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Original Research

Evaluation of Diagnostic Techniques for Early Detection of Chest Tuberculosis: A Comparative Study of Radiological and Molecular Methods

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ABSTRACT:
Aim: The aim of this study was to evaluate and compare the diagnostic accuracy of radiological and molecular techniques for the early detection of chest tuberculosis (TB). The study focused on assessing the sensitivity, specificity, and overall diagnostic effectiveness of these methods in identifying active TB cases. **Materials and Methods:** A comparative cross-sectional study was conducted at a tertiary care hospital with 100 adult participants divided into two groups: Group A underwent radiological diagnostic techniques (chest X-ray and CT scan), and Group B underwent molecular diagnostic techniques (GeneXpert MTB/RIF and PCR). Clinical assessments, radiological evaluations, and molecular analyses were carried out using standardized procedures. Data were analyzed using descriptive statistics, ROC curves, and logistic regression to compare the diagnostic efficacy of both methods. **Results:** The study found significant differences in diagnostic accuracy between radiological and molecular techniques. Molecular techniques demonstrated superior sensitivity (GeneXpert 95%, PCR 98%) and specificity (GeneXpert 85%, PCR 90%) compared to radiological methods (CXR sensitivity 75%, specificity 60%). The AUC values were significantly higher for molecular methods (0.92 for GeneXpert and 0.94 for PCR) than for radiological techniques (0.72 for CXR and 0.80 for CT scan), indicating greater diagnostic accuracy. **Conclusion:** Molecular diagnostic techniques, such as GeneXpert MTB/RIF and PCR, exhibited superior performance in terms of sensitivity, specificity, and predictive values compared to radiological methods. These findings suggest that molecular diagnostics should be integrated into standard TB diagnostic protocols for early and accurate detection, particularly in high-burden settings.
Keywords: Chest tuberculosis, Molecular diagnostics, Radiological techniques, Sensitivity, Early detection.

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INTRODUCTION

Tuberculosis (TB) remains one of the leading causes of morbidity and mortality worldwide, particularly in developing countries where access to healthcare resources is limited. Early detection of TB is crucial in controlling its spread and ensuring effective treatment, as delayed diagnosis can lead to severe complications, increased transmission rates, and poor treatment outcomes. The diagnostic landscape of TB has evolved significantly over the years, with various radiological and molecular techniques emerging as key tools in detecting the disease at an early stage. This study focuses on the evaluation of these diagnostic techniques, aiming to understand their comparative efficacy, sensitivity, and specificity in detecting chest tuberculosis.[1]TB is primarily caused by the bacterium *Mycobacterium tuberculosis*, which predominantly affects the lungs, leading to pulmonary TB, although it can also involve other organs in extrapulmonary cases. The early detection of pulmonary TB is particularly vital, as the lungs are the primary site of infection, making it the most contagious form of the disease. Chest tuberculosis presents with a range of clinical symptoms, including a persistent cough, chest pain, fever, night sweats, and weight loss. However, these symptoms can often overlap with those of other respiratory conditions, complicating the clinical diagnosis of TB. Therefore, accurate diagnostic techniques are essential to confirm the presence of TB and initiate appropriate treatment

strategies.[2]Radiological techniques, such as chest X-ray (CXR) and computed tomography (CT) scans, have long been utilized as frontline tools in diagnosing chest TB. These imaging techniques provide a visual representation of lung abnormalities, such as infiltrates, nodular lesions, cavitations, and other signs indicative of TB infection. Chest X-ray is widely used due to its accessibility and cost-effectiveness; it is often the first imaging modality employed in TB screening. Despite its benefits, CXR has limitations, including low specificity and variability in interpretation, which can lead to false positives or negatives, particularly in cases of early-stage TB or in patients with non-specific lung findings.

CT scans offer a more detailed evaluation of lung architecture and are often considered more sensitive than CXR in detecting subtle changes in lung tissue that may be indicative of TB. CT imaging can reveal detailed anatomical structures, helping to identify the extent of infection and distinguishing between active and inactive TB lesions. Although CT scans are more accurate, their use is limited by factors such as higher costs, increased radiation exposure, and limited availability in resource-constrained settings. Moreover, radiological methods, in general, are limited in their ability to confirm a definitive diagnosis of TB, as they cannot specifically detect the causative agent, *Mycobacterium tuberculosis*.[3]In contrast to radiological techniques, molecular diagnostic methods have gained prominence due to their ability to directly identify the genetic material of *Mycobacterium tuberculosis*. These methods, such as the GeneXpert MTB/RIF assay and polymerase chain reaction (PCR), have revolutionized TB diagnostics by offering rapid, accurate, and specific results. The GeneXpert MTB/RIF is a cartridge-based nucleic acid amplification test (NAAT) that detects the presence of *M. tuberculosis* DNA and simultaneously tests for resistance to rifampicin, one of the key antibiotics used in TB treatment. This dual capability makes it an invaluable tool in not only diagnosing TB but also in guiding treatment decisions, particularly in cases of drug-resistant TB.[4]PCR, on the other hand, is a highly sensitive molecular technique that amplifies specific DNA sequences of *M. tuberculosis* to enable its detection even in low concentrations. The use of real-time PCR allows for quantitative assessment, enhancing the sensitivity of TB diagnosis, especially in patients with low bacterial loads or in smear-negative cases. Molecular techniques like PCR are recognized for their rapid turnaround time and higher diagnostic accuracy compared to conventional methods, making them a preferred choice in many clinical settings. However, these techniques also come with challenges, such as higher costs, the need for specialized equipment, and the requirement for skilled personnel to interpret the results.[5]This comparative study aims to evaluate the diagnostic accuracy of these radiological and molecular methods, assessing their sensitivity, specificity, and overall effectiveness in detecting chest TB. Sensitivity refers to a test's ability to correctly identify those with the disease, while specificity denotes its ability to correctly identify those without the disease. Both parameters are critical in determining the reliability of a diagnostic test, with a higher sensitivity reducing the chance of false negatives and a higher specificity minimizing false positives.[6]The study's approach involves comparing the results obtained from patients who undergo radiological diagnostics (CXR and CT scan) with those who are assessed using molecular techniques (GeneXpert and PCR). The goal is to identify which method offers the most reliable diagnostic outcome, particularly in the early stages of TB when clinical symptoms might not be fully developed. Understanding the strengths and limitations of each diagnostic approach will help in developing more effective TB screening strategies and ensuring timely interventions, thereby reducing the transmission and impact of this infectious disease.[7]Moreover, this study addresses the practical aspects of implementing these diagnostic methods in various healthcare settings, considering factors such as cost, accessibility, speed of diagnosis, and the level of technical expertise required. These factors play a crucial role in determining the feasibility of widespread adoption of these techniques, particularly in low-resource environments where TB prevalence is high. By providing a comprehensive evaluation of these diagnostic tools, this study aims to contribute valuable insights that can guide clinicians and healthcare policymakers in optimizing TB detection and management strategies.

MATERIAL AND METHODS

This comparative cross-sectional study was conducted at a tertiary care hospital with a specialized tuberculosis (TB) unit, equipped with both radiological and molecular diagnostic facilities. The primary objective of the study was to evaluate the diagnostic accuracy of radiological and molecular techniques for the early detection of chest tuberculosis (TB). The study aimed to compare the sensitivity, specificity, and overall effectiveness of these diagnostic methods in identifying active TB cases among suspected patients.The study included adult patients aged 18 years and above who presented with symptoms suggestive of pulmonary tuberculosis, such as chronic cough, fever, night sweats, weight loss, and chest pain. To ensure statistical power for detecting significant differences in diagnostic accuracy, a sample size of 100 participants was deemed adequate. Participants were divided into two groups: Group A underwent radiological diagnostic techniques, and Group B underwent molecular diagnostic techniques.

Inclusion Criteria

- Adults aged 18 years and older.

- Patients presenting with clinical symptoms suggestive of pulmonary tuberculosis.
- Patients who had not received anti-TB treatment in the past six months.
- Willingness to provide informed consent for participation in the study.

Exclusion Criteria

- Patients with a known history of multi-drug resistant (MDR) or extensively drug-resistant (XDR) TB.
- Patients with severe immunosuppressive conditions (e.g., HIV/AIDS, chemotherapy) that could interfere with the study results.
- Individuals with incomplete medical records or those unwilling to undergo diagnostic testing.
- Pregnant women due to potential radiation exposure associated with radiological techniques.

Methodology

Data collection was carried out using a structured form that included patient demographic information, clinical history, and results of the diagnostic tests. The data collection process was organized into the following phases:

Clinical Assessment: Detailed patient history was obtained, focusing on the duration of symptoms like cough, sputum production, fever, weight loss, and chest pain. A thorough physical examination was conducted to document any clinical signs relevant to chest tuberculosis.

Radiological Techniques (Group A)

Chest X-ray (CXR): All participants in Group A underwent a standard chest X-ray to identify radiographic signs of tuberculosis, such as lung infiltrates, cavitation, and nodular opacities.

Computed Tomography (CT) Scan: If the chest X-ray results were ambiguous, a CT scan of the chest was performed to provide a more detailed imaging assessment of lung structures.

Molecular Techniques (Group B)

Sputum Smear Microscopy: Sputum samples were collected from each patient and analyzed using Ziehl-Neelsen staining to detect acid-fast bacilli (AFB).

GeneXpert MTB/RIF Assay: This molecular diagnostic test was conducted using the GeneXpert system to detect Mycobacterium tuberculosis DNA and determine rifampicin resistance directly from sputum samples.

Polymerase Chain Reaction (PCR): A real-time PCR assay was performed to amplify specific DNA sequences of Mycobacterium tuberculosis to enhance detection sensitivity.

Laboratory Procedures

Sputum samples were collected in sterile containers to ensure contamination was minimized, adhering strictly to standard biosafety protocols. The handling of these samples was crucial for maintaining the integrity of the diagnostic process. All laboratory procedures followed the guidelines established by the World Health Organization (WHO) and national TB control programs to guarantee consistency and reliability in the results. Throughout the testing process, internal and external quality control measures were rigorously implemented to verify the accuracy and precision of the diagnostic outcomes, ensuring that the data generated were both dependable and reproducible.

Statistical Analysis

Data were analyzed using a structured approach, beginning with descriptive statistics to summarize the demographic and clinical characteristics of the study population. Measures such as frequencies, percentages, means, and standard deviations were used to provide a clear overview of the participant data. The analysis further involved calculating the sensitivity, specificity, positive predictive value (PPV), and negative predictive value (NPV) of the radiological and molecular diagnostic methods to assess their accuracy. Comparative analysis was performed to evaluate the diagnostic efficacy of radiological techniques (such as CXR and CT scan) against molecular techniques (like GeneXpert and PCR) using Receiver Operating Characteristic (ROC) curves and Area Under the Curve (AUC) analysis. This comprehensive statistical approach was conducted using the Statistical Package for the Social Sciences (SPSS) software, version 21.0, with a significance threshold set at a p-value of less than 0.05 to determine statistical relevance.

RESULTS

Table 1: Demographic Characteristics of Study Participants

The demographic analysis of the study participants shows that the mean age of patients in Group A (radiological techniques) was 45.2 ± 12.3 years, while in Group B (molecular techniques), it was 44.8 ± 11.8 years. The p-value of 0.78 indicates no statistically significant difference in age distribution between the two groups, suggesting that age did not play a distinguishing role in the selection of patients for either diagnostic technique. Gender distribution was also similar between the two groups, with 30 males and 20 females in Group A and 28 males and 22 females in Group B, resulting in a p-value of 0.67, further confirming no significant gender differences. Additionally, the duration of symptoms was comparable between Group A (15.4 ± 5.2 days) and Group B (16.1 ± 4.8 days), with a p-value of 0.54, indicating no significant variation in the duration of symptoms experienced by patients across both diagnostic groups. These findings demonstrate that the patient characteristics were well-matched across both groups, providing a reliable basis for comparing the diagnostic accuracy of the two techniques.

Table 2: Sensitivity and Specificity of Diagnostic Techniques

The sensitivity and specificity analysis revealed significant differences between the diagnostic methods used in Group A (radiological techniques) and Group B (molecular techniques). Chest X-ray (CXR) in Group A demonstrated a sensitivity of 75% and a specificity of 60%, with a p-value of 0.03, indicating moderate diagnostic accuracy. The CT scan showed improved sensitivity (85%) and specificity (70%) compared to the CXR, with a statistically significant p-value of 0.02. In contrast, the molecular techniques in Group B, such as GeneXpert MTB/RIF and PCR, exhibited superior sensitivity (95% and 98%) and specificity (85% and 90%) with p-values of <0.001, highlighting their high diagnostic accuracy. These results suggest that molecular techniques are significantly more effective than radiological methods in detecting chest tuberculosis, making them more reliable for early TB diagnosis.

Table 3: Diagnostic Accuracy Analysis Using ROC and AUC

The diagnostic accuracy analysis, as determined by the Receiver Operating Characteristic (ROC) curves and Area Under the Curve (AUC) values, further supported the superior performance of molecular techniques. The AUC value for the Chest X-ray (CXR) in Group A was 0.72, while the CT scan showed a higher AUC of 0.80, with p-values of 0.04 and 0.03, respectively. Molecular techniques in Group B, such as GeneXpert MTB/RIF and PCR, demonstrated significantly higher AUC values of 0.92 and 0.94, respectively, with p-values of <0.001. These high AUC values indicate that molecular methods have a greater ability to distinguish between TB-positive and TB-negative cases, reinforcing their effectiveness as diagnostic tools.

Table 4: Comparative Predictive Values of Diagnostic Techniques

The comparative analysis of the Positive Predictive Value (PPV) and Negative Predictive Value (NPV) for both diagnostic groups revealed significant differences. Chest X-ray (CXR) in Group A had a PPV of 65% and an NPV of 58%, while the CT scan showed slightly higher values with a PPV of 72% and an NPV of 68%. These results were statistically significant with p-values of 0.04 and 0.03, respectively. Molecular techniques in Group B, such as GeneXpert MTB/RIF and PCR, exhibited much higher predictive values, with PPVs of 85% and 90% and NPVs of 90% and 92%, respectively, all with p-values of <0.001. This indicates that molecular methods are more reliable in both confirming and ruling out TB diagnoses, making them the preferred choice for accurate clinical decision-making.

Table 5: Logistic Regression Analysis of Diagnostic Techniques

The logistic regression analysis identified significant predictors of diagnostic outcomes for chest TB. Radiological techniques (Group A) had an odds ratio (OR) of 1.45 (95% CI: 1.10-1.90) with a p-value of 0.03, indicating a moderate association with accurate TB diagnosis. Molecular techniques (Group B), however, had a much higher odds ratio of 3.25 (95% CI: 2.20-4.75) with a p-value of <0.001, highlighting their strong diagnostic capability. The duration of symptoms and gender did not show significant associations with TB diagnostic accuracy, as indicated by their p-values of 0.17 and 0.29, respectively. These findings underscore the superior diagnostic performance of molecular techniques compared to radiological methods, suggesting that molecular diagnostics are a more powerful tool for the early detection of chest tuberculosis.

Table 1: Demographic Characteristics of Study Participants

Demographic Variable	Radiological Techniques (Group A)	Molecular Techniques (Group B)	P-value
Mean Age (years)	45.2 ± 12.3	44.8 ± 11.8	0.78
Gender Distribution (M/F)	30/20	28/22	0.67
Duration of Symptoms	15.4 ± 5.2 days	16.1 ± 4.8 days	0.54

Table 2: Sensitivity and Specificity of Diagnostic Techniques

Diagnostic Method	Sensitivity (%)	Specificity (%)	P-value
Chest X-ray (CXR) - Group A	75%	60%	0.03*
CT Scan - Group A	85%	70%	0.02*
GeneXpert MTB/RIF - Group B	95%	85%	<0.001**
PCR - Group B	98%	90%	<0.001**

Table 3: Diagnostic Accuracy Analysis Using ROC and AUC

Diagnostic Technique	AUC (Area Under Curve)	P-value
Chest X-ray (CXR) - Group A	0.72	0.04*
CT Scan - Group A	0.80	0.03*
GeneXpert MTB/RIF - Group B	0.92	<0.001**
PCR - Group B	0.94	<0.001**

Table 4: Comparative Predictive Values of Diagnostic Techniques

Diagnostic Method	Positive Predictive Value (PPV)	Negative Predictive Value (NPV)	P-value
Chest X-ray (CXR) - Group A	65%	58%	0.04*
CT Scan - Group A	72%	68%	0.03*
GeneXpert MTB/RIF - Group B	85%	90%	<0.001**
PCR - Group B	90%	92%	<0.001**

Table 5: Logistic Regression Analysis of Diagnostic Techniques

Variable	Odds Ratio (95% CI)	P-value
Radiological Techniques (Group A)	1.45 (1.10-1.90)	0.03*
Molecular Techniques (Group B)	3.25 (2.20-4.75)	<0.001**
Duration of Symptoms	1.18 (0.90-1.45)	0.17
Gender (Male vs. Female)	1.05 (0.75-1.35)	0.29

DISCUSSION

The demographic characteristics of the study participants showed no significant differences between the groups using radiological and molecular techniques. The mean age and gender distribution were statistically similar between Group A (radiological techniques) and Group B (molecular techniques). This is consistent with previous studies that have emphasized the importance of comparable demographic parameters in ensuring unbiased comparisons of diagnostic techniques. For example, a study by Udwadia et al. (2015) demonstrated that demographic factors like age and gender do not significantly influence the performance of TB diagnostic methods, thus supporting the validity of this study's design.[8] The comparable duration of symptoms between both groups also aligns with findings by Lienhardt et al. (2014), who suggested that symptom duration should not differ significantly between groups when assessing TB diagnostic tools, as it allows for a fair evaluation of the test's efficacy.[9]The sensitivity and specificity values observed for the diagnostic techniques highlight significant differences between radiological and molecular methods. Chest X-ray (CXR) and CT scans in Group A showed moderate diagnostic accuracy, with CXR sensitivity at 75% and specificity at 60%, which is in line with the findings of Davies et al. (2013), who reported similar values when using CXR for TB detection.[10] However, the molecular techniques in Group B, such as GeneXpert MTB/RIF and PCR, demonstrated much higher sensitivity (95% and 98%) and specificity (85% and 90%), indicating superior diagnostic performance. Studies by Boehme et al. (2011) also reported high sensitivity and specificity values for molecular techniques, supporting their effectiveness over traditional radiological methods. These findings suggest that molecular diagnostics are more accurate in detecting TB at an early stage, corroborating results from prior studies that advocate for the use of molecular tools in TB diagnostics.[11]The diagnostic accuracy analysis using ROC and AUC values further emphasized the superior performance of molecular techniques compared to radiological methods. The AUC values for GeneXpert MTB/RIF and PCR in Group B were significantly higher (0.92 and 0.94) than those for CXR and CT scan in Group A (0.72 and 0.80). These results are consistent with a study by Marais et al. (2012), which highlighted that molecular diagnostics have a better ability to distinguish between TB-positive and TB-negative cases, as evidenced by their higher AUC values.[12] The ability of molecular methods to provide precise diagnostic outcomes reinforces their suitability for early TB detection, as reported by Lawn et al. (2013), who found that high AUC values are indicative of robust diagnostic performance, especially in high-burden TB settings.[13]The comparative analysis of the Positive Predictive Value (PPV) and Negative Predictive Value (NPV) confirmed that molecular techniques are more reliable for diagnosing TB. The PPV and NPV values for GeneXpert MTB/RIF and PCR were significantly higher (85% and 90% PPV; 90% and 92% NPV) compared to CXR and CT scan in Group A (65% and 72% PPV; 58% and 68% NPV). Previous studies by Steingart et al. (2014) showed similar findings, with molecular tests providing higher predictive values than traditional radiological techniques. This indicates that molecular methods are not only more accurate in detecting TB but also more dependable in excluding false negatives, which is crucial in clinical decision-making and patient management.[14] The higher predictive values in molecular diagnostics suggest a reduced likelihood of misdiagnosis, aligning with the recommendations by Dheda et al. (2016), who emphasized the importance of reliable diagnostic methods in preventing the spread of TB.[15]Logistic regression analysis in this study identified molecular techniques as the strongest predictors of accurate TB diagnosis, with an odds ratio (OR) of 3.25 compared to radiological techniques (OR 1.45). This finding is in agreement with the work of Pai et al. (2012), who reported that molecular diagnostics like GeneXpert and PCR significantly increase the probability of correct TB detection compared to traditional imaging methods.[16] The lack of significant associations between gender, duration of symptoms, and diagnostic accuracy is consistent with findings from a study by Horne et al.

(2014), which concluded that these demographic factors do not substantially influence TB diagnosis outcomes. These results underscore the need for a shift towards using molecular diagnostics as the primary tools for TB detection, particularly in resource-limited settings where accurate and timely diagnosis is critical.[17]

CONCLUSION

The study concluded that molecular diagnostic techniques, such as GeneXpert MTB/RIF and PCR, demonstrated superior sensitivity, specificity, and overall diagnostic accuracy compared to radiological methods like chest X-ray and CT scans for the early detection of chest tuberculosis. The high predictive values and significant odds ratios associated with molecular techniques highlight their effectiveness in accurately identifying TB cases. Radiological techniques, although useful, showed limitations in sensitivity and specificity. These findings underscore the need for integrating molecular diagnostics into standard TB diagnostic protocols, particularly in high-burden settings, to enhance early detection and improve patient outcomes.

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