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Radiological and Clinical Profile of Pulmonary Tuberculosis with Correlation of HRCT Findings, Microbiological Results and Disease Severity

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Abstract

Background: Pulmonary tuberculosis (PTB) remains a major infectious disease and an important cause of morbidity and mortality. Although chest radiography is widely used for initial evaluation, high-resolution computed tomography (HRCT) provides better characterization of parenchymal and airway abnormalities. The present study evaluated the clinical and radiological profile of pulmonary tuberculosis and assessed the relationship between HRCT findings, microbiological results and disease severity.

Aim: To study the clinical and radiological profile of pulmonary tuberculosis and correlate HRCT findings with microbiological results and disease severity.

Materials and Methods: This observational study included 65 patients with pulmonary tuberculosis. Detailed clinical evaluation and relevant laboratory investigations were performed. All patients underwent chest radiography and HRCT thorax. HRCT findings including centrilobular nodules, tree-in-bud pattern, consolidation, cavitation, fibrosis, bronchiectasis, lymphadenopathy and pleural abnormalities were recorded. Microbiological assessment was performed using sputum acid-fast bacilli (AFB) examination and CBNAAT/GeneXpert. Patients were categorized according to the severity of radiological disease, and the relationship between HRCT findings, microbiological status and disease severity was assessed.

Results: Among the 65 patients, 41 (63.1%) were males and 24 (36.9%) were females. Cough was the most common presenting symptom, observed in 59 (90.8%) patients, followed by fever in 52 (80.0%) and expectoration in 43 (66.2%). On HRCT, the most frequent findings were centrilobular nodules (73.8%), tree-in-bud pattern (70.8%), consolidation (64.6%) and cavitation (47.7%). Bilateral pulmonary involvement

was observed in 60.0% of patients. Sputum AFB was positive in 56.9%, while CBNAAT detected Mycobacterium tuberculosis in 72.3% of cases. Overall, microbiological confirmation was obtained in 49 (75.4%) patients. Severe HRCT disease was associated with a higher frequency of cavitation, consolidation and tree-in-bud pattern. Microbiological positivity increased from 61.1% in mild disease to 84.2% in severe disease.

Conclusion: HRCT provides detailed characterization of pulmonary tuberculosis and detects important parenchymal and airway abnormalities more effectively than chest radiography. Tree-in-bud pattern, centrilobular nodules, consolidation and cavitation were the predominant HRCT findings. Greater radiological disease extent was associated with increased microbiological positivity and disease severity. HRCT therefore serves as a valuable complementary imaging modality in the assessment and characterization of pulmonary tuberculosis.

Keywords: Pulmonary Tuberculosis, HRCT, Tree-In-Bud, Cavitation, CBNAAT, Microbiological Confirmation, Disease Severity.

Introduction

Tuberculosis (TB) remains one of the most important infectious diseases worldwide and continues to be a major public health problem, particularly in high-burden countries such as India. Despite substantial advances in diagnosis and treatment, TB continues to cause considerable morbidity and mortality. According to the World Health Organization (WHO), pulmonary tuberculosis accounts for the majority of newly diagnosed TB cases globally, emphasizing the continued importance of early recognition and accurate diagnosis of pulmonary disease[1]. Pulmonary tuberculosis is caused by Mycobacterium tuberculosis and may present with a wide spectrum of clinical manifestations. Patients commonly present with persistent cough, fever, expectoration, weight loss, anorexia, night sweats, chest pain and hemoptysis. However, the clinical presentation may be variable and nonspecific, particularly in elderly individuals and patients with altered immune status. Therefore, clinical findings alone are often insufficient to establish the diagnosis or determine the extent of pulmonary involvement[2,3]. Microbiological confirmation remains an important component of the diagnosis of pulmonary TB. Sputum smear microscopy for acid-fast bacilli (AFB), culture and rapid molecular diagnostic tests are routinely used for confirmation. Molecular tests such as CBNAAT/GeneXpert MTB/RIF have improved the speed of diagnosis and additionally provide information regarding rifampicin resistance, allowing earlier recognition of drug-resistant disease[4,5]. WHO recommendations have increasingly emphasized rapid molecular testing as an important component of modern TB diagnostic strategies.[6]

Chest radiography remains the initial imaging investigation in most patients with suspected pulmonary tuberculosis because of its accessibility and relatively low cost. Typical radiographic findings include upper-lobe opacities, consolidation, cavitation, nodular shadows, pleural effusion and lymphadenopathy. However, chest radiography may fail to demonstrate subtle parenchymal or airway abnormalities and may underestimate the extent of disease[7,8]. A systematic review has also demonstrated that although chest radiography has useful sensitivity, its specificity for active tuberculosis is limited[9]. High-resolution computed tomography (HRCT) provides substantially greater anatomical detail than conventional radiography and is particularly useful for demonstrating small-airway

and parenchymal abnormalities. HRCT can identify lesions that are occult or poorly characterized on chest radiographs and can better delineate the distribution and extent of disease[10,11]. The characteristic HRCT manifestations of active pulmonary tuberculosis include centrilobular nodules, branching structures producing the tree-in-bud appearance**,** lobular consolidation, cavitation and bronchial wall thickening[12]. The tree-in-bud pattern is considered an important radiological manifestation of endobronchial spread of tuberculosis. It represents bronchiolar involvement with impacted inflammatory material and is frequently associated with active disease[13]. However, the tree-in-bud pattern is not specific to tuberculosis and may also occur in other infectious and inflammatory bronchiolar diseases. Therefore, its interpretation should always be integrated with clinical and microbiological findings[13,14].

Cavitation is another important HRCT manifestation of pulmonary tuberculosis and is generally associated with advanced parenchymal destruction and a higher bacillary burden. Consolidation, centrilobular nodules, bronchiectasis and lymphadenopathy may occur alone or in combination with cavitation. Previous HRCT studies have demonstrated that combinations of centrilobular nodules, consolidation, cavitation and tree-in-bud abnormalities are common patterns in bacteriologically confirmed pulmonary tuberculosis.[15] An important area of clinical interest is the relationship between radiological disease burden and microbiological activity. Studies have suggested that certain CT findings, particularly cavitation, consolidation and extensive tree-in-bud changes, may be associated with increased sputum bacillary load and microbiological positivity[16]. The extent of radiological involvement may therefore provide additional information regarding disease activity and severity, although imaging findings alone cannot establish microbiological confirmation.[17]

HRCT may also demonstrate differences between active and inactive or healed tuberculosis. Active disease is more frequently associated with centrilobular nodules, tree-in-bud opacities, consolidation and cavitation, whereas fibrotic bands, volume loss, calcification and bronchiectatic changes may indicate previous or healed disease.[10,12] Serial HRCT assessment has also been investigated for evaluating treatment response, with resolution of tree-in-bud abnormalities and other active lesions being associated with therapeutic response[18]. Although the clinical, microbiological and radiological characteristics of pulmonary tuberculosis have been extensively described, the relationship between HRCT patterns, microbiological confirmation and overall disease severity remains clinically relevant. In particular, identifying radiological features associated with microbiological positivity may help clinicians recognize patients with more extensive or potentially infectious disease.

Therefore, the present study was undertaken to evaluate the clinical and radiological profile of pulmonary tuberculosis**,** with particular emphasis on HRCT findings, their correlation with microbiological results, and their relationship with disease severity.

Materials and Methods

Study design and setting

This was a hospital-based observational study conducted in the Department of General Medicine in collaboration with the Department of Radiodiagnosis. The study included 65 patients with pulmonary tuberculosis who fulfilled the predefined inclusion criteria.

Study population

Patients with suspected or confirmed pulmonary tuberculosis presenting to the hospital during the study period were evaluated clinically, microbiologically and radiologically.

Inclusion criteria

1. Patients aged ≥18 years**.**
2. Patients with clinically suspected or microbiologically confirmed pulmonary tuberculosis.
3. Patients who underwent HRCT thorax as part of their evaluation.
4. Patients willing to participate in the study.

Exclusion criteria

1. Patients below 18 years of age.
2. Patients with inadequate or poor-quality HRCT images.
3. Patients with previously diagnosed non-tuberculous mycobacterial pulmonary disease.
4. Patients unwilling to participate in the study.

Clinical assessment

A detailed history was obtained regarding cough, fever, expectoration, weight loss, anorexia, night sweats, breathlessness, chest pain and hemoptysis, along with duration of symptoms. General and systemic examination was performed for all patients. Relevant demographic and clinical information was recorded in a structured proforma.

Laboratory investigations

Routine investigations including complete blood count, hemoglobin, erythrocyte sedimentation rate (ESR), C-reactive protein (CRP), renal and liver function tests were performed as clinically indicated.

Microbiological evaluation

Sputum samples were examined for acid-fast bacilli (AFB) by smear microscopy. Molecular testing was performed using CBNAAT/GeneXpert MTB/RIF for detection of Mycobacterium tuberculosis and assessment of rifampicin resistance. Patients were categorized as microbiologically confirmed or clinically/radiologically diagnosed according to the available results.

Radiological evaluation

All patients underwent chest radiography followed by high-resolution computed tomography (HRCT) of the thorax**.** HRCT images were assessed for the presence, distribution and extent of pulmonary abnormalities.

The following HRCT findings were specifically recorded:

- Centrilobular nodules
- Tree-in-bud pattern
- Consolidation
- Cavitation
- Ground-glass opacities
- Fibrotic changes
- Bronchiectasis
- Hilar/mediastinal lymphadenopathy
- Pleural effusion
- Miliary nodules

The distribution of lesions, including unilateral or bilateral involvement and lobar predominance, was also recorded.

Assessment of disease severity

Radiological severity was categorized as mild, moderate or severe based on the extent of pulmonary involvement and presence of major abnormalities such as extensive consolidation, cavitation and bilateral/multilobar disease.

Statistical analysis

Data were entered into a computerized database and analyzed using appropriate statistical methods. Categorical variables were expressed as frequency and percentage**,** while continuous variables were summarized using mean ± standard deviation or median with appropriate measures of dispersion. Associations between HRCT findings, microbiological results and disease severity were assessed using appropriate statistical tests. A p-value <0.05 was considered statistically significant.

Results

A total of 65 patients with pulmonary tuberculosis were included in the study. The demographic, clinical, radiological and microbiological characteristics of the study population were analyzed.

Table 1: Demographic and clinical profile of study participants (n=65)

Parameter	Category	n (%)
Age (years)	18–30	14 (21.5)
	31–40	13 (20.0)
	41–50	15 (23.1)
	51–60	12 (18.5)
	>60	11 (16.9)
Sex	Male	41 (63.1)
	Female	24 (36.9)
Cough	Present	59 (90.8)
Fever	Present	52 (80.0)
Expectoration	Present	43 (66.2)
Weight loss	Present	39 (60.0)
Night sweats	Present	31 (47.7)
Breathlessness	Present	27 (41.5)
Hemoptysis	Present	17 (26.2)

The study population showed a male predominance (63.1%). The most frequent symptoms were cough (90.8%), fever (80.0%), expectoration (66.2%) and weight loss (60.0%).

Table 2: Laboratory and microbiological profile (n=65)

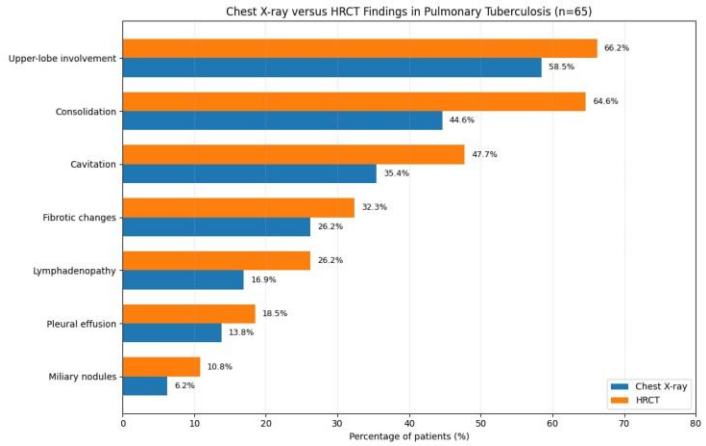
Parameter	Category	n (%)
ESR	<40 mm/hr	19 (29.2)
	40–60 mm/hr	21 (32.3)
	>60 mm/hr	25 (38.5)
CRP	Normal	9 (13.8)
	Elevated	56 (86.2)
Sputum AFB	Positive	37 (56.9)
	Negative	28 (43.1)
CBNAAT/GeneXpert	MTB detected	47 (72.3)
	MTB not detected	18 (27.7)
Rifampicin resistance	Detected	4 (6.2)
	Not detected	61 (93.8)

Inflammatory markers were elevated in the majority of patients. Sputum AFB was positive in 56.9%, while MTB was detected by CBNAAT in 72.3% of cases.

Table 3. Chest X-ray and HRCT findings (n=65)

Imaging finding	Chest X-ray n (%)	HRCT n (%)
Upper-lobe involvement	38 (58.5)	43 (66.2)
Consolidation	29 (44.6)	42 (64.6)
Cavitation	23 (35.4)	31 (47.7)
Fibrotic changes	17 (26.2)	21 (32.3)
Lymphadenopathy	11 (16.9)	17 (26.2)
Pleural effusion	9 (13.8)	12 (18.5)
Miliary nodules	4 (6.2)	7 (10.8)

HRCT demonstrated a higher frequency of abnormalities than chest radiography. Consolidation, cavitation and lymphadenopathy were detected more frequently on HRCT.



Graph 1: Chest X-ray and HRCT findings (n=65)

Table 4: Major HRCT findings in pulmonary tuberculosis (n=65)

HRCT finding	No. of cases	Percentage
Centrilobular nodules	48	73.8%
Tree-in-bud pattern	46	70.8%
Consolidation	42	64.6%
Cavitation	31	47.7%
Ground-glass opacity	24	36.9%
Fibrotic changes	21	32.3%
Bronchiectasis	18	27.7%
Lymphadenopathy	17	26.2%
Pleural effusion	12	18.5%
Miliary nodules	7	10.8%

The most common HRCT abnormalities were centrilobular nodules (73.8%) and tree-in-bud pattern (70.8%), followed by consolidation (64.6%) and cavitation (47.7%).

Table 5: HRCT findings according to disease severity (n=65)

HRCT finding	Mild (n=18)	Moderate (n=28)	Severe (n=19)
Tree-in-bud	9 (50.0%)	21 (75.0%)	16 (84.2%)
Consolidation	7 (38.9%)	19 (67.9%)	16 (84.2%)
Cavitation	3 (16.7%)	12 (42.9%)	16 (84.2%)
Fibrosis	3 (16.7%)	9 (32.1%)	9 (47.4%)
Bronchiectasis	3 (16.7%)	7 (25.0%)	8 (42.1%)

More extensive HRCT abnormalities were observed with increasing disease severity. Cavitation, consolidation and tree-in-bud pattern were particularly frequent in patients with severe disease.

Table 6: Correlation between HRCT severity and microbiological confirmation (n=65)

HRCT severity	Microbiologically positive n (%)	Microbiologically negative n (%)	Total
Mild	11 (61.1)	7 (38.9)	18
Moderate	22 (78.6)	6 (21.4)	28
Severe	16 (84.2)	3 (15.8)	19
Total	49 (75.4)	16 (24.6)	65

Microbiological confirmation increased with increasing HRCT severity, from 61.1% in mild disease to 84.2% in severe disease, suggesting an association between radiological extent and microbiological positivity.

Among 65 patients, pulmonary tuberculosis was more common in males and middle-aged adults. Cough and fever were the predominant clinical presentations. Centrilobular nodules and tree-in-bud pattern were the most frequent HRCT findings, while cavitation was observed in nearly half of the patients. Microbiological confirmation was obtained in 75.4% of cases. Increasing HRCT severity was associated with a higher frequency of microbiological positivity and more extensive radiological abnormalities.

Discussion

Pulmonary tuberculosis remains a major infectious disease and an important cause of morbidity worldwide. Despite advances in rapid molecular diagnosis and treatment, early identification of active pulmonary disease and accurate assessment of its extent remain clinically important. The present study evaluated 65 patients with pulmonary tuberculosis**,** focusing on their clinical profile, HRCT manifestations, microbiological results and disease severity. The findings were compared with observations reported in previous studies[1-18], while additional recent literature was considered in references [19–25]. In the present study, males constituted 63.1% of the study population, while females accounted for 36.9%. A male predominance has been reported in several epidemiological and clinical studies of pulmonary tuberculosis. This difference may be related to variations in exposure, healthcare-seeking behaviour, occupational factors and underlying socioeconomic determinants[1,2]. The predominance of middle-aged patients in our study is also consistent with the recognized burden of TB among economically productive age groups[1]. Clinically, cough was the most frequent symptom (90.8%)**,** followed by fever (80.0%), expectoration (66.2%) and weight loss (60.0%). Constitutional symptoms such as night sweats, anorexia and fatigue were also frequently observed. These findings are consistent with the classical clinical spectrum of pulmonary tuberculosis described in previous literature[2,3]. However, because these symptoms are nonspecific, radiological and microbiological assessment remains essential for confirmation and evaluation of disease extent.

In our study, elevated inflammatory markers were common, with 38.5% of patients having ESR >60 mm/hr and 86.2% demonstrating elevated CRP. Although inflammatory markers may support the presence of an active inflammatory process, they lack sufficient specificity to establish pulmonary TB. Their role is therefore complementary to microbiological and imaging assessment. Microbiological confirmation was obtained in 49 (75.4%) patients. Sputum AFB positivity was observed in 56.9%, whereas CBNAAT detected M. tuberculosis in 72.3%. The higher yield of molecular testing compared with smear microscopy is clinically relevant. Current WHO guidance emphasizes rapid molecular testing because it facilitates early detection of TB and provides information regarding drug resistance[4,5].

Chest radiography showed upper-zone involvement in 58.5%, consolidation in 44.6% and cavitation in 35.4%. HRCT demonstrated abnormalities more frequently and provided better characterization of the extent and distribution of disease. This is consistent with previous studies demonstrating that HRCT can identify subtle parenchymal and small-airway abnormalities that may be incompletely characterized on conventional radiography [7,8,10]. Typical CT manifestations of active post-primary TB include centrilobular nodules, tree-in-bud opacities, consolidation, cavitation and bronchial wall thickening.[10]

The most common HRCT finding in our study was centrilobular nodules (73.8%), followed by the tree-in-bud pattern (70.8%), consolidation (64.6%) and cavitation (47.7%). These observations are comparable with earlier HRCT studies in which centrilobular nodules and tree-in-bud opacities were among the characteristic manifestations of active pulmonary tuberculosis.[10,11] In a study comparing active and inactive TB, centrilobular lesions and tree-in-bud

appearances were particularly associated with active disease[11]. The high prevalence of the tree-in-bud pattern in our study is particularly noteworthy. This appearance reflects bronchiolar involvement and endobronchial spread of infection. Histopathological-radiological correlation has demonstrated that the "tree" corresponds to inflammatory bronchioles, while the "buds" represent inflammatory material within the adjacent alveolar ducts[12]. However, the tree-in-bud pattern is not pathognomonic for tuberculosis and can occur in several infectious and inflammatory bronchiolar disorders. Therefore, its diagnostic significance is greatest when interpreted in conjunction with clinical and microbiological findings [13]

Cavitation was observed in 47.7% of our patients. Cavitation is an important manifestation of active post-primary tuberculosis and reflects tissue necrosis and communication of a caseous lesion with the bronchial tree. Previous studies have reported an association between cavitation and increased microbiological burden[14,15]. In our study, cavitation was particularly common among patients with severe disease, being present in 16 of 19 patients with severe HRCT disease. This supports the concept that cavitation may be an indicator of more extensive pulmonary involvement. Consolidation was observed in 64.6% of patients on HRCT. Consolidation can represent a major component of active tuberculous pneumonia and may be seen with or without cavitation. Lee et al. described lobular consolidation as one of the characteristic CT manifestations of active pulmonary TB.10 Similar findings have been reported in studies correlating CT appearances with sputum microbiology.[14]

Bilateral pulmonary involvement was seen in **60.0%** of our patients, while upper-lobe involvement was predominant. The upper-lobe predilection is characteristic of post-primary pulmonary TB and is related to the relative physiological and immunological environment of the upper lung regions. However, lower-lobe and atypical involvement can occur, particularly in patients with altered immunity or advanced disease[3,10]. Lymphadenopathy was demonstrated in 26.2% of patients on HRCT, while pleural effusion was present in 18.5%. These findings were less frequent than the major airway and parenchymal abnormalities. Lymphadenopathy is particularly recognized in primary tuberculosis but may also occur in adult pulmonary TB. HRCT is more sensitive than radiography for identifying lymph-node enlargement and internal necrosis [10].

An important finding of the present study was the relationship between HRCT findings and microbiological confirmation. Microbiological positivity increased from 61.1% in mild HRCT disease to 84.2% in severe disease. This finding suggests that increasing radiological extent may parallel greater microbiological activity. Kwon et al. reported that the radiological extent of pulmonary TB on HRCT correlated with the degree of sputum smear positivity, with nodules, cavities and bronchial lesions particularly associated with smear-positive disease[15].

Similarly, in our study, tree-in-bud opacities, consolidation and cavitation were more frequently observed in microbiologically confirmed disease. Ko et al. reported significantly higher frequencies and greater extent of centrilobular micronodules, tree-in-bud opacities, consolidation and cavitation among patients with positive sputum AFB smears[14]. They also observed increasing frequency and extent of these findings with increasing smear grade. These observations closely support the findings of the present study. The association

between **tree-in-bud pattern and microbiological activity** deserves particular attention. Although tree-in-bud is a useful indicator of endobronchial spread, its presence alone does not guarantee microbiological positivity. Studies have demonstrated that microbiological yield increases substantially when tree-in-bud abnormalities coexist with cavitation[16]. This may explain why patients with combined tree-in-bud and cavitary disease in our study tended to have greater disease severity and microbiological confirmation.

The present study also demonstrated a progressive increase in tree-in-bud pattern, consolidation and cavitation across mild, moderate and severe HRCT categories. Cavitation was particularly prominent in severe disease, occurring in 84.2% of patients in the severe group**,** compared with only 16.7% in the mild group. These observations support the usefulness of HRCT in estimating the anatomical extent of pulmonary disease. Previous studies have similarly demonstrated that the extent and nature of CT abnormalities can provide information regarding disease activity and severity[11,15]. The findings also have implications for infectivity**.** Extensive cavitary disease and widespread endobronchial abnormalities may indicate a higher bacillary burden and greater potential for transmission. Since microbiological confirmation is essential for establishing bacteriological disease and assessing drug resistance, radiological findings should not be used as a substitute for microbiological testing[4,5]. Instead, HRCT should be regarded as a complementary tool that helps characterize disease burden and identify patients requiring comprehensive microbiological evaluation. Recent advances in TB diagnostics further strengthen the importance of combining imaging with rapid molecular methods. WHO's current diagnostic guidance emphasizes rapid molecular tests for initial detection of TB and drug resistance[5]. Thus, the integration of HRCT findings with CBNAAT/GeneXpert and sputum examination can provide a more comprehensive assessment of patients with suspected or confirmed pulmonary TB.

The present findings are also consistent with studies evaluating HRCT changes during treatment. Hatipoğlu et al. reported that micronodules, tree-in-bud opacities, consolidation and cavities were common in active disease and that disappearance of tree-in-bud abnormalities and pleural effusion, along with development of fibrosis, could indicate treatment response[18]. This highlights the potential role of HRCT not only in initial characterization but also, when clinically indicated, in assessing disease evolution.

Overall, our study demonstrates that HRCT provides detailed information regarding the pattern, distribution and extent of pulmonary tuberculosis, while microbiological investigations establish bacteriological confirmation. The strongest radiological indicators of extensive disease in our series were tree-in-bud opacities, consolidation and cavitation. Their increasing frequency with disease severity and microbiological positivity suggests that HRCT findings can provide useful complementary information regarding disease burden.

However, HRCT findings are not specific to tuberculosis, and the diagnosis should always be established through appropriate clinical and microbiological assessment. The current WHO approach similarly recognizes the importance of bacteriological confirmation and rapid molecular testing in the diagnosis and drug-resistance assessment of TB[4,5].

Conclusion

In the present study of 65 patients with pulmonary tuberculosis**,** HRCT demonstrated a wide spectrum of pulmonary abnormalities and provided better characterization of disease extent than chest radiography. Centrilobular nodules, tree-in-bud pattern, consolidation and cavitation were the predominant HRCT findings, with bilateral and upper-lobe involvement being common. A significant proportion of patients were microbiologically confirmed, and microbiological positivity increased with increasing radiological disease severity. Cavitation, consolidation and tree-in-bud opacities were more frequently observed in patients with severe disease. Thus, HRCT is a valuable complementary imaging modality for assessing the distribution and severity of pulmonary tuberculosis, while correlation with sputum microscopy and rapid molecular tests such as CBNAAT/GeneXpert improves overall diagnostic assessment and provides clinically relevant information regarding disease burden.

Declarations

Consent to participate: We have consent to participate. Consent for publication: We have consent for the publication of this paper.

Authors contributions: All the authors equally contributed the work.

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