



Rapid Detection of Tuberculosis Using Molecular Methods

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ABOVE THE STUDY

Tuberculosis (TB), caused by *Mycobacterium tuberculosis*, remains one of the leading infectious causes of morbidity and mortality worldwide, particularly in low- and middle-income countries. Early and accurate diagnosis is critical for effective treatment, prevention of transmission, and control of the disease. Traditional diagnostic methods, such as sputum smear microscopy and culture, have significant limitations in sensitivity and turnaround time. In recent years, molecular diagnostic techniques have revolutionized TB detection by providing rapid, sensitive, and specific identification of the pathogen and its resistance patterns.

Conventional methods like Ziehl-Neelsen staining for acid-fast bacilli are widely used due to their simplicity and low cost. However, smear microscopy has limited sensitivity, especially in patients with low bacterial load, such as those with HIV co-infection or extrapulmonary TB. Culture methods, considered the gold standard, offer higher sensitivity but are time-consuming, often requiring several weeks due to the slow-growing nature of *Mycobacterium tuberculosis*. These delays can lead to late initiation of treatment and increased risk of disease transmission.

Molecular methods have addressed many of these limitations by enabling direct detection of TB DNA from clinical samples. One of the most widely used technologies is Nucleic Acid Amplification tests (NAATs), particularly Polymerase Chain Reaction (PCR)-based assays. These tests can detect *Mycobacterium tuberculosis* complex within hours, significantly reducing diagnostic delays. Real-time PCR assays not only identify the presence of the pathogen but also quantify bacterial load, which can be useful for monitoring treatment response.

A major advancement in TB diagnostics is the development of automated cartridge-based systems, such as Xpert MTB/RIF. This assay simultaneously detects *Mycobacterium tuberculosis* and resistance to rifampicin, one of the key first-line anti-TB drugs. The ability to identify drug resistance at the time of diagnosis is crucial for initiating appropriate therapy and preventing the spread of Multidrug-Resistant TB (MDR-TB). Newer versions of this technology, such as Xpert Ultra, offer

improved sensitivity, particularly in smear-negative and pediatric cases.

Line Probe Assays (LPAs) represent another important molecular tool for TB detection and resistance profiling. These assays can identify genetic mutations associated with resistance to first-line and second-line anti-TB drugs. LPAs are particularly useful in reference laboratories for confirming drug resistance and guiding treatment decisions in complex cases.

Next-Generation Sequencing (NGS) is an emerging technology with significant potential in TB diagnostics. Whole-genome sequencing can provide comprehensive information about drug resistance, strain type, and transmission patterns. Although currently limited by cost and infrastructure requirements, NGS is increasingly being used in research and specialized settings to enhance TB surveillance and control efforts.

Despite the advantages of molecular methods, challenges remain in their widespread implementation. High costs, need for specialized equipment, and requirement for trained personnel can limit access in resource-constrained settings where TB burden is highest. Additionally, molecular tests may detect non-viable bacteria, which can complicate the interpretation of results in patients undergoing treatment. Therefore, molecular diagnostics are often used in conjunction with clinical assessment and conventional methods for comprehensive evaluation.

The integration of molecular diagnostics into national TB control programs has significantly improved case detection and management. Rapid identification of TB cases enables early initiation of treatment, reducing transmission and improving patient outcomes. Furthermore, the ability to detect drug resistance supports the implementation of appropriate treatment regimens, which is essential in combating the rise of drug-resistant TB.

In conclusion, molecular methods have transformed the diagnosis of tuberculosis by offering rapid, accurate, and comprehensive detection of *Mycobacterium tuberculosis* and its resistance patterns. While challenges related to cost and accessibility persist, continued advancements and global efforts to expand access to these technologies are critical for

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strengthening TB control programs. The adoption of molecular diagnostics represents a key step toward achieving timely

diagnosis, effective treatment, and ultimately, the global elimination of tuberculosis.