, occurring in 70 smear-positive patients (79.5%) and 30 smear-negative patients (48.4%), with more than four-fold higher odds of smear positivity (OR = 4.15, 95% CI: 2.02–8.51; $p < 0.001$).

Table 1. Baseline Demographic Characteristics and Sputum Smear Status of the Study Population

Variable	Frequency (n)	Percentage (%)
Total sample	150	100.0
Age, years	38.6 ± 14.2	—
Age group		
15–30 years	42	28.0
31–45 years	51	34.0
46–60 years	36	24.0
>60 years	21	14.0
Gender		
Male	92	61.3
Female	58	38.7
Sputum smear status		
Smear-positive	88	58.7
Smear-negative	62	41.3

Table 2. Frequency of HRCT Findings in the Study Population

HRCT Finding	Frequency (n)	Percentage (%)
Consolidation	108	72.0
Tree-in-bud pattern	100	66.7
Centrilobular nodules	90	60.0
Cavitation	73	48.7
Ground-glass opacity	58	38.7
Lymphadenopathy	46	30.7
Fibrosis	34	22.7

Consolidation was numerically more frequent in smear-positive patients than smear-negative patients, 68/88 (77.3%) versus 40/62 (64.5%), but this difference did not reach statistical significance (OR = 1.87, 95% CI: 0.91–3.84; $p = 0.087$). Similarly, centrilobular nodules were observed in 58 smear-positive patients (65.9%) and 32 smear-negative patients (51.6%), showing a non-significant trend toward higher occurrence in smear-positive disease (OR = 1.81, 95% CI: 0.93–3.52; $p = 0.078$). Ground-glass opacity showed an inverse pattern and was more frequent among smear-negative patients, being present in 28 smear-positive patients (31.8%) and 30 smear-negative patients (48.4%), with lower odds of smear positivity among patients with ground-glass opacity (OR = 0.50, 95% CI: 0.25–0.97; $p = 0.040$).

Table 3. Association of HRCT Findings with Sputum Smear Positivity

HRCT Finding	Smear-Positive (n = 88)	Smear-Negative (n = 62)	Odds Ratio	95% CI	p-value
Cavitation	60 (68.2%)	13 (21.0%)	8.08	3.78–17.24	<0.001
Tree-in-bud pattern	70 (79.5%)	30 (48.4%)	4.15	2.02–8.51	<0.001
Consolidation	68 (77.3%)	40 (64.5%)	1.87	0.91–3.84	0.087
Centrilobular nodules	58 (65.9%)	32 (51.6%)	1.81	0.93–3.52	0.078
Ground-glass opacity	28 (31.8%)	30 (48.4%)	0.50	0.25–0.97	0.040

Disease extent on HRCT also differed substantially according to smear status. Bilateral lung involvement was present in 66 of 88 smear-positive patients (75.0%) compared with 28 of 62 smear-negative patients (45.2%), indicating significantly higher odds of smear positivity in patients with bilateral disease (OR =

3.64, 95% CI: 1.82–7.30; p < 0.001). Conversely, unilateral disease was more frequent in smear-negative patients, occurring in 34 patients (54.8%) compared with 22 smear-positive patients (25.0%). Multilobar involvement showed a similar pattern, being present in 70 smear-positive patients (79.5%) and 32 smear-negative patients (51.6%), with significantly increased odds of smear positivity among patients with multilobar disease (OR = 3.65, 95% CI: 1.78–7.48; p < 0.001). Single-lobe disease was more common in smear-negative patients, occurring in 30 patients (48.4%) compared with 18 smear-positive patients (20.5%). These findings suggest that smear-positive patients had more extensive pulmonary involvement on HRCT, particularly in terms of bilateral and multilobar distribution.

Table 4. Distribution of Disease Extent on HRCT According to Sputum Smear Status

Disease Extent	Smear-Positive (n = 88)	Smear-Negative (n = 62)	Total (n = 150)	Odds Ratio	95% CI	p-value
Unilateral involvement	22 (25.0%)	34 (54.8%)	56 (37.3%)			
Bilateral involvement	66 (75.0%)	28 (45.2%)	94 (62.7%)	3.64	1.82–7.30	<0.001
Single-lobe involvement	18 (20.5%)	30 (48.4%)	48 (32.0%)			
Multilobar involvement	70 (79.5%)	32 (51.6%)	102 (68.0%)	3.65	1.78–7.48	<0.001

Overall, the results demonstrate that cavitation and tree-in-bud pattern were the most clinically meaningful HRCT correlates of sputum smear positivity. Cavitation showed the largest effect size, with smear-positive patients having markedly higher cavitation frequency than smear-negative patients by an absolute difference of 47.2 percentage points. Tree-in-bud pattern also showed a strong association, with an absolute difference of 31.1 percentage points between smear-positive and smear-negative groups. Ground-glass opacity was more frequent in smear-negative disease, supporting its possible association with lower bacillary burden or less advanced disease patterns. In addition, bilateral and multilobar involvement were significantly more frequent among smear-positive patients, indicating that greater radiological disease extent was associated with higher likelihood of sputum smear positivity.

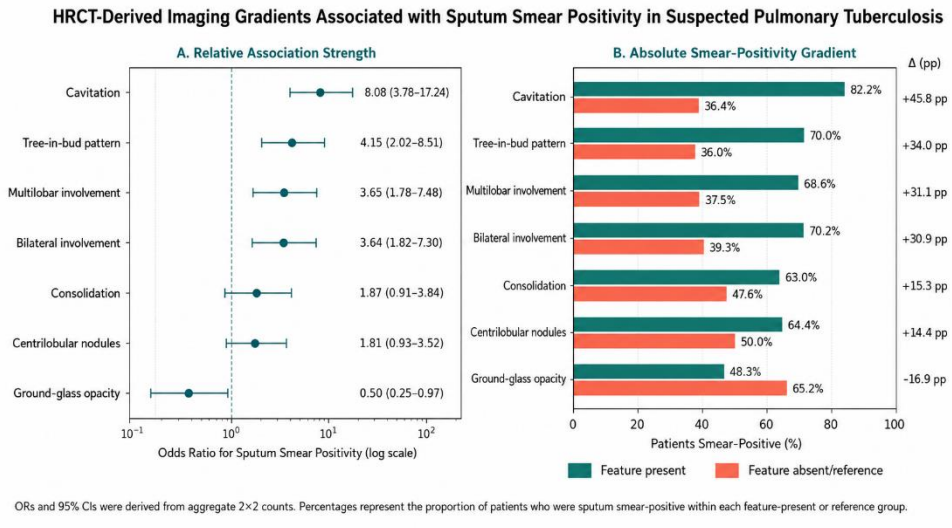

Figure 1 HRCT-Derived Imaging Gradients Associated with Sputum Smear Positivity in Suspected Pulmonary Tuberculosis.

Cavitation showed the strongest association with sputum smear positivity, with an odds ratio of 8.08 (95% CI: 3.78–17.24) and an absolute smear-positivity gradient of +45.8 percentage points between patients with and without cavitation. Tree-in-bud pattern also demonstrated a strong positive gradient, with OR 4.15 (95% CI: 2.02–8.51) and a +34.0 percentage-point increase in smear positivity. Multilobar and bilateral involvement showed comparable gradients, with ORs of 3.65 and 3.64, respectively, supporting the clinical interpretation that greater radiological disease extent is associated with higher bacillary burden. In contrast, ground-glass opacity demonstrated an inverse association, with OR 0.50 (95% CI: 0.25–0.97) and a −16.9 percentage-point gradient, suggesting that this pattern was more frequent in smear-negative or lower-burden disease.

DISCUSSION

This cross-sectional study evaluated HRCT patterns among patients with clinically suspected pulmonary tuberculosis and examined their association with sputum smear positivity. The principal finding was that cavitation and tree-in-bud pattern were the strongest HRCT correlates of smear positivity, while bilateral and multilobar disease extent were also significantly associated with smear-positive status. In contrast, ground-glass opacity showed an inverse association and was more frequent in smear-negative patients. These findings support the clinical value of HRCT as an adjunctive imaging tool for characterizing pulmonary disease activity and extent, particularly in settings where sputum smear microscopy remains widely used but has limited sensitivity in early or paucibacillary tuberculosis (15,16).

The demographic pattern observed in this cohort was consistent with the epidemiological profile commonly reported in pulmonary tuberculosis, with a predominance of males and a large proportion of patients in economically productive adult age groups. The mean age was 38.6 ± 14.2 years, and the largest age group was 31–45 years, accounting for 34.0% of the study population. Male patients represented 61.3% of the cohort, reflecting the recognized tendency for pulmonary tuberculosis to be more frequently detected among men in many high-burden settings, possibly due to occupational exposure, smoking patterns, health-seeking behavior, and social determinants influencing access to care (1,2). The high proportion of smear-positive patients, 58.7%, also indicates that a substantial number of included patients had microbiologically detectable bacillary burden at the time of HRCT assessment.

Consolidation was the most frequent HRCT finding, present in 72.0% of patients, followed by tree-in-bud pattern in 66.7%, centrilobular nodules in 60.0%, and cavitation in 48.7%. These findings are consistent with the known pathological spectrum of pulmonary tuberculosis, in which alveolar exudation, bronchiolar spread, granulomatous inflammation, and caseous necrosis may coexist within the same patient (4,5,8). However, consolidation alone did not show a statistically significant association with smear positivity, despite being numerically more frequent in smear-positive patients than smear-negative patients, 77.3% versus 64.5%. This suggests that consolidation is a common but relatively non-specific imaging manifestation of pulmonary tuberculosis and may reflect inflammatory parenchymal involvement across a range of bacillary burdens rather than serving as a reliable marker of smear-positive disease.

Cavitation demonstrated the strongest association with sputum smear positivity. Cavitary lesions were observed in 68.2% of smear-positive patients compared with 21.0% of smear-negative patients, corresponding to an odds ratio of 8.08 with a 95% confidence interval of 3.78–17.24. This strong association is biologically plausible because cavitation reflects advanced tissue destruction, liquefaction of caseous material, and communication with airways, allowing a high concentration of bacilli to be expectorated in sputum. Cavities also provide an oxygen-rich environment that favors multiplication of Mycobacterium tuberculosis, thereby increasing the likelihood of smear positivity and transmission risk (11,12). The present findings therefore reinforce the clinical importance of identifying cavitation on HRCT, not as a standalone diagnostic criterion, but as a radiological marker that may indicate higher bacillary burden and potential infectiousness in patients with suspected pulmonary tuberculosis.

Tree-in-bud pattern was also strongly associated with sputum smear positivity. It was present in 79.5% of smear-positive patients compared with 48.4% of smear-negative patients, with an odds ratio of 4.15 and a 95% confidence interval of 2.02–8.51. The tree-in-bud pattern reflects centrilobular branching opacities caused by bronchiolar impaction and endobronchial dissemination, and it is widely recognized as an imaging feature of active infectious bronchiolitis in pulmonary tuberculosis (9,10). The strong association observed in this study supports the interpretation that tree-in-bud pattern may represent ongoing bronchogenic spread and a higher probability of sputum smear positivity. Clinically, this finding is important because it may help radiologists and clinicians identify patients in whom microbiological

confirmation should be pursued aggressively, particularly when initial smear results are negative or pending.

Centrilobular nodules were common, occurring in 60.0% of the total cohort, and were more frequent among smear-positive patients than smear-negative patients, 65.9% versus 51.6%. However, this association did not reach statistical significance. This finding suggests that centrilobular nodules may reflect active small-airway or peribronchiolar involvement but may not independently distinguish smear-positive from smear-negative disease. The overlap between groups is clinically expected because nodular bronchiolar involvement may occur across different stages of pulmonary tuberculosis, including early or less bacilliferous disease. Similarly, consolidation showed only a non-significant trend toward smear positivity, indicating that these findings should be interpreted in combination with more specific markers such as cavitation and tree-in-bud pattern rather than in isolation.

Ground-glass opacity showed an inverse relationship with sputum smear positivity. It was present in 31.8% of smear-positive patients and 48.4% of smear-negative patients, with an odds ratio of 0.50 and a 95% confidence interval of 0.25–0.97. This pattern may represent partial air-space involvement, subtle inflammatory change, early parenchymal disease, or lower bacillary burden. The higher frequency of ground-glass opacity among smear-negative patients supports the concept that HRCT may detect pulmonary abnormalities even when sputum smear microscopy does not identify acid-fast bacilli. This observation is clinically relevant because smear-negative pulmonary tuberculosis can be diagnostically challenging, and reliance on microscopy alone may delay further evaluation or treatment in patients with compatible clinical and imaging features (15,17).

Disease extent on HRCT was also significantly related to smear positivity. Bilateral involvement was present in 75.0% of smear-positive patients compared with 45.2% of smear-negative patients, while multilobar involvement was present in 79.5% and 51.6%, respectively. Both bilateral and multilobar disease showed more than three-fold higher odds of smear positivity. These findings indicate that patients with smear-positive disease had more extensive radiological involvement, which may reflect a larger burden of active pulmonary lesions and greater likelihood of bacillary expectoration. The association between disease extent and smear positivity also has practical infection-control implications, as patients with diffuse pulmonary involvement and radiological features such as cavitation or tree-in-bud pattern may require heightened clinical attention while microbiological confirmation and treatment decisions are being finalized.

The findings of this study should be interpreted in the context of routine clinical practice. HRCT should not be considered a replacement for microbiological confirmation, culture, or molecular testing; rather, it provides complementary anatomical and pattern-based information that can support diagnostic reasoning. In settings where molecular diagnostics are not readily available, HRCT patterns may help identify patients with higher probability of smear-positive disease and may guide decisions regarding isolation, repeat sputum testing, or further microbiological workup (16,20). Conversely, the presence of ground-glass opacity in smear-negative patients emphasizes that absence of smear positivity does not exclude clinically relevant pulmonary involvement, particularly in early or paucibacillary disease.

This study has several limitations. First, it was conducted at a single tertiary care hospital, which may limit generalizability to community-based populations or lower-level healthcare settings. Second, sputum smear microscopy was used as the microbiological comparator, but more sensitive tests such as culture or molecular assays were not incorporated into the primary analysis. This limits the ability to determine the true diagnostic accuracy of HRCT patterns for active tuberculosis. Third, although HRCT findings were evaluated systematically, interobserver agreement was not reported, and radiological interpretation may be influenced by reader experience. Fourth, the cross-sectional design allows assessment of association but does not establish temporal or causal relationships between imaging patterns and smear positivity. Finally, potential confounders such as smoking status, diabetes, HIV status, symptom duration, nutritional status, and prior antibiotic exposure were not included in adjusted

analysis. Future multicenter studies using standardized HRCT interpretation, culture or molecular confirmation, and multivariable modeling are needed to validate these findings and determine whether combined imaging–clinical prediction models can improve decision-making in suspected pulmonary tuberculosis.

Despite these limitations, the study provides clinically useful evidence that specific HRCT features are differentially associated with sputum smear status. Cavitation and tree-in-bud pattern showed the strongest positive associations with smear positivity, while bilateral and multilobar disease extent further supported the relationship between radiological burden and microbiological detectability. Ground-glass opacity was more frequent in smear-negative disease, suggesting a potentially different radiological phenotype that may correspond to lower bacillary burden or earlier disease. These findings highlight the importance of integrating HRCT patterns with clinical assessment and microbiological testing to improve evaluation of suspected pulmonary tuberculosis.

CONCLUSION

HRCT provides valuable supportive information in the evaluation of clinically suspected pulmonary tuberculosis by identifying radiological patterns associated with sputum smear positivity and disease extent. In this study, cavitation and tree-in-bud pattern were the strongest imaging correlates of smear-positive disease, while bilateral and multilobar involvement were also significantly associated with higher likelihood of smear positivity. Ground-glass opacity was more frequent among smear-negative patients, suggesting that HRCT may help detect pulmonary involvement even when sputum microscopy is negative. These findings support the use of HRCT as a complementary tool alongside clinical assessment and microbiological testing, particularly in settings where smear microscopy remains widely used and rapid molecular confirmation may not always be available.

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