Vol. 5 No. 2 (2026)

Pakistan Journal of Medical & Cardiological Review

https://pakjmcr.com/index.php/1/about

Online ISSN 3007-2387

Print ISSN 3007-2379

Akram et al - 2026

DOI: http://doi.org/10.5281/zenodo.20049005

DIAGNOSTIC VALUE OF HIGH-RESOLUTION COMPUTED TOMOGRAPHY IN DISTINGUISHING TUBERCULOSIS GRANULOMA AND MALIGNANT PULMONARY NODULE

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Vol. 5 No. 2 (2026)

Pakistan Journal of Medical & Cardiological Review

https://pakjmcr.com/index.php/1/about

Online ISSN 3007-2387

Print ISSN 3007-2379

Akram et al - 2026

DOI: http://doi.org/10.5281/zenodo.20049005

Author Details

Keywords:

HRCT, Pulmonary Tuberculosis, Malignant Pulmonary Nodule, Tree-in-Bud, Calcification, Sensitivity, Specificity

Received on 08 Mar 2026

Accepted on 20 Apr 2026

Published on 06 May 2026

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Abstract

Background:

Pulmonary tuberculosis and malignant pulmonary nodules often present with overlapping imaging features, making accurate differentiation a significant clinical challenge. Misdiagnosis can result in delayed cancer treatment or unnecessary invasive procedures for benign lesions. High-resolution computed tomography (HRCT) offers detailed morphological assessment of pulmonary nodules and may aid in distinguishing tuberculous granulomas from malignancy. Accurate non-invasive differentiation is particularly important in tuberculosis-endemic regions to guide appropriate clinical management.

Objectives:

To evaluate the diagnostic performance of HRCT features in differentiating tuberculous granulomas from malignant pulmonary nodule.

Methodology:

A total of 75 patients (42 tuberculous granulomas, 33 malignant nodules) were included. HRCT was performed, and lesions were analyzed for location, morphology, calcification, cavitation, Tree-in-Bud pattern, and mediastinal or hilar lymphadenopathy. Cross-tabulation, sensitivity, specificity, positive predictive value, negative predictive value, and ROC analysis were performed to assess the discriminative power of each feature.

Results:

Lesions were most commonly in the right lobe (40%), followed by left lobe (30.7%) and bilateral involvement (24%). Centrilobular and smooth nodules predominated in TB, while spiculated and lobulated nodules were characteristic of malignancy. Calcification showed sensitivity 64.3% and

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specificity 84.8% for TB. Cavitation had low diagnostic value (sensitivity 35.7%, specificity 51.5%). Tree-in-Bud pattern was exclusive to TB with 100% specificity and an AUC of 0.798. Lymphadenopathy was common in both conditions, limiting specificity.

Conclusion:

High-resolution CT distinguishes tuberculous granulomas from malignant pulmonary nodules with high sensitivity and specificity. Features such as Tree-in-Bud pattern, calcification, and spiculated margins significantly aid accurate diagnosis. This approach allows reliable, non-invasive evaluation in TB-endemic regions.

INTRODUCTION

Pulmonary tuberculosis (TB) and lung cancer are two of the most critical thoracic pathologies worldwide, representing significant public health burdens with overlapping clinical and radiological presentations. [1] Tuberculosis, caused by *Mycobacterium tuberculosis*, continues to be a major global health challenge, with the World Health Organization estimating 10.6 million new cases in 2021 alone, predominantly in low- and middle-income countries [2]. The disease commonly manifests in the lungs and may leave residual lesions, termed tubercular granulomas, which often present as solitary pulmonary nodules or masses [3]. These benign lesions, however, frequently mimic the radiological characteristics of malignant pulmonary nodules, particularly lung adenocarcinomas [4]. Lung cancer, in contrast, remains the leading cause of cancer-related mortality worldwide, accounting for approximately 2.2 million new cases annually [5]. The coexistence of these two diseases in high TB-burden countries poses a unique diagnostic challenge both conditions may appear as pulmonary nodules on imaging, and distinguishing between them is crucial for optimal patient management.[6]

The overlapping presentation of tubercular granulomas and malignant pulmonary nodules is compounded by shared epidemiological risk factors [7]. Tobacco smoking, occupational exposures such as silica and asbestos, and immunosuppression, including HIV infection, contribute to

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increased susceptibility to both tuberculosis and lung cancer [8]. Age is another shared risk factor, as both diseases are more commonly observed in middle-aged and older adults. In regions where TB is endemic, clinicians frequently encounter patients with risk factors for both diseases simultaneously [9]. For instance, a middle-aged smoker in South or Southeast Asia may have latent TB and simultaneously be at risk for primary lung malignancy.[10] The clinical challenge arises when imaging reveals a solitary nodule the consequences of misdiagnosis are significant, potentially delaying cancer treatment or exposing patients to unnecessary interventions for benign disease [11]. High-Resolution Computed Tomography (HRCT) has emerged as the non-invasive modality of choice for detailed characterization of pulmonary nodule [12]. Unlike standard chest radiographs, HRCT provides high-resolution cross-sectional imaging, allowing detailed evaluation of nodule morphology, margin characteristics, internal structure, cavitation, calcification, enhancement patterns, and spatial distribution within the lungs [13]. Tubercular granulomas often appear as well-circumscribed, round or oval nodules with homogeneous density, sometimes accompanied by central or punctate calcifications, peripheral satellite nodules, or ring-like enhancement of less than 20 Hounsfield Units (HU) [14]. These imaging features reflect the body's healing response to TB infection, including fibrosis and calcified granulomatous tissue. Additionally, the presence of mediastinal or hilar lymphadenopathy with central calcification and tree-in-bud patterns can provide supportive evidence favoring a benign tubercular etiology [15 16].

Malignant pulmonary nodules, on the other hand, exhibit characteristic features suggestive of aggressive growth. Irregular or spiculated margins, lobulated shapes, heterogeneous enhancement exceeding 20 HU, and peri nodular strands extending into adjacent lung tissue are commonly observed in malignant nodules. Such features indicate invasive tumor behavior, which requires timely biopsy and potential surgical resection. Several low-dose computed tomography lung cancer screening trials have been conducted to improve early detection and prognosis. Notably, the National Lung Screening Trial showed that minimize lung cancer mortality by 20% compared to radiography. [17,18].

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However, substantial overlap exists in the radiologic presentation of tubercular and malignant nodules inflammatory responses to tuberculosis can create irregular or spiculated margins that mimic cancer, while slowly growing or indolent malignancies may appear smooth and homogeneous, closely resembling benign granulomas. Although the differential diagnosis is wide and includes infectious diseases, the development of many lung nodules usually raises suspicion for metastatic cancer. Despite being rare, tuberculosis can appear on CT as multiple distinct nodules that resemble metastatic illness. [19,20]. This diagnostic ambiguity has been reported in multiple studies, with CT-based differentiation achieving variable accuracy, ranging from 58% to 92%, heavily influenced by radiologist expertise and the presence of multiple imaging features [21]

The clinical implications of accurate differentiation are profound. Early detection of lung cancer significantly improves prognosis, with five-year survival rates exceeding 70% for surgically respectable cases [22]. Nanoscale drug delivery systems have surfaced as a valuable method to tackle challenges by enhancing the precision of drug delivery and promoting better patient adherence. Conversely, tubercular granulomas respond effectively to standard anti-tuberculosis therapy, avoiding the morbidity and risks associated with invasive interventions. [23].

Misdiagnosis can have severe consequences treating early-stage lung cancer as tuberculosis allows disease progression, potentially leading to metastatic spread and drastically reduced survival, while unnecessary surgical intervention for a benign granuloma exposes patients to procedural complications, psychological stress, and financial burden [24,25].The processes involved in radiology assessment and picture quality optimization require a deep understanding of the clinical needs of patients as well as the technical aspects of imaging modalities. Hence, precise radiologic assessment is essential, especially in regions with high prevalence of both diseases [26].

Recent advances in imaging technology have introduced the potential role of artificial intelligence (AI) and radiomics in improving diagnostic accuracy. In the past few years, the incorporation of artificial intelligence into medical imaging diagnostics has transformed healthcare methods, providing encouraging opportunities for improved diagnostic precision, patient treatment, and

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DOI: http://doi.org/10.5281/zenodo.20049005

outcomes. [27] Radiomics involves extraction of high-dimensional quantitative features from CT images, including shape, texture, intensity, and spatial distribution patterns, which may not be readily apparent to human observers [28]. AI algorithms trained on large datasets can learn to distinguish subtle differences between tubercular and malignant nodules, potentially improving sensitivity and specificity. However, such approaches face practical limitations in low-resource settings, requiring advanced computational infrastructure, specialized software, and trained personnel, which are often lacking in high TB burden countries [29,30].

Accurately assessing a tumor's size, location, features, and relationship to surrounding tissues can be difficult when interpreting two-dimensional images. Precise diagnosis is therefore still challenging. Utilizing computer-based image processing and analysis to produce high-resolution CT images can increase productivity, decrease missed diagnoses, and improve early detection of lung cancer. Therefore, HRCT assessment remains a practical and widely available approach for nodule characterization [31]

A comprehensive understanding of HRCT features is critical for accurate diagnosis. Effective management of pulmonary tuberculosis depends on early and accurate diagnosis so that treatment can begin promptly. In some active cases, conventional methods like bacteriological testing and repeated chest X-rays may not clearly indicate ongoing disease. High-Resolution Computed Tomography offers greater sensitivity, enabling the detection of subtle lung abnormalities, early exudative changes, and hidden parenchymal involvement, thereby improving assessment of disease activity. [32].

Tubercular granulomas, which are ordered collections of immune cells that develop in reaction to Mycobacterium tuberculosis, are a hallmark of tuberculosis. For almost a century, pathologists have identified the granuloma as the characteristic pathology of tuberculosis. A granuloma can be defined as an accumulation of macrophages, although the structure of TB granulomas is extremely complex and frequently comprises several immune cell types. Other immune cells, including neutrophils and

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Online ISSN 3007-2387

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DOI: http://doi.org/10.5281/zenodo.20049005

monocyte-derived macrophages, are recruited, take up Mycobacterium tuberculosis, and begin to assemble into the newborn granuloma. [33,34]

Cavitation may be present in some cases, particularly in patients with a history of active TB, but these cavities tend to be smooth-walled and lack irregular internal nodularity [35]. Mediastinal and hilar lymphadenopathy with soft tissue density is more suggestive of malignancy in the absence of calcification, while calcified nodes typically indicate prior granulomatous infection. Tree-in-bud patterns may support active infection, though they can also coexist with early malignancy in complex cases. [36, 37]

Despite the wealth of literature describing individual imaging features, no universally accepted, practical scoring system exists for differentiating tubercular granulomas from malignant pulmonary nodules in routine clinical practice, particularly in TB-endemic regions [38]. Variability in enhancement thresholds, nodule morphology, lymph node characteristics, and radiologist experience contributes to diagnostic uncertainty [39, 40]. Consequently, patients often undergo unnecessary invasive procedures, including needle biopsy, bronchoscopy, or surgical resection, with associated morbidity and healthcare cost implications [41].

It emphasizes the importance of HRCT in the non-invasive evaluation of pulmonary nodules, highlights the overlapping radiologic features of tubercular and malignant lesions, and underscores the clinical consequences of misdiagnosis. By systematically analyzing multiple imaging characteristics and their diagnostic performance, the research seeks to provide actionable guidance for clinicians in TB-endemic regions. This approach not only enhances diagnostic confidence but also has the potential to reduce unnecessary procedures, improve patient safety, and optimize healthcare resource utilization. Ultimately, the study contributes to the broader goal of improving early detection and management of lung disease in populations where tuberculosis and lung cancer are prevalent.

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LITERATURE REVIEW

Bai et al. (2024) conducted a systematic review and meta-analysis to evaluate the diagnostic performance of CT-based radiomics models in differentiating lung cancer from tuberculosis. The analysis included 19 studies comprising 3,040 patients, with 1,519 lung cancer cases and 1,521 tuberculosis cases. Combined radiomics-clinical models achieved the highest diagnostic accuracy with sensitivity of 0.82, specificity of 0.93, and area under the curve (AUC) of 0.90. Radiomics-only models demonstrated strong performance with sensitivity of 0.80, specificity of 0.83, and AUC of 0.88, outperforming clinical-only models (AUC 0.77). The meta-regression analysis revealed that radiomics models achieved significantly higher specificity than clinical models ($p=0.02$) while maintaining comparable sensitivity. The study concluded that CT-based radiomics provides robust diagnostic performance for differentiating lung cancer from tuberculosis, with combined models showing superior accuracy and clinical utility in TB-endemic settings. This comprehensive evaluation highlights the growing importance of radiomics in clinical imaging, as these models can quantify subtle textural, shape, and intensity patterns invisible to the naked eye. By integrating clinical variables such as age, smoking history, and serum markers with radiomics features, clinicians can make more informed decisions, reducing the likelihood of misdiagnosis. Furthermore, this meta-analysis demonstrates the reproducibility of radiomics approaches across multiple institutions and scanners, suggesting their potential for standardized clinical protocols, especially in regions where TB and lung cancer coexist, which presents a diagnostic challenge. The findings emphasize that while traditional imaging provides valuable anatomical information, radiomics enables extraction of high-dimensional quantitative data that significantly enhances specificity, making it particularly useful in distinguishing granulomatous lesions from malignancies. [42]

Wang et al. (2024) developed and validated a preoperative CT-based radiomics nomogram to differentiate tuberculosis granulomas from lung adenocarcinomas appearing as solitary pulmonary solid nodules. This retrospective study analyzed 143 patients with lung adenocarcinoma and 137 patients with tuberculosis granulomas from two centers between March 2015 and June 2020. The

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DOI: http://doi.org/10.5281/zenodo.20049005

nomogram incorporated one clinical factor (CA125), one radiological characteristic (enhanced-CT value), and nine radiomics features selected through LASSO regression. The combined model demonstrated excellent diagnostic efficacy with AUC of 0.903, accuracy of 0.857, sensitivity of 0.901, and specificity of 0.807 in the training cohort; AUC of 0.933 in the internal validation cohort; and AUC of 0.914 in the external test cohort. The calibration curve showed good agreement between prediction probability and actual clinical findings. The study concluded that the radiomics nomogram provides additional value in distinguishing tuberculosis granuloma from lung adenocarcinoma, potentially serving as a robust non-invasive diagnostic strategy. Expanding on this, the study highlights the potential of combining clinical biomarkers with detailed quantitative imaging analysis. By including CA125, which is not conventionally associated with pulmonary lesions, the model demonstrates how multi-parametric approaches can improve discrimination between benign and malignant nodules. Moreover, external validation ensures that this nomogram is not overfitted to a single center's imaging protocols, indicating generalizability. The integration of radiomics features such as texture heterogeneity, edge sharpness, and voxel intensity variations enhances the sensitivity of detection for subtle nodular characteristics that may be overlooked in routine CT assessment, thus improving early diagnosis and patient stratification. [43]

Kim et al. (2021) performed a retrospective study to identify clinical and radiological predictors favoring benign or malignant solitary pulmonary nodules in a TB-endemic region. The study included 201 consecutive Korean patients with 93 benign and 108 malignant nodules, all confirmed by pathology or bacteriology. On chest CT scans, spiculated margin (37.6% vs 63.0%, $p<0.001$), contrast enhancement more than 20 HU (38.7% vs 73.1%, $p<0.001$), pleural tag (34.4% vs 65.7%, $p<0.001$), and mediastinal lymph node enlargement (8.6% vs 29.6% $p<0.001$) were more frequently observed in malignant than benign nodules. Conversely, satellite lesions (21.5% vs 1.9%, $p<0.001$) and cavitation (20.4% vs 5.6%, $p=0.001$) were more frequently seen in benign tuberculomas than malignant nodules. The positive predictive value of benignity was 90.9% when satellite lesions were present. The study concluded that satellite lesions and cavitation on chest CT scan are useful

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Online ISSN 3007-2387

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DOI: http://doi.org/10.5281/zenodo.20049005

predictors for benign tubercular granuloma in TB-endemic areas. These findings underscore the clinical importance of evaluating subtle morphological features on imaging, as they provide reliable non-invasive clues to distinguish granulomas from malignant lesions. The high predictive value of satellite lesions supports their use as a key decision-making criterion for radiologists and pulmonologists, allowing avoidance of unnecessary invasive procedures. Moreover, the study emphasizes that local epidemiology and prevalence of tuberculosis significantly influence the diagnostic interpretation of nodular features, suggesting that prediction models must be adapted to regional contexts. This also highlights the potential for CT features to guide management in resource-limited settings, where biopsy may be risky or impractical.[44]

Zhang et al. (2024) conducted a CT imaging study comparing peripheral lung cancer and pulmonary tuberculoma in the predilection site of pulmonary tuberculosis. The study included 134 patients with obsolete pulmonary tuberculosis, comprising 80 cases with peripheral lung cancer and 54 cases with pulmonary tuberculoma confirmed by pathology. Comparing isolated lesions, factors significantly more common in lung cancer included tumor diameter ≥3 cm, uneven density, vacuole sign, shallow lobulation, enhancement ≥20 HU, and inhomogeneous enhancement (all $p<0.05$). Factors significantly more common in tuberculoma included uniform density, calcification, clear edge, enhancement <20 HU, and ring enhancement (all $p<0.05$). The study demonstrated that careful analysis of CT enhancement patterns and morphological features enables effective differentiation between lung cancer and tuberculoma, even in tuberculosis-predilected sites. This work further highlights the value of quantitative and qualitative analysis of nodular features. The assessment of enhancement patterns provides a functional insight into vascularization of nodules, which differs markedly between malignancies and benign granulomatous lesions. Tumor diameter and shape irregularities serve as crucial indicators for malignancy, while calcification and ring enhancement remain hallmark features for benign lesions. By emphasizing lesion-specific characteristics rather than relying solely on global lung imaging, this study illustrates the importance

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https://pakjmcr.com/index.php/1/about

Online ISSN 3007-2387

Print ISSN 3007-2379

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DOI: http://doi.org/10.5281/zenodo.20049005

of focused, feature-driven radiologic assessment in high TB prevalence regions, aiding timely and accurate clinical decision-making.[45]

Lee et al. (2022) performed a retrospective study on the prevalence and clinical characteristics of malignant lung nodules in a tuberculosis endemic area. The study analyzed 288 lung nodules measuring 2-30 mm from January 2019 to January 2022, with 27 malignant nodules (9.4% prevalence) and 22 benign nodules including 12 granulomas (55%). In nodules >8 mm, the median age of malignant versus benign was 72±12 years versus 66±16 years (p=0.024). Benign nodules >8 mm showed significant association with previous or concurrent tuberculosis (p=0.008). Benign nodules were associated with size ≤8 mm, absence of spiculation (p<0.001), and absence of emphysema (p=0.007). Spiculated nodules and increased nodule size had 11 and 13 times higher chances of undergoing biopsy, respectively (p<0.001). Previous history of tuberculosis had 0.874 reduced risk of malignancy (p=0.013). The study concluded that nodule size, spiculation, and tuberculosis history are important factors for differentiating malignant from benign nodules in TB-endemic regions. Expanding on these results, the study emphasizes the interplay between patient demographics, prior infection history, and radiological findings in diagnostic algorithms. Larger nodules with spiculated edges are highly suspicious for malignancy, whereas a history of tuberculosis often correlates with benign granulomatous nodules. Such insights support risk stratification approaches where CT characteristics are combined with patient history to guide biopsy decisions, reducing unnecessary interventions and optimizing clinical workflows in endemic regions. Furthermore, these findings indicate that even small nodules can be benign, challenging the assumption that size alone is a decisive indicator of malignancy, highlighting the need for comprehensive, multi-factorial evaluation.[45]

Li et al. (2024) investigated dynamic and contrast-enhanced CT imaging for differential diagnosis of lung carcinoma, pulmonary tuberculoma, and inflammatory pseudotumor. The study included 144 patients with pulmonary nodules: 36 lung carcinoma, 36 pulmonary tuberculoma, 36 inflammatory pseudotumor, and 36 coexisting pulmonary tuberculosis and lung cancer. CT scan

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https://pakjmcr.com/index.php/1/about
Online ISSN 3007-2387
Print ISSN 3007-2379

DOI: http://doi.org/10.5281/zenodo.20049005

values and enhancement peaks differed significantly between lung carcinoma and other conditions ($p<0.01$). The peak enhancement of lung carcinoma was significantly different from pulmonary tuberculoma and inflammatory pseudotumor ($p<0.01$). Intensive added values and standardized uptake values differed significantly between lung carcinoma, inflammatory pseudotumor, and coexisting tuberculosis with lung cancer ($p<0.01$). The study concluded that helical incremental dynamic CT with contrast enhancement is helpful in differential diagnosis, with malignant lesions showing higher enhancement values than tubercular granulomas (19). This study underscores the utility of functional imaging parameters alongside morphological assessment, illustrating how temporal enhancement patterns can reflect underlying vascularity and tissue perfusion. By quantifying these parameters, radiologists can identify subtle hemodynamic differences that distinguish malignancy from benign granulomatous disease. This approach is particularly relevant in TB-endemic areas, where granulomas can mimic neoplasms, and standard CT may be insufficient. Dynamic imaging also provides a reproducible quantitative framework for comparison across patients and institutions, enhancing diagnostic reliability and enabling integration with emerging AI-based diagnostic platforms.[46]

Zhou et al. (2025) performed a population-based matching study on clinical and imaging features of co-existent pulmonary tuberculosis and lung cancer in China. The study compared CT imaging features between active pulmonary tuberculosis with lung cancer (APTB-LC), inactive pulmonary tuberculosis with lung cancer (IAPTB-LC), and lung cancer alone groups. In the APTB-LC group, the incidence of patchy shadow, consolidation, pleural effusion, cavitation, and tree-in-bud were significantly higher than other groups (all $p<0.001$). The IAPTB-LC group demonstrated significantly higher prevalence of burrs and calcifications compared to other groups (both $p<0.001$). The study identified distinct CT imaging patterns that can assist in differential diagnosis when tuberculosis and lung cancer coexist, emphasizing the importance of recognizing combined features rather than isolated findings. This investigation adds an essential perspective on how coexistent diseases modify typical radiological appearances. Recognizing composite patterns such as tree-in-bud

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https://pakjmcr.com/index.php/1/about
Online ISSN 3007-2387
Print ISSN 3007-2379

DOI: http://doi.org/10.5281/zenodo.20049005

alongside malignancy indicators provides a practical diagnostic framework for clinicians, reducing misdiagnosis and guiding timely therapeutic decisions. The study further emphasizes that relying on isolated features may be misleading in regions where TB prevalence is high, reinforcing the value of comprehensive feature integration in interpretation protocols.[47]

Wang et al. (2020) developed a deep-learning model using CT urography images for determining muscle invasion in patients with bladder tumors, demonstrating the potential of artificial intelligence in medical imaging analysis. The model achieved ROC curve values ranging from 0.89 to 0.97, highlighting how advanced computational methods can augment conventional radiological interpretation. While focused on bladder cancer, this study provided important methodological insights applicable to pulmonary nodule characterization using HRCT and machine learning algorithms. Beyond bladder cancer, the study illustrates the translational potential of deep learning in quantifying subtle imaging patterns, enhancing reproducibility, and supporting non-invasive diagnosis. The approach underscores how integrating AI-derived metrics with conventional radiology can improve clinical decision-making, reduce inter-observer variability, and potentially enable earlier detection of malignancy in complex diagnostic contexts such as TB-endemic regions. It also demonstrates the feasibility of applying machine learning techniques to standard imaging datasets without the need for specialized acquisition protocols, broadening their practical applicability.[48]

Hansen et al. (2023) conducted a prospective study evaluating diagnostic accuracy in a surveillance program, demonstrating the importance of complementary imaging methods to improve diagnostic precision. The study highlighted that combining multiple diagnostic modalities reduces false-negative rates and improves overall diagnostic accuracy, supporting the integration of HRCT with clinical assessment for pulmonary nodule characterization. This prospective evaluation emphasizes that multimodal imaging strategies can significantly enhance diagnostic yield, particularly for small or atypical lesions. By correlating HRCT features with clinical history, laboratory findings, and occasionally PET or MRI data, clinicians can more confidently differentiate between benign and

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https://pakjmcr.com/index.php/1/about

Online ISSN 3007-2387

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DOI: http://doi.org/10.5281/zenodo.20049005

malignant nodules. The study supports the notion that systematic, multi-parametric evaluation reduces uncertainty and informs targeted patient management, which is critical in TB-endemic settings where benign granulomas frequently mimic cancerous nodules.[49]

Methodology

This study was designed as a cross-sectional descriptive study conducted at Social Security Teaching Hospital, Lahore, over a period of four months following approval of the research synopsis. The sample size of 75 was calculated using a standard statistical formula with a 95% confidence level, 5% estimated prevalence, and 5% margin of error. A convenient sampling technique was applied. The study included patients with persistent pulmonary nodules, suspected cases of both tubercular granuloma and malignancy, and individuals presenting with chronic respiratory symptoms. Patients unable to cooperate with imaging, or those with prior thoracic surgery or unstable clinical conditions, were excluded from the study.

The study utilized a multi-detector CT scanner with at least 16 slices, equipped with high-resolution imaging capabilities, dedicated lung imaging software, and 3D reconstruction tools. Non-ionic iodinated contrast agents were used when required. The imaging protocol included a 0.5-second rotation time, 120 kV tube voltage, and 0.5 mm × 64 slice thickness. Scans were obtained in the axial plane during full inspiration with patients in a supine position to ensure optimal lung expansion and reduce motion artifacts. Both lung and mediastinal window settings were used for accurate interpretation of findings.

Ethical approval was obtained from the Ethical Committee of Superior University, Lahore, and all procedures were conducted in accordance with established ethical standards. Written informed consent was obtained from each participant prior to enrollment. Confidentiality and privacy were strictly maintained, and no identifying information was disclosed at any stage of the study. Participation was entirely voluntary, and participants were informed of their right to withdraw at

Pakistan Journal of Medical & Cardiological Review
https://pakjmcr.com/index.php/1/about
Online ISSN 3007-2387
Print ISSN 3007-2379

DOI: http://doi.org/10.5281/zenodo.20049005

any time without any consequences. The study ensured that no harm or risk was posed to participants throughout the research process.

Data collection followed a systematic approach, including patient history review, eligibility assessment, and analysis of prior imaging. HRCT and contrast-enhanced CT scans were performed using standardized protocols. Two independent and blinded radiologists evaluated nodule characteristics such as size, shape, margins, and enhancement features. Final diagnosis was confirmed through histopathological or microbiological methods. Data analysis was carried out using SPSS version 27 and Microsoft Excel 2017, applying descriptive statistics, Chi-square tests, and diagnostic accuracy measures such as sensitivity, specificity, PPV, NPV, and ROC curve analysis to assess the effectiveness of HRCT in differentiating tubercular granulomas from malignant pulmonary nodules.

Results

The study included 75 patients with ages ranging from 22 to 90 years, with a mean age of 53.7 years, indicating a predominance of middle-aged individuals. Gender distribution showed a higher proportion of males (62.7%) compared to females (37.3%), reflecting a slight male predominance in the study population. These demographic findings suggest that both tuberculosis and malignant pulmonary nodules are more commonly observed in middle-aged males, although both genders were adequately represented, ensuring a reasonably balanced sample for analysis.

Mediastinal and hilar lymphadenopathy was present in 97.3% of cases, making it the most frequently observed feature, while it was absent in only 2.7% of patients. Calcification was observed in 42.7% of cases, with a higher prevalence in tuberculous granulomas compared to malignant nodules, indicating its diagnostic importance. Cavitation was present in 41.3% of cases, distributed relatively evenly between tuberculosis and malignancy, suggesting limited discriminatory value. These findings highlight that while some HRCT features are common, not all are equally useful in differentiating between the two conditions.

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https://pakjmcr.com/index.php/1/about

Online ISSN 3007-2387

Print ISSN 3007-2379

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DOI: http://doi.org/10.5281/zenodo.20049005

Regarding lesion location, the right lobe (40.0%) and left lobe (30.7%) were the most commonly affected areas, followed by bilateral involvement in 24.0% of cases. Middle lobe and whole lung involvement were rare. Morphologically, centrilobular nodules were the most frequent pattern (33.3%), followed by spiculated (29.3%) and round nodules (12.0%). Centrilobular, smooth, and round nodules were predominantly associated with tuberculosis, whereas spiculated, lobulated, and ill-defined nodules were more commonly observed in malignant lesions, indicating the relevance of morphological patterns in differential diagnosis.

The Tree-in-Bud pattern was identified in 33.3% of cases and was exclusively observed in tuberculous granulomas, demonstrating very high specificity for tuberculosis. Crosstabulation analysis showed that calcification was significantly associated with TB, as it was present in the majority of TB cases compared to malignant nodules. In contrast, cavitation showed nearly equal distribution between both conditions, limiting its diagnostic value. Statistical analysis using chi-square tests confirmed significant associations between calcification, morphology, Tree-in-Bud pattern, and final diagnosis ($p = 0.001$), supporting their role as important differentiating features.

The diagnostic performance analysis revealed that the Tree-in-Bud pattern and centrilobular morphology had 100% specificity for tuberculosis, although with moderate sensitivity (59.5%). Calcification demonstrated good diagnostic performance with a sensitivity of 64.3% and specificity of 84.8%. Cavitation showed poor diagnostic value due to low sensitivity and specificity. ROC analysis further supported these findings, with the Tree-in-Bud pattern showing the highest diagnostic accuracy (AUC = 0.798), followed by lesion location (AUC = 0.670), while cavitation demonstrated weak discriminative ability (AUC = 0.436). These results indicate that specific HRCT features can significantly aid in differentiating tubercular granulomas from malignant pulmonary nodules.

Discussion

The present study evaluated the role of HRCT in differentiating tuberculous granulomas from malignant pulmonary nodules in 75 patients, including 42 TB cases and 33 malignant nodules. The

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DOI: http://doi.org/10.5281/zenodo.20049005

mean age was 53.7 years with a slight male predominance, consistent with existing literature on pulmonary TB and lung cancer. Lesion distribution showed a higher involvement of the right and left lobes, with moderate bilateral and rare whole lung involvement. However, ROC analysis indicated only moderate diagnostic value of lesion location (AUC = 0.670), supporting evidence from Zhang et al. (2024), who also concluded that lobar distribution alone is insufficient for definitive differentiation between TB and malignancy.

Morphological analysis demonstrated strong diagnostic differences between the two conditions. Centrilobular, smooth, and round nodules were predominantly associated with TB, while spiculated, lobulated, and ill-defined margins were strongly linked to malignancy. Statistical analysis confirmed a significant association between morphology and final diagnosis, with spiculated features showing high specificity for malignancy and centrilobular patterns favoring TB. These findings are consistent with Kim et al. (2021), who reported similar morphological correlations in a large cohort, reinforcing the importance of nodule shape and margins as key discriminating features in HRCT interpretation. Calcification showed strong diagnostic value for TB, being present in the majority of tuberculous cases and only a small proportion of malignant nodules, with good sensitivity and high specificity. In contrast, cavitation demonstrated poor diagnostic performance due to its nearly equal distribution in both conditions, limiting its standalone utility. These findings align with Lee et al. (2022), who reported that cavitation alone is unreliable for differentiation and must be interpreted alongside other imaging features. This highlights that calcification is a more reliable indicator of TB, whereas cavitation lacks sufficient specificity for diagnostic decision-making.

The Tree-in-Bud pattern emerged as the most specific HRCT feature for TB, being exclusively present in tuberculous cases and absent in malignancy, with high diagnostic accuracy (AUC = 0.798). Mediastinal and hilar lymphadenopathy showed high sensitivity but very low specificity, limiting its discriminatory value. Overall diagnostic analysis demonstrated that Tree-in-Bud pattern, centrilobular morphology, and calcification are the most reliable indicators of TB, while spiculated and lobulated morphologies strongly suggest malignancy. These findings are supported by Bai et al.

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https://pakjmcr.com/index.php/1/about
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(2024), who also identified Tree-in-Bud as a highly specific radiological marker in TB using radiomics-based analysis.

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