INTERNATIONAL JOURNAL OF PHARMACEUTICAL SCIENCES
[ISSN: 0975-4725; CODEN(USA): IJPS00]
Journal Homepage: https://www.ijpsjournal.com

OPEN ACCESS

Review Article

Ege Tuberculosis: A Comprehensive Review Of Epidemiology, Pathogenesis, Diagnosis, Treatment, And Prevention

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ARTICLE INFO

Published: 23 Aug. 2026

Keywords:

Tuberculosis (TB), Mycobacterium tuberculosis, Pulmonary Tuberculosis, Extrapulmonary Tuberculosis, Drug-Resistant Tuberculosis (DR-TB), Multidrug-Resistant Tuberculosis (MDR-TB), Epidemiology, Pathogenesis, Diagnosis, GeneXpert MTB/RIF, Treatment, BCG Vaccine, Prevention, Public Health, Artificial Intelligence, Genomic Technologies.

DOI:

10.5281/zenodo.22068108

ABSTRACT

Tuberculosis (TB) is a chronic infectious disease caused by Mycobacterium tuberculosis and remains one of the leading causes of illness and death worldwide, particularly in low- and middle-income countries. Despite significant advances in medical science, TB continues to pose a major global public health challenge due to delayed diagnosis, limited healthcare access, socioeconomic disparities, and the emergence of drug-resistant strains. The disease is primarily transmitted through airborne droplets released when an infected individual coughs, sneezes, or speaks. Although pulmonary tuberculosis is the most common form, the infection can also affect several other organs, resulting in extrapulmonary tuberculosis. The progression of the disease depends on the interaction between the pathogen and the host immune system, leading to either latent infection or active disease. This review paper provides a comprehensive overview of tuberculosis by examining its epidemiology, causative organism, transmission, pathogenesis, clinical manifestations, diagnostic approaches, treatment strategies, prevention methods, and recent scientific developments. The review discusses conventional diagnostic techniques such as sputum smear microscopy, culture methods, chest radiography, and tuberculin skin testing, as well as advanced molecular diagnostic tools including nucleic acid amplification tests and GeneXpert MTB/RIF. Current treatment protocols for drug-sensitive tuberculosis and multidrug-resistant tuberculosis (MDR-TB) are also described, emphasizing the importance of treatment adherence and antimicrobial stewardship to prevent the development of further resistance. Preventive strategies, including Bacillus Calmette–Guérin (BCG) vaccination, infection control measures, contact tracing, and public health awareness programs, are highlighted as essential components of tuberculosis control. In addition, recent advances in vaccine development, artificial intelligence-assisted diagnosis, genomic technologies, and hostdirected therapies are explored for their potential to improve TB management. The review concludes that tuberculosis remains a significant global health concern requiring coordinated efforts in early detection, effective treatment

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Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

improved surveillance, research, and equitable access to healthcare. Continued investment in innovative diagnostic methods, novel therapeutics, and public health interventions is essential to reduce the global burden of tuberculosis and achieve the World Health Organization's End TB Strategy goals.

INTRODUCTION

Tuberculosis (TB) is a chronic infectious disease caused by *Mycobacterium tuberculosis* and remains one of the leading causes of infectious disease-related morbidity and mortality worldwide. The disease primarily affects the lungs (pulmonary tuberculosis), although it can also involve other organs such as the lymph nodes, bones, kidneys, brain, and pleura, resulting in extrapulmonary tuberculosis. TB is transmitted through airborne droplets expelled when an infected person coughs, sneezes, speaks, or sings. Despite being a preventable and curable disease, tuberculosis continues to pose a major public health challenge, particularly in low- and middle-income countries where poverty, malnutrition, overcrowding, HIV infection, diabetes, and limited access to healthcare contribute to its persistence. According to the World Health Organization (WHO), millions of new TB cases are reported each year, highlighting the need for effective prevention, early diagnosis, and timely treatment.

The pathogenesis of tuberculosis involves a complex interaction between *Mycobacterium tuberculosis* and the host immune system. Following inhalation, the bacteria reach the alveoli, where they are engulfed by macrophages and may remain dormant as latent tuberculosis infection or progress to active disease. The emergence of multidrug-resistant (MDR-TB) and extensively drug-resistant tuberculosis (XDR-TB) has further complicated global TB control by reducing treatment success rates and increasing healthcare costs. Recent advances in molecular diagnostics, novel anti-tuberculosis drugs, vaccine development, and artificial intelligence-based diagnostic tools have significantly improved disease detection and management. This review provides a comprehensive overview of tuberculosis, including its epidemiology, etiology, pathogenesis, clinical manifestations, diagnosis, treatment, prevention, drug resistance, and recent research developments, emphasizing current challenges and future directions for global tuberculosis control. [4,14,20]

1. Need for Tuberculosis Control

Tuberculosis (TB) remains one of the most serious infectious diseases worldwide, affecting millions of people every year. Although TB is both preventable and curable, it continues to be a major public health concern because of delayed diagnosis, poor treatment adherence, drug resistance, and socioeconomic inequalities. Effective tuberculosis control requires a multidisciplinary approach involving healthcare providers, governments, researchers, and communities. The following aspects highlight the need for comprehensive tuberculosis control. [1,6]

1.1 High Global Disease Burden

Tuberculosis is among the leading causes of death from infectious diseases worldwide. Every year, millions of people develop active TB, with the majority of cases occurring in low- and middle-income countries. The disease places a significant burden on healthcare systems and national economies. Reducing the global incidence of TB requires continuous surveillance, effective public health programs, and universal access to healthcare services.

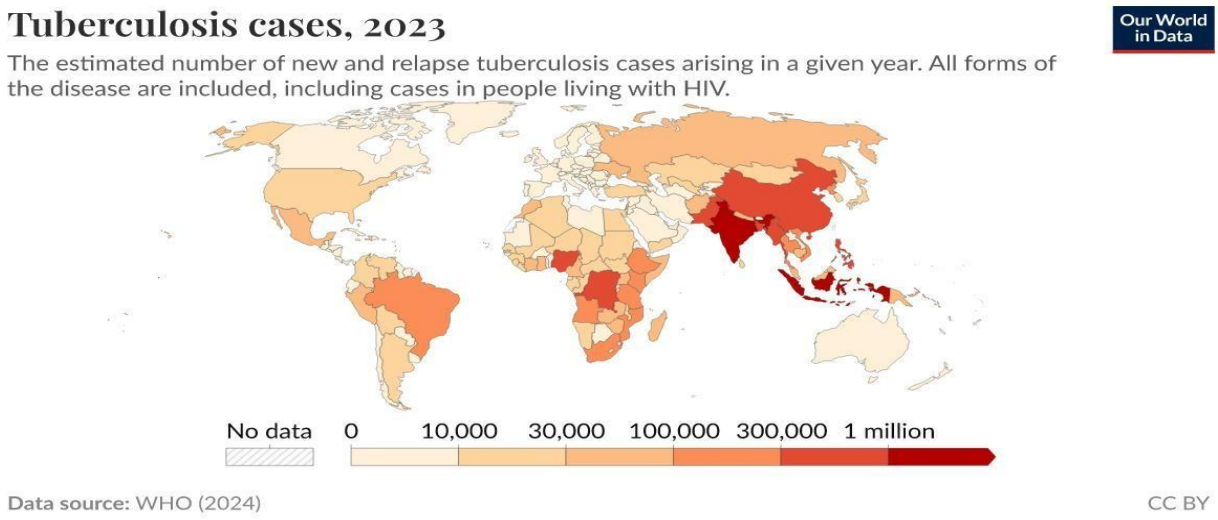


Figure 1.1. Global distribution of tuberculosis showing the high disease burden, particularly in low- and middle-income countries.

1.2 Prevention of Disease Transmission

TB is transmitted through airborne droplets when infected individuals cough, sneeze, or speak. Close contact, overcrowded living conditions, and poor ventilation increase the risk of disease transmission. Early identification of infected individuals, isolation of infectious cases, contact tracing, and appropriate infection-control measures are essential to interrupt the chain of transmission.

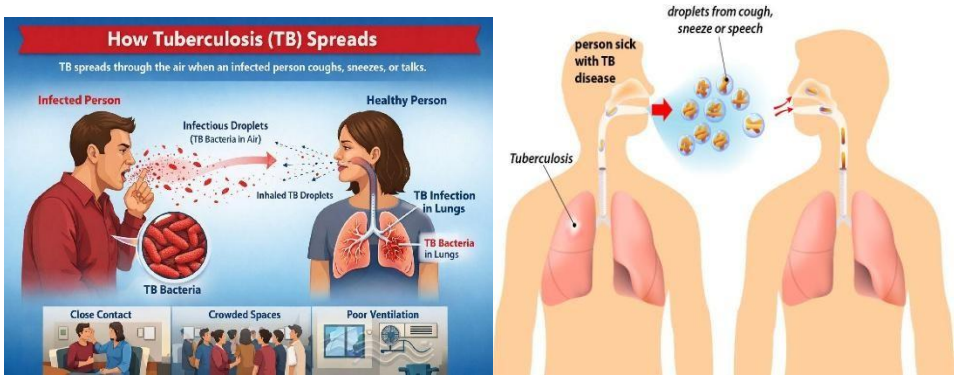


Figure 1.2. Airborne transmission of Mycobacterium tuberculosis through respiratory droplets

1.3 Early Diagnosis and Timely Treatment

Delayed diagnosis remains one of the major reasons for continued TB transmission. Early diagnosis using sputum microscopy, culture, chest radiography, and molecular diagnostic techniques such as GeneXpert MTB/RIF allows prompt initiation of treatment. Timely treatment not only improves patient outcomes but also reduces the spread of infection within the community.

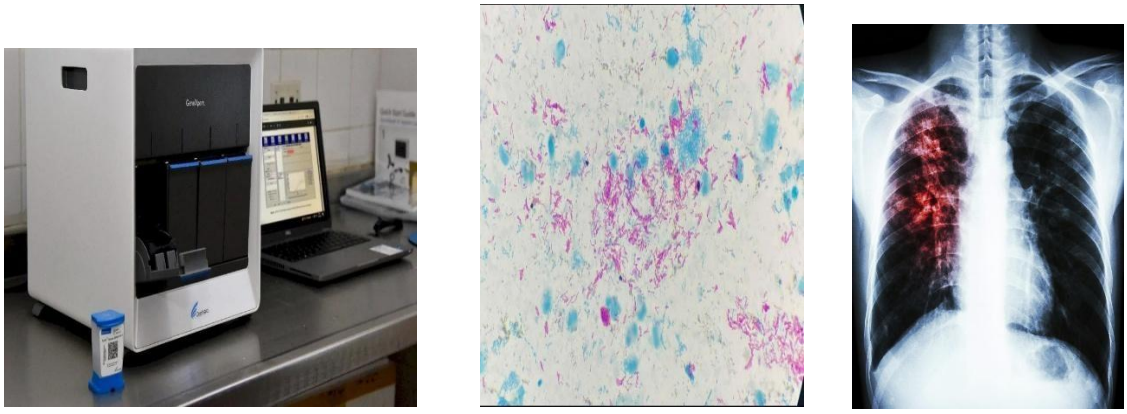


Figure 1.3. Common diagnostic methods for tuberculosis including sputum microscopy, chest radiography, and GeneXpert MTB/RIF.

1.4 Control of Drug-Resistant Tuberculosis

The emergence of multidrug-resistant tuberculosis (MDR-TB) and extensively drug-resistant tuberculosis (XDR-TB) has become a major challenge in TB control. Drug resistance develops mainly because of incomplete treatment, poor patient compliance, and inappropriate use of antibiotics. Effective monitoring, adherence to treatment guidelines, and rapid drugsusceptibility testing are necessary to prevent the spread of resistant strains.

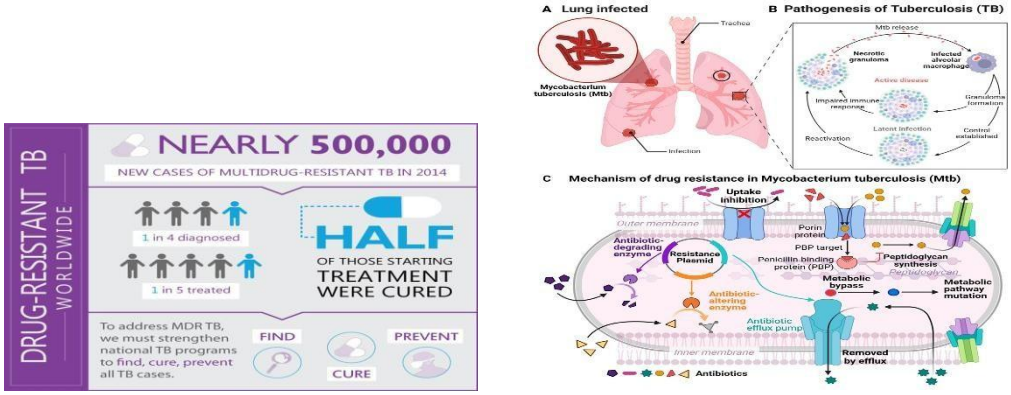


Figure 1.4. Development and spread of multidrug-resistant tuberculosis (MDR-TB).

1.5 Protection of High-Risk Populations

Certain populations are at greater risk of developing active tuberculosis, including individuals with HIV/AIDS, diabetes mellitus, chronic kidney disease, cancer, malnutrition, and weakened immune systems. Healthcare workers, elderly individuals, prisoners, migrants, and people living in overcrowded settings are also vulnerable. Targeted screening and preventive therapy among these groups are important components of TB control**.** [9,12]

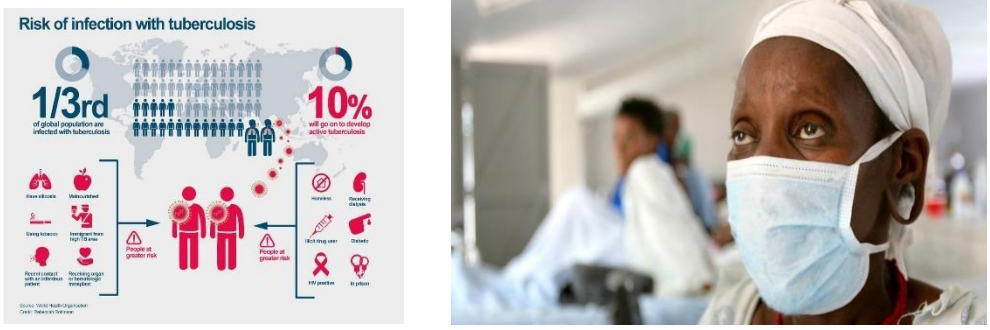
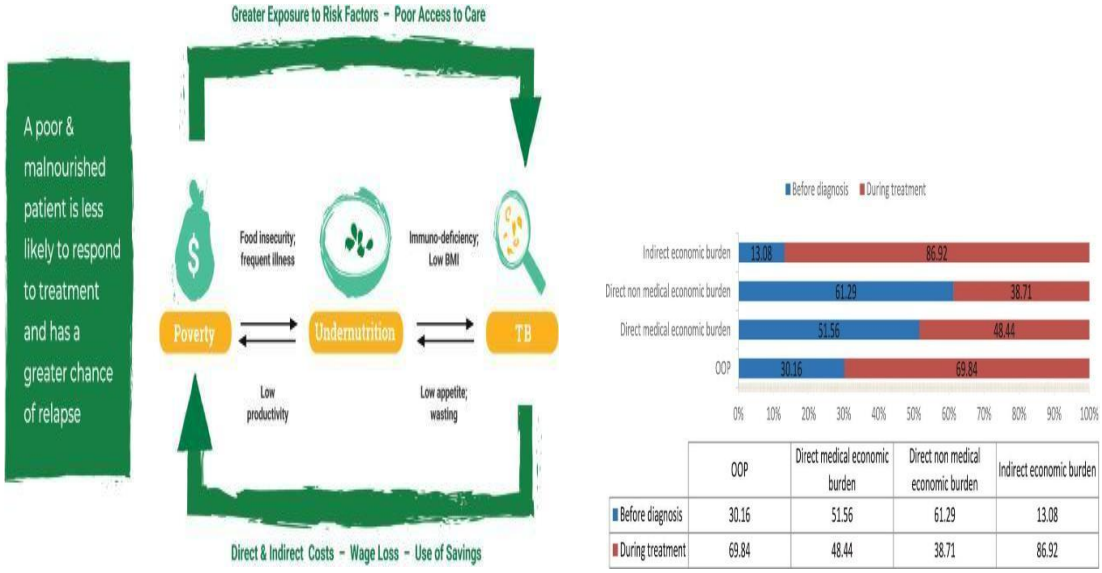


Figure 1.5. Populations at increased risk of tuberculosis infection and disease progression.

1.6 Reduction of Socioeconomic Burden

Tuberculosis affects not only health but also the social and economic well-being of individuals and families. Patients often experience loss of income, prolonged hospitalization, reduced productivity, and increased medical expenses. Effective tuberculosis control programs help reduce these financial burdens while improving quality of life and national economic productivity.



	OOP	Direct medical economic burden	Direct non medical economic burden	Indirect economic burden
Before diagnosis	30.16	51.56	61.29	13.08
During treatment	69.84	48.44	38.71	86.92

Figure 1.6. Economic and social consequences of tuberculosis on individuals and communities.

1.7.Improvement of Diagnostic Technologies

Conventional diagnostic methods have certain limitations in sensitivity and turnaround time. Advanced molecular diagnostic techniques, including GeneXpert, polymerase chain reaction (PCR), line probe assays, and whole-genome sequencing, provide rapid and accurate diagnosis. Continued research is necessary to develop affordable, sensitive, and point-of-care diagnostic tools that can be implemented in resource-limited settings.

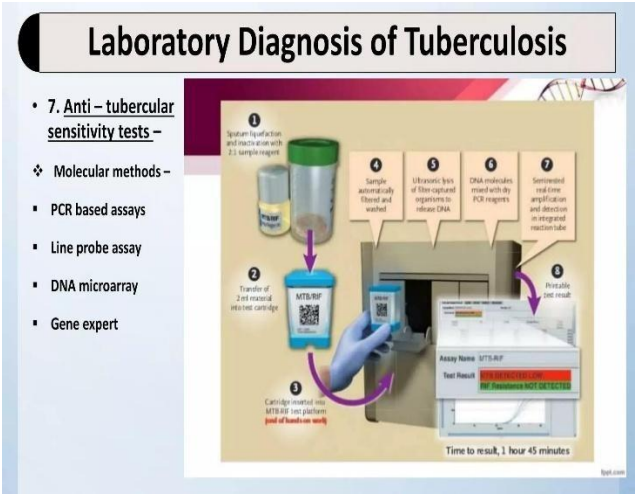


Figure 1.7. Advanced molecular diagnostic techniques used for rapid tuberculosis detection.

1.8 Development of New Drugs and Vaccines

The increasing prevalence of drug-resistant tuberculosis highlights the urgent need for new anti-tuberculosis drugs with improved safety and efficacy. Although the Bacillus Calmette– Guérin (BCG) vaccine provides protection against severe childhood tuberculosis, it offers limited protection against adult pulmonary TB. Ongoing research focuses on developing novel vaccines and shorter, more effective treatment regimens. [10,13,17]

Figure 1.8. Current anti-tuberculosis treatment and vaccine research.

1.9.Public Health Awareness and Community Participation

Public awareness plays a crucial role in tuberculosis control. Health education programs encourage early healthcare seeking, improve treatment adherence, reduce stigma associated with the disease, and promote healthy behaviors. Community participation strengthens surveillance, supports contact tracing, and enhances the success of national tuberculosis control programs.

Figure 3.9. Community participation and public awareness activities supporting tuberculosis control.

1.10Achieving the WHO End TB Strategy

The World Health Organization's End TB Strategy aims to reduce tuberculosis incidence and mortality through integrated patient-centered care, early diagnosis, effective treatment, preventive measures, and continued research. Achieving these goals requires strong political commitment, increased healthcare funding, international collaboration, and equitable access to quality healthcare services.

THE END TB STRATEGY

VISION	**A world free of tuberculosis** – zero deaths, disease and suffering due to tuberculosis			
GOAL	**End the global tuberculosis epidemic**			
INDICATORS	**MILESTONES**		**TARGETS**	
	2020	**2025**	**SDG 2030***	**END TB 2035**
Reduction in number of TB deaths compared with 2015 (%)	35%	75%	90%	95%
Reduction in TB incidence rate compared with 2015 (%)	20% (<85/100 000)	50% (<55/100 000)	80% (<20/100 000)	90% (<10/100 000)
TB-affected families facing catastrophic costs due to TB (%)	Zero	Zero	Zero	Zero

* The United Nations is in the process of defining a post-2015 development agenda. A set of "Sustainable Development Goals" (SDGs) are being developed for 2030; TB is proposed to be part of the agenda and goals.

12/21/2016 End TB Strategy 16

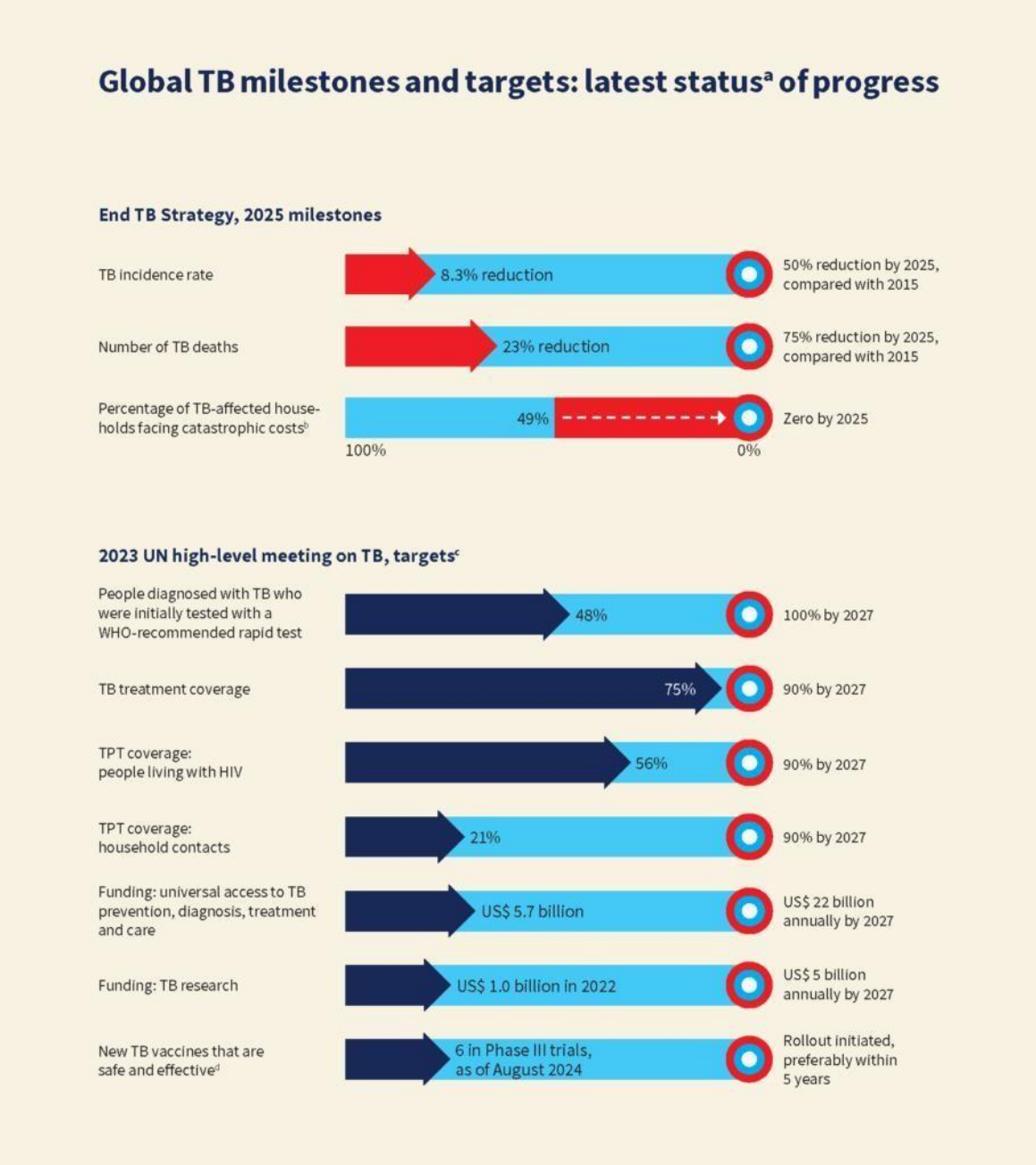


Figure 1.10. The WHO End TB Strategy emphasizing patient-centered care, prevention, diagnosis, treatment, and researc

1.11Future Perspectives

Future tuberculosis control depends on strengthening healthcare infrastructure, improving access to rapid diagnostics, developing effective vaccines, discovering novel therapeutic agents, implementing digital health technologies, and integrating artificial intelligence into disease diagnosis and surveillance. Collaborative research and sustained public health initiatives will be essential for achieving global tuberculosis elimination.

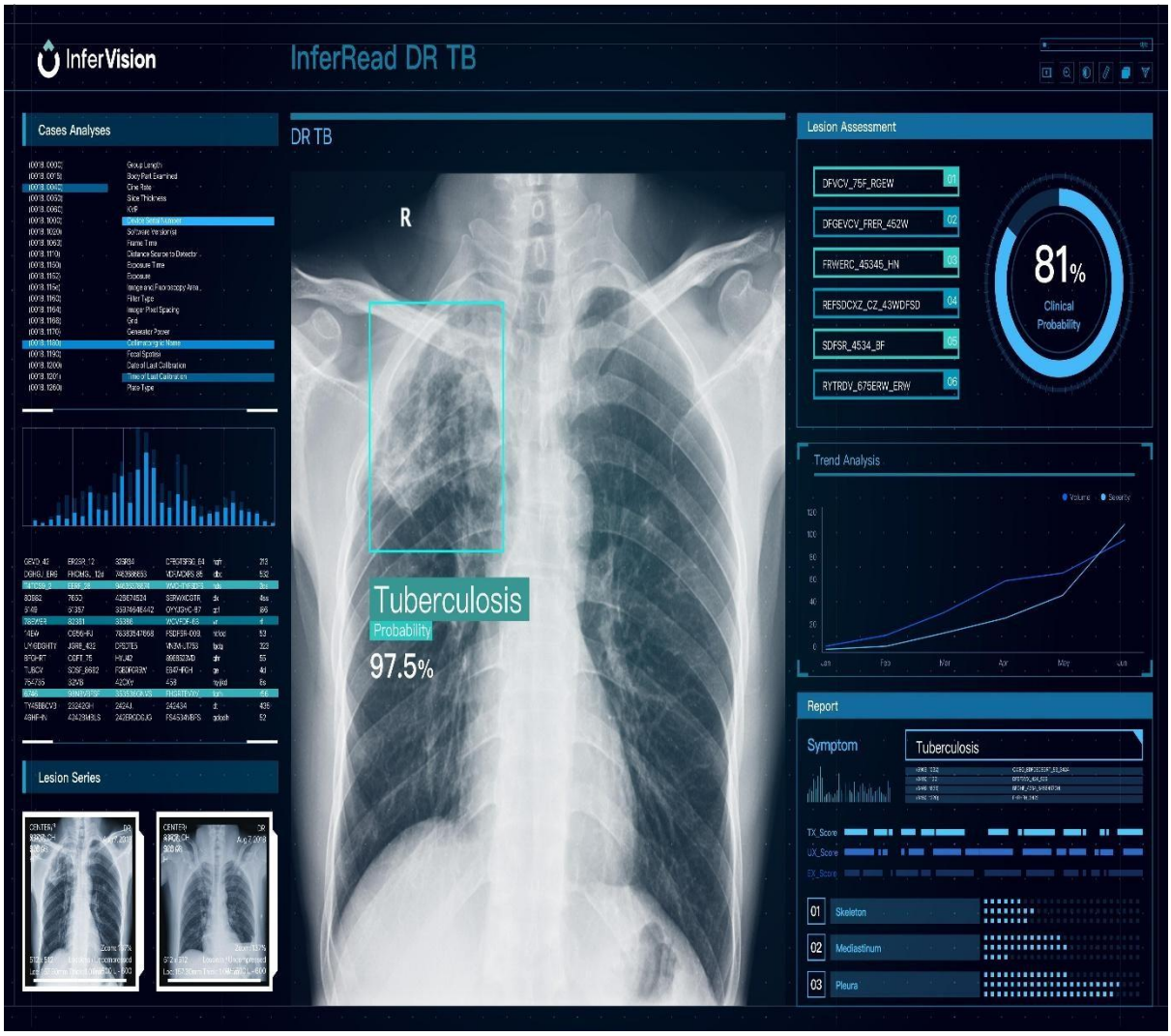
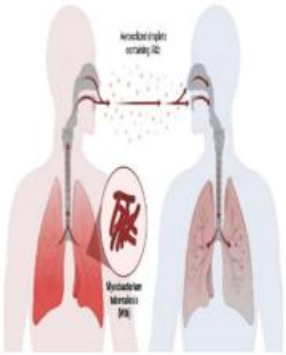


Figure 1.11. Emerging technologies including artificial intelligence, digital health, and advanced diagnostics for future tuberculosis control.

2 Mechanism of Tuberculosis Control (Step-by-Step)

The following step-by-step mechanism explains how tuberculosis spreads and how different control measures interrupt the transmission cycle. This section is suitable for inclusion in a review paper. [3,21]

Step 1: Release of *Mycobacterium tuberculosis* from an Infected Person



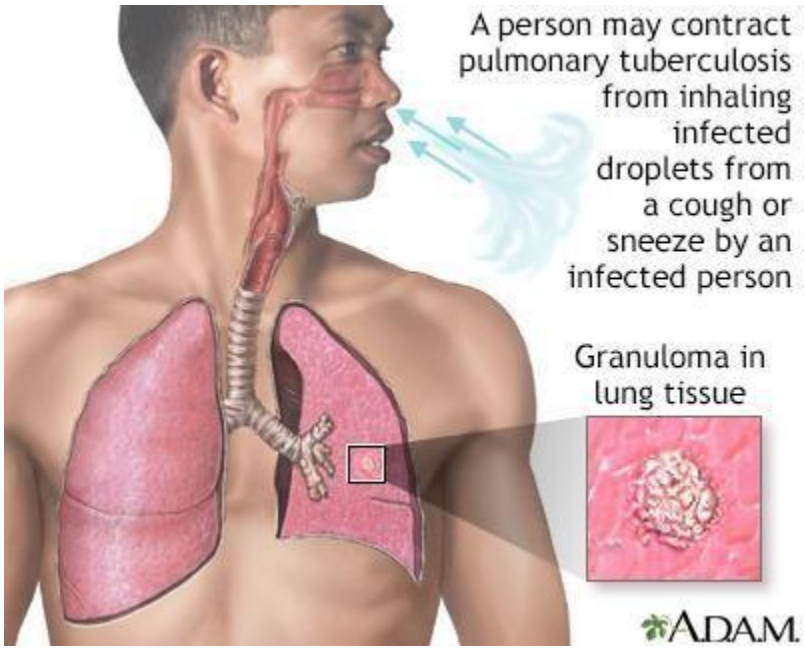
Explanation

Tuberculosis is caused by the bacterium *Mycobacterium tuberculosis*. Individuals with active pulmonary TB release infectious droplet nuclei into the air while coughing, sneezing, speaking, or singing. These microscopic droplets can remain suspended in the air for several hours, especially in poorly ventilated environments.

Key Points

- Source of infection: Active pulmonary TB patient
- Mode of spread: Airborne droplet nuclei
- High-risk settings: Crowded and poorly ventilated places

Step 2: Airborne Transmission to Healthy Individuals



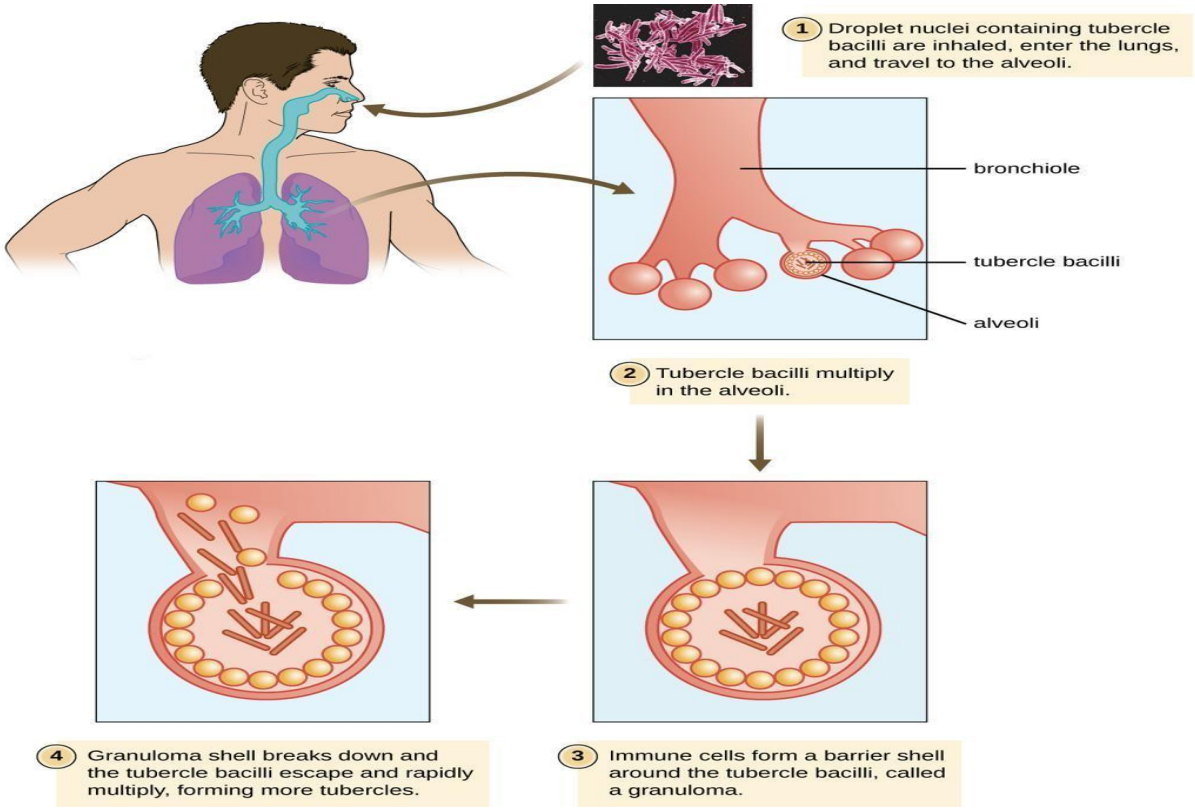
Explanation

Healthy individuals become infected when they inhale airborne droplets containing *M. tuberculosis*. The bacteria travel through the respiratory tract and reach the alveoli of the lungs.

Key Points

- Infection occurs through inhalation.
- Close and prolonged contact increases risk.
- Not spread through food, water, or touching surfaces.

Step 3: Infection of the Lungs



Explanation

After reaching the lungs, the bacteria are engulfed by alveolar macrophages.

However, *M. tuberculosis* can survive inside these immune cells and multiply.

The immune system responds by forming granulomas to contain the infection**.**

Key Points

- Bacteria invade lung alveoli.
- Macrophages engulf bacteria.
- Granuloma formation helps contain infection.
- Step 4: Treatment Adherence and DOT

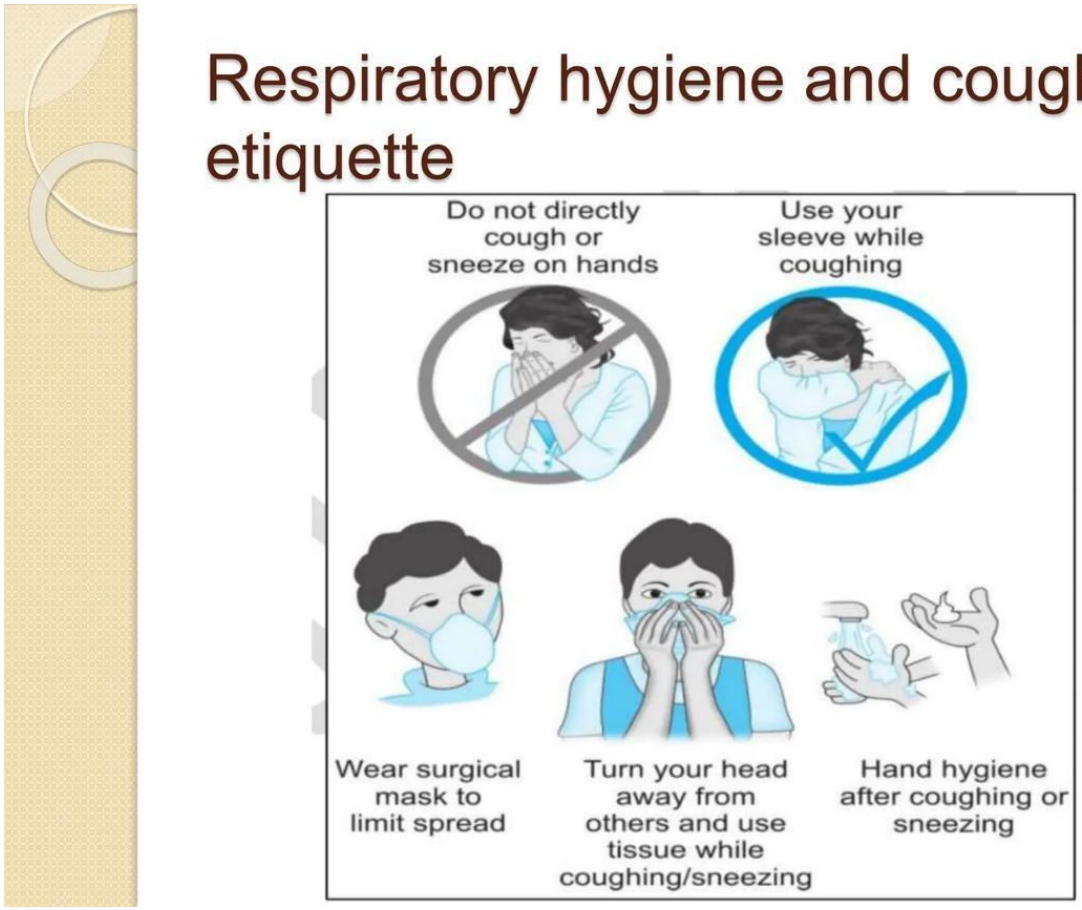
Explanation

Treatment adherence is essential because incomplete therapy may lead to relapse and drug resistance. Directly Observed Treatment (DOT) ensures that patients complete their prescribed medication course under healthcare supervision.

Advantages

- Higher treatment success • Reduced drug resistance
- Better patient compliance

Step 5: Infection Prevention and Control



Explanation

Various infection-control measures reduce TB transmission in hospitals and communities.

Preventive Measures

- Isolation of infectious patients
- Use of face masks
- Good ventilation
- Respiratory hygiene
- Contact tracing
- Screening of household contacts

5.Advantages and Disadvantages of Tuberculosis Control

Advantages

1. Reduces Disease Transmission

Effective tuberculosis (TB) control measures such as early diagnosis, prompt treatment, isolation of infectious patients, and contact tracing reduce the spread of *Mycobacterium tuberculosis* within communities.

2. Early Detection of TB Cases

Screening programs and advanced diagnostic techniques (e.g., GeneXpert MTB/RIF, PCR, and chest X-ray) enable early diagnosis, allowing treatment to begin before severe disease develops.

3. Improves Treatment Success

Standardized treatment regimens and Directly Observed Treatment (DOT) improve medication adherence, resulting in higher cure rates and lower relapse rates.

4. Prevents Drug-Resistant TB

Proper treatment monitoring and drug susceptibility testing help prevent the development and spread of multidrug-resistant (MDR-TB) and extensively drug-resistant tuberculosis (XDRTB).

5. Protects High-Risk Populations

Targeted screening and preventive therapy reduce the risk of active TB among vulnerable groups such as people with HIV/AIDS, diabetes, malnutrition, healthcare workers, and the elderly.

6. Reduces Mortality

Timely diagnosis and effective treatment significantly decrease TB-related deaths and improve patient survival.

7. Lowers Healthcare Costs

Early intervention reduces hospital admissions, complications, and the need for prolonged treatment, thereby lowering healthcare expenditure.

8. Improves Quality of Life

Successful TB treatment restores physical health, enables patients to return to work, and improves their overall quality of life.

9. Supports Public Health

National TB control programs strengthen disease surveillance, infection control, and community awareness, contributing to improved public health outcomes.

10. Contributes to Global TB Elimination

Comprehensive TB control supports the World Health Organization's End TB Strategy by reducing TB incidence, mortality, and transmission worldwide

Disadvantages

1. Long Duration of Treatment

Standard TB treatment usually lasts at least six months, while treatment for drug-resistant TB may continue for 18–24 months, making adherence challenging.

2. Drug Side Effects

Anti-tuberculosis drugs may cause adverse effects such as liver toxicity, skin rashes, nausea, vomiting, peripheral neuropathy, and visual disturbances.

3. Development of Drug Resistance

Incomplete treatment, poor patient compliance, or inappropriate antibiotic use can lead to MDR-TB and XDR-TB, which are more difficult and expensive to treat.

4. High Cost of Advanced Diagnostics

Modern diagnostic methods such as GeneXpert, PCR, and whole-genome sequencing require specialized equipment and trained personnel, limiting their availability in low-resource settings.

5. Limited Vaccine Protection

The Bacillus Calmette–Guérin (BCG) vaccine provides good protection against severe TB in children but offers limited protection against adult pulmonary tuberculosis.

6. Social Stigma

TB patients may experience discrimination, social isolation, and psychological stress, which can discourage them from seeking timely diagnosis and treatment.

7. Resource-Intensive Programs

Effective TB control requires continuous funding, trained healthcare workers, laboratory infrastructure, and public health surveillance systems.

8. Difficulty in Reaching Remote Areas

Limited healthcare access in rural and underserved regions may delay diagnosis and treatment, allowing continued disease transmission.

9. Risk of Reinfection

Even after successful treatment, individuals living in high-burden settings may become reinfected if exposure continues.

10. Challenges in Managing Drug-Resistant TB

MDR-TB and XDR-TB require longer treatment courses, more expensive medications, and intensive patient monitoring, resulting in lower treatment success rates compared with drugsensitive TB.

CONCLUSION

Tuberculosis (TB) continues to be one of the world's most significant infectious diseases, posing substantial health, social, and economic challenges despite being preventable and curable. The persistence of TB is driven by delayed diagnosis, poor treatment adherence, the emergence of multidrug-resistant (MDR-TB) and extensively drug-resistant tuberculosis (XDR-TB), limited healthcare access, and socioeconomic inequalities. Effective tuberculosis control therefore requires a comprehensive and multidisciplinary approach that integrates early diagnosis, prompt and appropriate treatment, infection prevention, vaccination, public awareness, and continuous surveillance.

Recent advances in molecular diagnostics, including GeneXpert, polymerase chain reaction (PCR), line probe assays, and whole-genome sequencing, have significantly improved the speed and accuracy of TB diagnosis. In addition, the development of novel anti-tuberculosis drugs, shorter treatment regimens, and vaccine research offers promising opportunities to enhance disease management and reduce the global burden of TB. Digital health technologies, artificial intelligence, and data-driven surveillance systems are also emerging as valuable tools for improving case detection, treatment monitoring, and public health decisionmaking.

Achieving the World Health Organization (WHO) End TB Strategy goals will require sustained political commitment, adequate financial investment, strengthened healthcare infrastructure, and international collaboration. Community participation, health education, and targeted interventions for high-risk populations are equally important to ensure equitable access to quality healthcare services. Continued research into improved diagnostics, effective vaccines, innovative therapeutics, and integrated public health strategies will be essential for overcoming existing challenges.

In conclusion, tuberculosis control is fundamental to reducing disease transmission, preventing drug resistance, lowering mortality, and improving global public health. A coordinated effort involving governments, healthcare professionals, researchers, and communities will be critical for achieving the long-term goal of tuberculosis elimination and ensuring a healthier future for populations worldwide. [6,8,10,17].

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HOW TO CITE: Thota Srinivas Rao , K.Pravallika* , R.Devika , S.K.Shabeena, K.Bhuvana Naga Saisri, Mohammed Zainab , Dr.B.Thangabalan, Ege Tuberculosis: A Comprehensive Review Of Epidemiology, Pathogenesis, Diagnosis, Treatment, And Prevention, Int. J. of Pharm. Sci., 2026, Vol 4, Issue 8,