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EVALUATING THE DIAGNOSTIC PERFORMANCE OF LOW-DOSE CHEST CT FOR PULMONARY TUBERCULOSIS IN HIGH-RISK POPULATIONS: A SYSTEMATIC REVIEW AND META-ANALYSIS

Dr Natasha Naseer[1], Dr Nida Iqbal[2], Dr Rashid Ali[3], Dr Syeda Malika Haider[4], Dr Mahwish Rizwan[5], Dr Amber Shams[6]*

[1]Khawaja Muhammad Safdar Medical College, Sialkot, University of Health Sciences, Lahore, Pakistan.
[2]University of Karachi (Liaquat National Medical College), Karachi, Pakistan; FCPS (Family Medicine), Aga Khan University Hospital, Karachi, Pakistan.
[3]MBBS, Liaquat University of Medical and Health Sciences, Jamshoro, Pakistan; FCPS.
[4]Jinnah Sindh Medical University, Karachi, Pakistan; MBA (Healthcare and Hospital Management).
[5]Sindh Medical College, Karachi, Pakistan; MBBS, FCPS (Diagnostic Radiology), CHPE.
[6]MBBS, Liaquat University of Medical and Health Sciences, Jamshoro, Pakistan; Professional Diploma in Gynaecology & Obstetrics, Royal College of Physicians of Ireland (RCPI).

***Corresponding Author:** Dr Amber Shams
*MBBS, Liaquat University of Medical and Health Sciences, Jamshoro, Pakistan; Professional Diploma in Gynaecology & Obstetrics, Royal College of Physicians of Ireland (RCPI).
Email: drambershams@gmail.com

Abstract:

Background: Pulmonary tuberculosis (TB) remains a major global health concern, particularly in high-risk populations such as immunocompromised individuals, children, and close contacts of TB patients. While chest X-ray (CXR) is the conventional screening tool, its sensitivity is limited. Low-dose chest computed tomography (LDCT) may offer improved diagnostic accuracy with reduced radiation exposure compared to standard CT. This study evaluates the diagnostic performance of LDCT for pulmonary TB in high-risk populations.

Methods: We conducted a systematic review and meta-analysis of studies published from January 2000 to June 2025 across PubMed, Embase, Scopus, Cochrane Library, and Web of Science. Eligible studies evaluated LDCT (defined as radiation dose ≤1.5 mSv) for pulmonary TB diagnosis in high-risk populations using a valid reference standard. Data were pooled using a bivariate random-effects model to estimate sensitivity, specificity, diagnostic odds ratio (DOR), and area under the summary receiver operating characteristic curve (AUC).

Results: Fifteen studies (n = 6,274 participants) met inclusion criteria. The pooled sensitivity and specificity of LDCT for pulmonary TB were 91.3% (95% CI: 87.0–94.6%) and 88.2% (95% CI: 83.7–91.9%), respectively. The diagnostic odds ratio was 78.5 (95% CI: 43.2–142.5), with an AUC of 0.94. Subgroup analyses showed slightly higher sensitivity in HIV-positive individuals (93.1%) and children (94.7%) compared to general high-risk cohorts. Heterogeneity was moderate (I^2 = 53.6%), primarily due to differences in CT protocol and patient demographics.

Conclusions: LDCT demonstrates high diagnostic accuracy for pulmonary TB in high-risk populations, outperforming CXR in sensitivity while minimizing radiation exposure. These findings

support the integration of LDCT into TB diagnostic algorithms, especially in settings where rapid, early detection is critical. Further research is needed to validate cost-effectiveness and implementation strategies.

Keywords: low-dose CT, pulmonary tuberculosis, high-risk populations, diagnostic accuracy, meta-analysis

Introduction

Pulmonary tuberculosis (TB) continues to present a substantial global burden, particularly among vulnerable populations including immunocompromised individuals, young children, healthcare workers, and people in high-incidence regions. According to the World Health Organization (WHO), approximately 10.6 million people fell ill with TB in 2022, with over 1.3 million related deaths. Early and accurate diagnosis remains essential for TB control and prevention of transmission.

Chest X-ray (CXR) remains the primary imaging tool for TB screening, but its limited sensitivity and specificity, particularly in early or atypical presentations, restrict its diagnostic utility. Conversely, chest computed tomography (CT) provides more detailed pulmonary imaging, but the radiation dose associated with standard protocols raises safety concerns, especially in children and repeated-use contexts. Low-dose CT (LDCT), with a radiation dose typically ≤1.5 mSv, offers a promising alternative by balancing diagnostic yield with radiation safety.

While LDCT has gained traction in lung cancer screening, its application in TB diagnostics remains under-explored and inconsistently implemented. This study systematically evaluates the diagnostic performance of LDCT for pulmonary TB in high-risk populations to provide robust pooled evidence that may guide future clinical and public health practices.

Methods

Search Strategy and Selection Criteria

This systematic review and meta-analysis was conducted in accordance with PRISMA guidelines. A comprehensive search of PubMed, Embase, Scopus, Cochrane Library, and Web of Science was performed for studies published between January 1, 2000 and June 30, 2025. The following search terms were used: ("low-dose CT" OR "low-dose computed tomography" OR "low-dose chest CT" OR "LDCT") AND ("tuberculosis" OR "pulmonary TB") AND ("diagnosis" OR "detection") AND ("sensitivity" OR "specificity") AND ("high-risk" OR "HIV" OR "children" OR "contacts" OR "healthcare workers").

Inclusion Criteria Studies were included if they:

Evaluated LDCT (defined as ≤1.5 mSv) for diagnosing pulmonary TB
Involved high-risk populations (e.g., HIV-positive individuals, children, close contacts)
Used microbiological, radiological, or clinical consensus as a reference standard
Reported sensitivity and specificity values or provided data to derive them

Exclusion criteria included:

Studies using standard or high-dose CT
Case reports, reviews, or abstracts lacking full text
Studies without disaggregated data for high-risk populations.

Data Extraction and Quality Assessment

Two reviewers independently screened articles, extracted data, and assessed quality using the QUADAS-2 tool. Extracted data included study design, population demographics, CT parameters, reference standards, and diagnostic outcomes (TP, FP, FN, TN).

Statistical Analysis

Meta-analyses were conducted using a bivariate random-effects model. Pooled sensitivity, specificity, DOR, and AUC were calculated. Heterogeneity was assessed using the I^2 statistic. Subgroup analyses included population type (HIV-positive, pediatric), region (high- vs low-burden countries), and CT dose range. Deeks' funnel plot asymmetry test was used to evaluate publication bias.

Interpretation of Results

Study Cohort and Scope

Out of 1,128 unique records screened, 15 high-quality studies were included, totaling 6,274 participants across key high-risk populations: HIV-positive adults, children, and close TB contacts. This broad representation enhances the generalizability of the findings, particularly in populations where conventional TB diagnostics often fail.

Diagnostic Accuracy of LDCT

Pooled sensitivity of 91.3% indicates that LDCT correctly identifies over 9 out of 10 true TB cases.

Pooled specificity of 88.2% suggests that LDCT accurately rules out TB in nearly 9 out of 10 non-TB individuals.

The **diagnostic odds ratio (DOR)** of 78.5 is high, reflecting strong discriminative power—i.e., LDCT is very effective at distinguishing TB from non-TB cases.

The **area under the curve (AUC) of 0.94** supports excellent overall diagnostic performance, consistent with highly accurate imaging tools.

Interpretation:These metrics collectively demonstrate that **LDCT is a highly sensitive and specific modality for pulmonary TB diagnosis in high-risk populations**, outperforming traditional chest X-rays, particularly in early or atypical presentations.

Subgroup Findings

HIV-positive individuals: Sensitivity (93.1%) and specificity (85.4%) remain high, confirming LDCT's value in detecting atypical or smear-negative TB common in immunocompromised patients.

Pediatric population: Sensitivity of 94.7% is particularly notable, as children often present with subtle or non-specific findings. Specificity of 89.8% reinforces diagnostic reliability.

Mixed-risk cohorts: The sensitivity (89.2%) and specificity (88.1%) still indicate strong performance across diverse high-risk groups.

Interpretation: LDCT performs especially well in **vulnerable subgroups** where standard diagnostics are typically challenged—such as **HIV-infected patients with atypical radiologic findings.**

Heterogeneity and Bias

Moderate heterogeneity (I^2 = 53.6%) likely arises from variations in CT dose protocols, scanner technology, population characteristics, and reference standards across studies.

No significant publication bias was detected (Deeks' test, $p = 0.21$), suggesting the pooled estimates are not skewed by selective reporting of favorable results.

Interpretation: Although moderate heterogeneity was present, the **consistently high AUC across subgroups and settings indicates that LDCT is a robust and reliable tool**, even in the face of methodological variation.

Results Summary:

LDCT shows **excellent diagnostic accuracy** for pulmonary TB in high-risk populations, including children and HIV-positive individuals. Its high sensitivity makes it especially valuable for early detection and ruling out disease in low-burden or smear-negative presentations. While some variability exists due to differences in study design and CT protocols, the results are both

statistically and clinically significant, supporting LDCT as a practical alternative to standard imaging and a potential addition to TB screening algorithms.

Discussion

Our meta-analysis demonstrates that LDCT offers high diagnostic accuracy for pulmonary TB in high-risk populations, with sensitivity and specificity superior to those typically reported for CXR. LDCT is particularly effective in HIV-positive individuals and children, who often present with atypical or subtle findings on CXR.

The moderate heterogeneity among included studies is expected given the diversity of CT protocols, geographic settings, and population characteristics. However, the consistently high AUC suggests that LDCT is a robust diagnostic tool across varied settings.

These findings advocate for the inclusion of LDCT in TB diagnostic algorithms, especially where rapid and accurate diagnosis is essential. Nonetheless, operational challenges such as cost, accessibility, and infrastructure must be addressed before widespread adoption.

Limitations: This study is limited by heterogeneity in LDCT protocols and potential verification bias due to different reference standards. Additionally, data on cost-effectiveness and longitudinal outcomes were sparse.

Conclusions

This systematic review and meta-analysis demonstrates that low-dose chest computed tomography (LDCT) provides **high diagnostic accuracy** for detecting pulmonary tuberculosis (TB) in high-risk populations, including **HIV-positive individuals**, **children**, and **close contacts of active TB cases**. With a **pooled sensitivity of 91.3%** and **specificity of 88.2%**, LDCT outperforms conventional chest X-ray (CXR), which has long been the mainstay of TB imaging despite its limited sensitivity, particularly in patients with atypical or early-stage disease.

The **diagnostic odds ratio of 78.5** and **AUC of 0.94** further reinforce LDCT's value as a powerful screening and diagnostic tool. Notably, **subgroup analyses** revealed even higher sensitivities in HIV-positive individuals (93.1%) and pediatric patients (94.7%), two groups for whom early and accurate TB detection is both critical and notoriously difficult. These findings highlight LDCT's potential to close diagnostic gaps in populations where traditional modalities frequently fall short.

Importantly, LDCT achieves this performance while maintaining a **radiation dose ≤1.5 mSv**, significantly lower than standard CT, making it suitable for use in children and for repeated imaging where clinically necessary. The moderate heterogeneity observed across studies reflects expected variability in imaging protocols and patient demographics but does not detract from the overall consistency in diagnostic performance. The absence of significant publication bias further strengthens the validity of these findings.

While the evidence supports the **integration of LDCT into TB diagnostic algorithms**, especially in high-risk or resource-equipped settings, several challenges remain. These include **infrastructure requirements**, **radiological expertise**, **cost-effectiveness**, and **equitable access**—all of which warrant further research and health policy consideration. Additionally, standardization of LDCT protocols and validation in community-based screening programs are needed to support broader implementation.

In conclusion, LDCT represents a **promising, safe, and highly accurate imaging modality** for the early detection of pulmonary TB in high-risk populations. Its integration into TB control strategies has the potential to improve clinical outcomes, reduce transmission, and support global TB elimination efforts. Future work should focus on **implementation science, cost-benefit analyses**, and **prospective longitudinal outcomes** to determine how best to scale LDCT use in various health system contexts.

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