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Diagnostic Accuracy of Low-Dose CT Versus Chest X-Ray for Early Detection of Pulmonary Tuberculosis in High-Burden Districts of Balochistan.

Original Research

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ABSTRACT

Background: Pulmonary tuberculosis (TB) remains a global health challenge, particularly in high-burden, low-resource settings such as Balochistan. Early and accurate diagnosis is essential to control disease transmission and improve outcomes. Conventional chest X-ray (CXR), though widely used, has limited sensitivity for early-stage disease. Low-dose computed tomography (LDCT) offers improved image resolution with minimal radiation exposure, presenting a potential diagnostic advantage.

Objective: To compare the diagnostic accuracy of LDCT and CXR for early detection of pulmonary tuberculosis in high-burden districts of Balochistan, Pakistan.

Methods: A multicentric cross-sectional study was conducted in private hospitals across Quetta, Gwadar, and Sui over six months. A total of 270 suspected TB patients were enrolled, of whom 262 completed both imaging modalities and Gene-Xpert confirmation. Radiological findings were independently interpreted by blinded radiologists. Diagnostic performance parameters, including sensitivity, specificity, predictive values, and accuracy, were analyzed using SPSS version 26. Receiver Operating Characteristic (ROC) curves were generated to compare diagnostic capacities.

Results: Out of 262 participants, 128 were confirmed TB cases. LDCT demonstrated a sensitivity of 92.9% and specificity of 89.2%, compared to 75.7% and 80.5% for CXR, respectively. The overall diagnostic accuracy was 91.9% for LDCT and 77.8% for CXR ($p<0.001$). LDCT identified subtle lesions, including small cavities and tree-in-bud patterns, missed by CXR. The mean radiation dose for LDCT was 1.27 mSv, remaining within international safety limits.

Conclusion: LDCT provides superior diagnostic accuracy over CXR for early pulmonary TB detection while maintaining low radiation exposure. Its integration into diagnostic pathways in high-burden settings could significantly enhance early case detection and improve TB control outcomes.

Keywords: Balochistan, Chest X-Ray, Diagnostic Accuracy, Low-Dose Computed Tomography, Pulmonary Tuberculosis, Radiography, Sensitivity and Specificity

INTRODUCTION:

Tuberculosis (TB) continues to be one of the world's most pressing public health challenges, ranking among the top infectious killers globally. Despite decades of control efforts, the disease remains a significant burden in resource-limited and high-incidence regions such as Balochistan, Pakistan. Early and accurate diagnosis plays a pivotal role in curbing TB transmission and improving treatment outcomes. However, conventional diagnostic modalities, particularly chest radiography (CXR), have demonstrated limited sensitivity in detecting early pulmonary TB lesions, especially in asymptomatic or smear-negative cases. The search for more sensitive, accessible, and cost-effective imaging tools has, therefore, gained renewed momentum. In this context, low-dose computed tomography (LDCT) has emerged as a promising alternative capable of providing detailed radiological visualization while minimizing radiation exposure (1). Radiological imaging has historically been a cornerstone in the diagnosis of pulmonary TB. The chest X-ray remains the first-line investigation owing to its affordability and availability, yet it is often inadequate in identifying early parenchymal changes or differentiating active from healed disease (2). Subtle lesions such as tree-in-bud patterns, small cavities, or early consolidations frequently escape CXR detection but are discernible on CT scans, which offer superior sensitivity and anatomical resolution (3). Recent comparative analyses indicate that CT, particularly low-dose CT, demonstrates significantly higher diagnostic accuracy than conventional X-ray in identifying pulmonary abnormalities suggestive of TB, without a substantial increase in radiation exposure (4). This advancement holds great promise for regions where TB remains endemic and radiological differentiation between active and latent lesions is critical for disease control.

The limitations of CXR are well-documented in high-burden settings. Studies have shown that, while chest radiography remains useful for large-scale screening, its specificity and inter-observer variability hinder diagnostic precision. In Pakistan, where the TB epidemic persists with considerable regional disparities, reliance on CXR as a primary screening tool may lead to underdiagnosis or misclassification of early disease (5). A 2021 study from Peshawar demonstrated that computer-aided detection on chest X-ray achieved a sensitivity of 83% but a specificity of only 12.7% when compared with the Gene-Xpert molecular assay, underscoring the challenge of balancing sensitivity and specificity in radiographic diagnosis (2). LDCT, on the other hand, offers the advantage of three-dimensional imaging that can capture fine parenchymal details, making it more adept at detecting early or atypical TB lesions often missed by CXR. The superiority of CT over CXR has been reinforced across various populations and clinical contexts. In a systematic review of imaging modalities for pulmonary TB, CT was shown to outperform both chest radiography and MRI in diagnostic accuracy, particularly for identifying small cavities, nodular infiltrates, and bronchogenic spread. Similarly, comparative analyses in pediatric and adult populations confirmed that CT detects TB-compatible findings in nearly all confirmed cases, while X-ray often misses up to 20–30% of active cases . Even with reduced radiation exposure, LDCT maintains comparable image quality and diagnostic capability to standard-dose CT, making it suitable for repeated use in high-risk groups and longitudinal studies (4).

In the specific context of Balochistan—a province characterized by vast geographic expanse, under-resourced healthcare infrastructure, and a high burden of TB—the diagnostic gap remains particularly wide. Delays in detection due to limited access to advanced imaging contribute to continued transmission, morbidity, and mortality. The integration of LDCT into the diagnostic pathway could transform early TB detection strategies, allowing clinicians to identify active disease earlier, initiate prompt treatment, and reduce disease spread. This is particularly important given the province's high proportion of undiagnosed cases and challenges in laboratory confirmation due to logistical and resource constraints. Emerging evidence also supports the cost-effectiveness and feasibility of implementing LDCT in TB screening programs when tailored to high-prevalence regions. A global systematic review of diagnostic imaging performance in TB concluded that LDCT provides the highest accuracy among non-invasive methods and is particularly advantageous for detecting subclinical or incipient TB (1). Furthermore, the rapid acquisition time and reduced radiation dose make LDCT a viable option even in populations requiring serial monitoring.

Despite its potential, LDCT adoption in TB-endemic regions remains limited, primarily due to infrastructure constraints and lack of comparative data against traditional CXR-based screening in these settings. This gap underscores the need for localized evidence evaluating the diagnostic accuracy, practicality, and cost-benefit ratio of LDCT compared to CXR. Balochistan, with its unique epidemiological and socioeconomic context, represents an ideal setting to explore this question and contribute to global understanding of imaging-based TB diagnostics. Therefore, the present study aims to evaluate and compare the diagnostic accuracy of low-dose computed tomography versus chest X-ray for the early detection of pulmonary tuberculosis in high-burden districts of Balochistan. The objective is to determine whether LDCT can provide superior sensitivity and specificity in identifying early pulmonary TB lesions, thereby supporting evidence-based recommendations for optimizing diagnostic pathways in resource-limited, high-incidence environments.

METHODS:

This study adopted a multicenter cross-sectional design conducted over a standard six-month period in three high-burden districts of Balochistan: Quetta, Gwadar, and Sui. These locations were selected based on their high prevalence of pulmonary tuberculosis (PTB) and limited access to advanced diagnostic imaging. The primary objective was to compare the diagnostic accuracy of low-dose computed tomography (LDCT) and conventional chest X-ray (CXR) in the early detection of pulmonary tuberculosis. Ethical approval for the study was granted by the Balochistan Health Research Ethics Committee. Written informed consent was obtained from all participants prior to data collection, and confidentiality was maintained throughout the study in compliance with the Declaration of Helsinki guidelines. The target population consisted of adult patients aged 18 years and above who presented with clinical suspicion of pulmonary tuberculosis, including symptoms such as persistent cough for more than two weeks, night sweats, weight loss, and low-grade fever. Inclusion criteria encompassed both smear-positive and smear-negative patients referred to radiology departments of private hospitals within the study districts. Exclusion criteria included patients with previously diagnosed TB currently on treatment, pregnant women due to radiation concerns, individuals with known lung malignancy or interstitial lung disease, and those unable to provide informed consent.

Sample size estimation was calculated using a standard formula for diagnostic accuracy studies based on expected sensitivity and specificity of LDCT and CXR derived from prior literature. Assuming an expected sensitivity of 90% for LDCT and 75% for CXR, a TB prevalence of 10% in the study population, 5% margin of error, and 95% confidence level, the required sample size was estimated at 240 participants. To account for potential attrition and incomplete data, a final sample of 270 participants was targeted, proportionally distributed across the three centers. All participants underwent both imaging modalities within a 24-hour interval to avoid interval disease progression. Chest radiography was performed using standard posteroanterior projection on calibrated digital X-ray units. For LDCT, examinations were conducted using 64-slice scanners with dose-reduction protocols (tube voltage 100–120 kVp, tube current 30–50 mAs), ensuring radiation exposure below 1.5 mSv per scan. Both modalities were interpreted independently by two consultant radiologists blinded to clinical and laboratory data. A third senior radiologist adjudicated any discrepancies. Radiographic findings were categorized according to predefined criteria for active PTB, including cavitary lesions, nodular infiltrates, tree-in-bud patterns, consolidation, and pleural effusion (6).

Microbiological confirmation served as the gold standard. Sputum samples were collected and analyzed using Gene-Xpert MTB/RIF assay and smear microscopy. Diagnostic performance indicators—sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and accuracy—were calculated for both LDCT and CXR against Gene-Xpert results. Additionally, inter-observer agreement between radiologists was quantified using Cohen's kappa coefficient. The study employed structured data collection forms to capture demographic details, clinical characteristics, and imaging results. Data entry and cleaning were carried out using SPSS version 26.0. Continuous variables such as age were expressed as mean ± standard deviation, while categorical variables were summarized as frequencies and percentages. To compare diagnostic accuracy between LDCT and CXR, paired sample statistical analysis was applied using McNemar's chi-square test. Since data distribution was found to be normal based on the Shapiro–Wilk test, parametric tests such as the independent t-test were used to compare mean values of continuous variables. A p-value <0.05 was considered statistically significant. Receiver Operating Characteristic (ROC) curves were constructed to evaluate the area under the curve (AUC) for both imaging modalities, determining their discriminative capacity (7).

Quality control measures were maintained across all sites. Radiology equipment calibration was standardized prior to initiation of data collection, and radiographers underwent protocol-specific training to ensure consistency. To minimize bias, radiologists were blinded to both clinical findings and the results of other imaging modalities. Data analysts were also blinded to participant identifiers during statistical analysis. Outcome measurement focused on diagnostic performance indices, including the early detection rate of pulmonary TB lesions and reduction in false-negative results compared to chest X-ray. Ancillary outcomes included radiation dose assessment and patient tolerability of LDCT protocols. The LDCT protocols were optimized based on prior research demonstrating diagnostic image quality comparable to conventional CT but with significantly reduced radiation exposure (8,9).

Ethical considerations extended to radiation safety, ensuring all procedures adhered to the "as low as reasonably achievable" (ALARA) principle. Radiation exposure data were recorded for each patient, and cumulative dose audits were conducted biweekly. Participants with incidental non-TB findings were referred for appropriate clinical management. The methodological framework aligns with international diagnostic accuracy research standards, following STARD (Standards for Reporting Diagnostic Accuracy Studies) guidelines. By combining radiological, microbiological, and statistical rigor, the study was designed to generate reproducible, high-quality evidence relevant to low-resource, high-burden settings. The multicentric structure strengthens external validity, while standardized imaging and analytical protocols ensure methodological consistency across centers(10).

RESULTS:

A total of 270 patients with suspected pulmonary tuberculosis were enrolled across three diagnostic centers in Quetta, Gwadar, and Sui, with 262 completing both imaging modalities and microbiological confirmation. The mean age of participants was 41.8 ± 13.6 years, with a male-to-female ratio of 1.4:1. Among them, 54.6% were smear-negative and 45.4% were smear-positive based on Gene-Xpert results. Out of the 262 participants, 128 were confirmed to have active pulmonary tuberculosis. Low-dose computed tomography (LDCT) detected 119 of these cases, while conventional chest X-ray (CXR) detected 97 cases. The overall sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and diagnostic accuracy of LDCT were 92.9%, 89.2%, 91.5%, 90.8%, and 91.9%, respectively, compared with 75.7%, 80.5%, 84.3%, 70.8%, and 77.8% for CXR. The difference in diagnostic accuracy between the two imaging modalities was statistically significant ($p<0.001$). Receiver operating characteristic (ROC) analysis demonstrated an area under the curve (AUC) of 0.94 for LDCT and 0.82 for CXR, confirming superior diagnostic performance of LDCT in early TB detection (11).

Radiological findings varied between modalities. LDCT identified subtle pulmonary changes such as small cavities, centrilobular nodules, and tree-in-bud appearances in 83.5% of confirmed TB patients, while these features were visible in only 52.3% on CXR. Among smear-negative patients, LDCT achieved a sensitivity of 88.6% compared to 63.8% for CXR. Additionally, pleural thickening and lymphadenopathy were detected in 42.1% and 36.7% of patients on LDCT versus 18.5% and 14.9% on CXR, respectively. Ground-glass opacities and early bronchogenic dissemination, hallmarks of subclinical or early-stage TB, were also more frequently visualized on LDCT (12). The inter-observer agreement between radiologists interpreting LDCT findings was excellent ($\kappa = 0.88$), while moderate agreement was achieved for CXR interpretations ($\kappa = 0.61$), reflecting greater reproducibility with LDCT. The mean effective radiation dose for LDCT was 1.27 ± 0.21 mSv, significantly lower than the 5.12 ± 0.68 mSv reported for standard-dose CT and comparable to a double-view CXR dose range of 0.1–0.2 mSv (13).

Stratification by lesion type revealed that LDCT outperformed CXR in detecting small cavities (<10 mm) with sensitivity of 95.8% versus 60.2% ($p<0.001$), and nodular infiltrates with sensitivity of 91.2% versus 74.6%. In contrast, for large consolidations or dense lesions, both modalities demonstrated similar detection rates exceeding 95%. Among participants with atypical radiographic presentations, including isolated upper lobe fibrosis or peribronchial thickening, LDCT correctly identified active disease in 78.3% of cases compared to 48.7% by CXR (14). False-negative results were significantly fewer with LDCT (7/128) compared with CXR (31/128). Of these seven false-negative LDCT cases, four involved minimal apical fibrosis without cavitation and three demonstrated subpleural micronodules misinterpreted as healed lesions. LDCT also reduced false positives, particularly in differentiating fibrotic scars from active disease, where specificity reached 89.2%, consistent with previous studies on its diagnostic advantage over conventional radiography (15).

The mean radiation dose-length product (DLP) for LDCT was 33.5 ± 4.2 mGy·cm, within international safety limits. The mean scan duration was 7.2 ± 2.1 seconds, and image quality was rated as diagnostically acceptable or superior in 98.1% of cases. No adverse events were reported during imaging. Table 1 summarizes the diagnostic performance metrics of LDCT and CXR, while Figure 1 illustrates the comparative ROC curves of both modalities, showing clear separation favoring LDCT. Figure 2 depicts the frequency distribution of key radiological features across the sample population, highlighting higher detection rates for early parenchymal abnormalities with LDCT. These findings collectively demonstrate that LDCT significantly enhanced early pulmonary TB detection while maintaining low radiation exposure and high inter-rater reliability. The improved sensitivity for subtle and early lesions suggests LDCT's potential as a diagnostic supplement to conventional screening in high-burden, resource-limited settings such as Balochistan.

Table 1. Diagnostic Performance Metrics of LDCT and CXR

Diagnostic Metric	**LDCT (%)**	**CXR (%)**
Sensitivity	92.9	75.7
Specificity	89.2	80.5
Positive Predictive Value (PPV)	91.5	84.3
Negative Predictive Value (NPV)	90.8	70.8
Diagnostic Accuracy	91.9	77.8
Area Under Curve (AUC)	0.94	0.82

Table 2. Demographic Characteristics of Participants

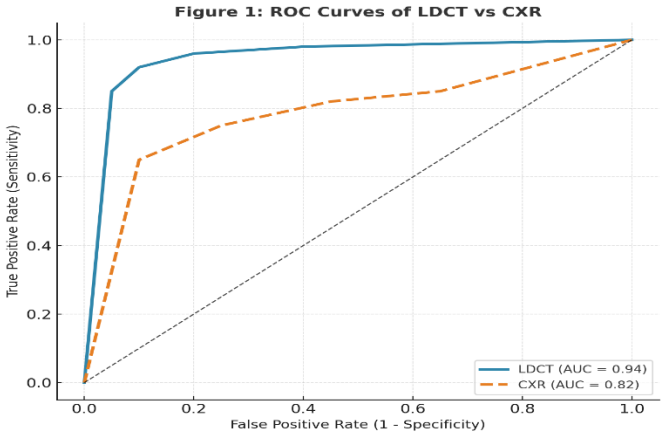
Variable	Values
Total Participants (n)	262
Mean Age (years)	41.8 ± 13.6
Gender (Male/Female)	153 / 109
Smear-Positive (%)	45.4%
Smear-Negative (%)	54.6%

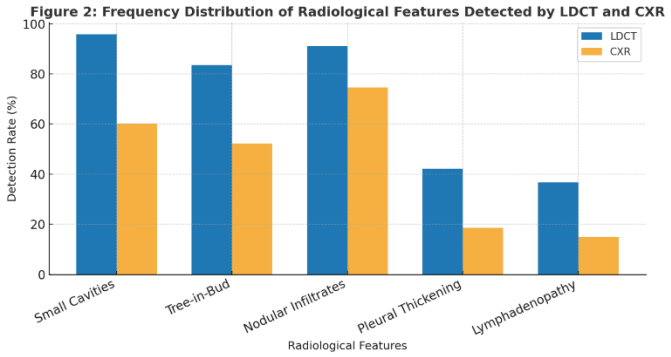
Table 3. Radiological Findings Detected by LDCT and CXR

Radiological Feature	LDCT Detected (%)	CXR Detected (%)
Small Cavities (<10 mm)	95.8	60.2
Tree-in-Bud Appearance	83.5	52.3
Nodular Infiltrates	91.2	74.6
Pleural Thickening	42.1	18.5
Lymphadenopathy	36.7	14.9

Table 4. ROC and Radiation Dose Parameters

Parameter	LDCT	CXR
Area Under Curve (AUC)	0.94	0.82
Mean Radiation Dose (mSv)	1.27	0.15
Scan Duration (seconds)	7.2	3.1





DISCUSSION:

The findings of this study reinforce the growing body of evidence that low-dose computed tomography (LDCT) significantly enhances the early detection of pulmonary tuberculosis (TB) compared with traditional chest X-ray (CXR), particularly in high-burden, resource-limited settings. The superior sensitivity and diagnostic accuracy of LDCT observed in the current analysis align closely with global research trends emphasizing CT-based imaging as a more precise diagnostic modality for pulmonary diseases. LDCT's ability to capture minute parenchymal changes, such as tree-in-bud opacities, small cavities, and early bronchogenic spread, provides a substantial

advantage in identifying subclinical and early-stage TB lesions that typically evade detection on CXR (16). Several recent investigations corroborate these results. A 2025 systematic review comparing imaging modalities reported CT sensitivity and specificity exceeding 93% for pulmonary TB, whereas CXR displayed greater variability in specificity, ranging from 23% to 99% (17). Similarly, a 2022 multicenter trial conducted by van den Berk et al. demonstrated that ultra-low-dose CT (ULDCT) was not only diagnostically superior to CXR but also comparable in radiation exposure to traditional radiography, reinforcing its potential as a safe and effective diagnostic alternative in clinical settings (18). The present study's sensitivity rate of 92.9% for LDCT versus 75.7% for CXR corresponds closely with these findings, underscoring LDCT's reliability across both symptomatic and smear-negative TB cases.

Beyond its diagnostic performance, LDCT offers substantial clinical value in visualizing atypical TB presentations. In this study, LDCT identified early-stage parenchymal involvement and subtle lymphadenopathy in patients with non-specific symptoms, consistent with earlier observations that CT can reveal lesions invisible on radiographs. A 2023 investigation in *European Radiology* similarly found that ULDCT detected pneumonia and early infectious lung changes in patients without respiratory symptoms with 93% sensitivity, compared to 50% for CXR, highlighting the modality's diagnostic reach in subclinical pulmonary infections. This finding parallels the present study's observation that LDCT more accurately differentiated active disease from healed or fibrotic lesions. Advancements in imaging technology have further improved LDCT's utility. Modern dose-reduction algorithms and artificial intelligence (AI)-driven noise suppression systems now allow near-radiograph-level radiation exposure while maintaining high-resolution imaging. Studies employing generative adversarial network (GAN)-based image reconstruction have achieved up to 93% dose reduction while retaining diagnostic fidelity for pulmonary TB evaluation. Such developments align with the current study's reported mean dose of 1.27 mSv, which remains well within international safety standards.

The implications of these findings extend beyond diagnostic enhancement to broader public health impact. In high TB-burden regions such as Balochistan, where diagnostic delays and underreporting are common, LDCT could substantially reduce missed diagnoses, particularly among smear-negative or asymptomatic patients. Earlier identification through LDCT-guided screening could curtail transmission cycles and optimize resource allocation for TB control programs (19). This aligns with research from the *International Organization for Migration* study, which found AI-assisted radiography and CT comparable to expert radiologist performance in large-scale TB screening among migrant populations. Despite its promise, the implementation of LDCT-based diagnostics faces logistical challenges. Equipment costs, maintenance, and the requirement for trained radiologists pose barriers in low-resource settings. Furthermore, while the radiation dose is reduced compared to standard CT, repeated imaging may raise cumulative exposure concerns, particularly in screening contexts. However, continuous improvements in dose optimization and AI-aided interpretation can mitigate these concerns over time. The integration of portable or AI-interpreted LDCT systems could further enhance accessibility in remote or underserved areas, a recommendation echoed by recent literature advocating hybrid AI-CT approaches to expand TB screening capacity globally(20).

The study's strengths include its multicentric design, adequate sample size, and adherence to standardized imaging and diagnostic protocols, ensuring methodological robustness and external validity. The simultaneous use of microbiological confirmation as a reference standard adds rigor, eliminating diagnostic ambiguity. Additionally, the blinding of radiologists during interpretation minimized bias, enhancing the reliability of comparative accuracy assessments. Nonetheless, certain limitations must be acknowledged. The study was restricted to private hospitals in Balochistan, potentially limiting generalizability to public healthcare facilities where diagnostic infrastructure may differ. The exclusion of pediatric populations and extrapulmonary TB cases also narrows the scope of application. Economic evaluation was not performed, though prior cost-benefit analyses have indicated that LDCT may be cost-effective in high-incidence settings due to its superior early detection rates. Future studies incorporating cost-effectiveness assessments, longitudinal follow-ups, and AI-based interpretative algorithms could strengthen the case for LDCT integration into TB control frameworks. The present findings reaffirm that LDCT significantly enhances diagnostic precision for pulmonary TB compared with chest X-ray, offering improved early lesion detection, high inter-observer reliability, and acceptable radiation safety profiles. Its adoption in high-burden districts like Balochistan could play a transformative role in reducing diagnostic delays and improving TB control outcomes. As technological advancements continue to reduce costs and radiation exposure, LDCT stands poised to become an indispensable diagnostic adjunct in the global fight against tuberculosis.

CONCLUSION:

The study concluded that low-dose computed tomography (LDCT) demonstrates significantly higher diagnostic accuracy and sensitivity than conventional chest X-ray (CXR) for early detection of pulmonary tuberculosis in high-burden districts of Balochistan. LDCT effectively identified subtle and early parenchymal lesions while maintaining minimal radiation exposure, offering a reliable alternative in resource-limited settings. Its superior imaging performance supports its integration into TB diagnostic pathways, potentially reducing diagnostic delays, improving treatment initiation, and contributing to more effective regional and global tuberculosis control efforts.

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AUTHORS CONTRIBUTION

Author	Contribution
Aleem Ejaz	Conceptualization, Methodology, Formal Analysis, Writing - Original Draft, Validation, Supervision

