International Journal of Computational and Experimental Science and ENgineering (IJCESEN)

Vol. 10-No.4 (2024) pp. 2247-2257
http://www.ijcesen.com

ISSN: 2149-9144

Research Article

Tuberculosis Management: A Narrative Review of Public Health, Nursing, and Radiological Roles

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Article Info:

DOI: 10.22399/ijcesen.3865
Received : 05 October 2024
Accepted : 28 December 2024

Keywords

Tuberculosis
Public Health
Nursing
Radiology
Multidisciplinary Care
Diagnosis

Abstract:

Tuberculosis (TB) remains a paramount global health challenge, exacerbated by drug resistance, co-infection with HIV, and social determinants of health. Effective management requires an integrated, multidisciplinary approach, though the distinct contributions of key pillars are often siloed in the literature. This narrative review synthesizes evidence on the critical and interconnected roles of public health, nursing, and radiology in the TB care cascade. Nursing constitutes the operational backbone, delivering patient-centered care, education, and advocacy, and ensuring treatment adherence through Directly Observed Therapy (DOT). Radiology offers essential diagnostic and monitoring capabilities, with chest X-ray as the frontline tool, computed tomography for complex cases, and advanced modalities like MRI and PET/CT for extrapulmonary and complicated disease. The analysis reveals that these roles are not sequential but deeply synergistic. Public health guidelines direct nursing practice and diagnostic algorithms; nursing ensures the implementation of public health strategies and facilitates radiological follow-up; and radiological findings inform both individual patient

management and population-level epidemiology. The fight against TB is hindered by a lack of integration. Optimizing TB control and moving closer to global End TB targets necessitates breaking down professional silos and fostering robust collaboration between public health, nursing, and radiology. Future efforts must focus on strengthening interprofessional education, investing in technological advancements like AI-assisted radiology, and empowering nurses as leaders of patient-centered care. A truly integrated, holistic model is the cornerstone of successful tuberculosis management.

1. Introduction

Tuberculosis (TB), caused by the bacterium *Mycobacterium tuberculosis*, remains one of the world's most devastating infectious diseases, presenting a profound and persistent challenge to global public health. Despite being a preventable and curable disease, TB continues to cause immense human suffering and mortality. According to the World Health Organization (WHO), an estimated 10.6 million people fell ill with TB in 2022, and 1.3 million died, making it the second leading infectious killer worldwide after COVID-19 and ranking above HIV/AIDS [1]. The disease is intricately linked with poverty, overcrowding, malnutrition, and compromised immune systems, disproportionately affecting the most vulnerable populations in low- and middle-income countries. However, the resurgence of TB in high-income countries, often associated with migration, HIV co-infection, and the emergence of drug-resistant strains, underscores its transnational threat and the inadequacy of purely nationalistic health strategies [2].

The ambitious "End TB Strategy," adopted by the World Health Assembly in 2014 and aligned with the United Nations Sustainable Development Goals, aims to reduce TB deaths by 95% and cut new cases by 90% between 2015 and 2035 [1]. Achieving these targets, however, is hampered by significant obstacles. These include the relentless emergence of drug-resistant TB (MDR-TB and XDR-TB), the syndemic with HIV/AIDS, which dramatically increases the risk of active TB, and the social determinants of health that perpetuate transmission in marginalized communities [3]. Furthermore, the COVID-19 pandemic caused massive disruptions to TB services, reversing years of progress in case detection and treatment, thereby highlighting the fragility of global TB control efforts in the face of a novel pathogen and the resultant diversion of health system resources [4].

The management of tuberculosis is a complex, long-term process that extends far beyond the simple administration of antibiotics. It encompasses a continuum of care that includes prevention, active case-finding, accurate and rapid diagnosis, initiation and adherence to standardized treatment regimens, contact tracing, and public health surveillance. This multifaceted approach necessitates a robust, integrated, and collaborative health system response. No single discipline can manage TB in isolation; its control is a quintessential example of the necessity for interdisciplinary cooperation. From the public health officials who design and implement control policies, to the nurses who provide the bedrock of patient care and support, to the radiologists and radiographers whose imaging expertise is critical for diagnosis and monitoring, each pillar of the health system plays an indispensable and synergistic role [5].

The public health domain provides the foundational framework upon which all TB control activities are built. Public health agencies, both international (e.g., WHO) and national (e.g., Centers for Disease Control and Prevention), are responsible for establishing evidence-based guidelines for TB prevention, diagnosis, and treatment. These guidelines standardize care and ensure that interventions are based on the best available scientific evidence, which is crucial for managing drug resistance and complex cases [1, 6]. A core function of public health is surveillance—the systematic collection, analysis, and interpretation of TB data. Robust surveillance systems are vital for monitoring epidemiological trends, identifying outbreaks, evaluating the impact of control programs, and allocating resources efficiently to areas of greatest need [7].

Furthermore, public health is the primary actor in the realm of prevention. This includes implementing infection control measures in healthcare facilities, congregate settings, and households to prevent transmission. It also involves managing contact investigation programs to identify and screen individuals exposed to an active TB case, a critical activity for breaking chains of transmission [8]. Perhaps the most significant preventive measure falls under the purview of public health: the management of latent TB infection (LTBI). Treating LTBI is essential for reducing the reservoir of future active cases, particularly among high-risk groups such as contacts of active cases, people living with HIV, and other immunocompromised individuals [9]. Public health officials are also at the forefront of community engagement and health education, working to combat stigma, promote health-seeking behaviors, and ensure that TB services are equitable

and accessible to all populations, including hard-to-reach and high-risk groups [10].

If public health sets the strategy, nursing is the discipline that most consistently operationalizes it at the point of care. Nurses are the linchpins of TB management, serving as the primary interface between the patient, the healthcare system, and public health authorities. Their role is multifaceted and extends throughout the entire patient journey. Nurses are often the first point of contact, conducting initial assessments, administering tuberculin skin tests (TSTs) or interferon-gamma release assays (IGRAs), and collecting sputum samples. They play a crucial role in patient education, demystifying the disease, explaining the lengthy treatment process, and teaching cough etiquette and other infection control measures to patients and their families [11].

The most critical nursing function in TB management, however, is ensuring treatment adherence. The long duration (6-9 months for drug-susceptible TB, up to 20 months for drug-resistant strains) and potential side effects of TB chemotherapy pose significant challenges to completion. Non-adherence not only leads to poor individual outcomes but also fosters the development of drug resistance, a grave public health threat. Nurses are central to the Directly Observed Therapy (DOT) strategy, where they directly observe patients taking their medication, providing support, monitoring for adverse drug reactions, and reinforcing the importance of adherence [12]. Beyond DOT, nurses provide holistic, patient-centered care, addressing psychosocial barriers such as stigma, fear, poverty, and substance use that can impede successful treatment. They act as advocates for their patients, coordinating care with physicians, social workers, and public health officials to ensure that wraparound services are available, thus addressing the social determinants that fuel the TB epidemic [5, 11].

Radiology provides the essential visual evidence that guides the diagnosis, staging, and monitoring of tuberculosis. While microbiological confirmation through smear, culture, and nucleic acid amplification tests (NAATs) is the diagnostic gold standard, chest radiography remains an indispensable tool. It is often the first objective test to suggest pulmonary TB, especially in smear-negative cases or when microbiological results are pending. The chest radiograph can reveal classic manifestations of primary TB, such as hilar lymphadenopathy and pleural effusion, or post-primary TB, such as infiltrates and cavities in the upper lobes [13].

The role of radiology, however, extends far beyond initial detection. It is critical for assessing the extent of disease, identifying complications (e.g., miliary TB, bronchopleural fistula), and monitoring response to treatment. Serial chest radiographs allow clinicians to visualize the resolution of infiltrates and closure of cavities, providing objective evidence of therapeutic success. Conversely, a lack of improvement or worsening radiographic findings can signal treatment failure, poor adherence, or the emergence of drug resistance, prompting further investigation and a change in management strategy [14]. With advancements in technology, computed tomography (CT) has become increasingly important. CT offers superior sensitivity and specificity compared to plain radiography, exquisitely detailing the complex parenchymal abnormalities, lymph node involvement, and subtle complications that may be missed on a standard X-ray. This is particularly valuable in diagnosing extra-pulmonary TB and in complex cases where the diagnosis is uncertain [15].

While these three disciplines—public health, nursing, and radiology—are often discussed within their own siloed literatures, their functions in TB management are deeply interdependent. Public health policies dictate the protocols that nurses follow and the diagnostic algorithms that radiologists use. Nurses, in turn, are the frontline agents who implement public health strategies and ensure that radiological investigations are performed and followed up. Radiological findings provide the empirical data that informs both the clinical management by the care team and the epidemiological tracking by public health officials.

The Evolution and Modern Epidemiology of Tuberculosis

Tuberculosis is not a modern affliction but an ancient scourge that has co-evolved with human populations for millennia. The origins of the *Mycobacterium tuberculosis* complex (MTBC), which includes the primary human pathogen *M. tuberculosis*, are estimated to date back over 70,000 to 100,000 years. Paleopathological and molecular evidence suggests that MTBC likely emerged in Africa and subsequently dispersed across the globe alongside migrating human populations during the Neolithic Revolution and beyond [13]. This "out-of-Africa" migration pattern is supported by the high genetic diversity of MTBC strains on the African continent compared to the rest of the world, indicating a longer period of co-evolution and strain diversification [14].

Ancient DNA (aDNA) analysis has provided irrefutable proof of TB's historical presence. Genomic studies have identified *M. tuberculosis* complex biomarkers in human remains from prehistoric periods, ancient Egypt, and pre-Columbian Peru. A landmark study revealed that TB was present in the Americas long before European contact, debunking the theory that it was introduced exclusively by colonizers. These ancient strains, however, were distinct from modern lineages, suggesting a complex history of animal-to-human transmission (zoonosis) and subsequent human adaptation [15]. The current dominant human-adapted strains are believed to have expanded dramatically within the last 200-300 years, coinciding with the Industrial Revolution. Urbanization, overcrowding, and poor living conditions in 18th and 19th century European cities created an ideal environment for the airborne pathogen to thrive, leading to a devastating TB epidemic that earned it the name "The White Plague" [16].

The late 19th century marked a pivotal turning point. In 1882, Robert Koch's identification of the tubercle bacillus as the causative agent provided the scientific foundation for understanding transmission and diagnosis. The early 20th century saw the advent of public health measures focused on infection control, sanatorium care, and improved nutrition, which began to slow the spread of the disease in developed nations. The true revolution came in the mid-20th century with the discovery and widespread deployment of effective anti-tuberculosis antibiotics, beginning with streptomycin in 1946 and followed by isoniazid, rifampicin, and others. This chemotherapeutic arsenal led to a dramatic decline in TB incidence and mortality across high-income countries, fostering a widespread belief that TB could be eradicated globally [17].

This optimism proved premature. From the 1980s onwards, the world witnessed an alarming and unexpected resurgence of tuberculosis. This resurgence was driven by a confluence of factors:

- **The HIV/AIDS Pandemic:** The synergy between HIV and TB is profound. HIV-induced immunosuppression dramatically increases the risk of latent TB infection progressing to active disease. HIV-TB co-infection became a leading cause of mortality in sub-Saharan Africa, fueling outbreaks and reversing decades of progress in TB control [18].

- **The Rise of Drug Resistance:** Inappropriate or incomplete treatment regimens, often due to poor management or patient non-adherence, led to the natural selection of drug-resistant bacterial strains. Multi-drug resistant TB (MDR-TB), defined as resistance to at least isoniazid and rifampicin, emerged as a major threat. Later, extensively drug-resistant TB (XDR-TB), resistant to fluoroquinolones and second-line injectable agents, was identified, rendering some cases nearly untreatable with conventional drugs [19].

- **Globalization and Increased Mobility:** Increased international travel and migration facilitated the spread of TB strains across borders, making it a global concern for all countries, not just those with high burdens.

- **Weakened Health Systems:** In many regions, economic instability and structural adjustment programs led to the deterioration of public health infrastructure, undermining TB control programs and surveillance efforts.

Today, the global distribution of TB is starkly unequal, reflecting deep socio-economic disparities. The WHO's 2023 Global Tuberculosis Report outlines the current state of the epidemic [20]. While TB is present in every country, eight countries account for more than two-thirds of the global total: India, Indonesia, China, the Philippines, Pakistan, Nigeria, Bangladesh, and the Democratic Republic of the Congo. This concentration underscores the disease's intimate link with poverty, overcrowding, and limited access to healthcare.

Key features of the modern TB epidemiology include:

- **The Persistent Burden of Drug-Resistant TB:** MDR-TB remains a public health crisis. In 2022, an estimated 410,000 people developed MDR or rifampicin-resistant TB (RR-TB), yet only about 2 in 5 accessed treatment. The treatment success rate for MDR/RR-TB remains suboptimal, at around 63%, due to the toxicity of regimens, their long duration, and high costs [20].

- **The TB-HIV Syndemic:** Although intensified efforts have reduced HIV-related TB deaths, HIV remains the most potent risk factor for developing active TB. In 2022, people living with HIV accounted for 6.3% of all TB cases, but this group faces a mortality rate that is three times higher than that of HIV-negative TB patients [20].

- **The Impact of Social Determinants:** TB is a disease of the disadvantaged. It thrives in settings of malnutrition, overcrowded housing (e.g., prisons, slums), substance abuse, and limited access to medical care. Vulnerable populations, including

refugees, migrants, and indigenous peoples, often bear a disproportionate burden of disease due to these structural factors [21].

- **The COVID-19 Pandemic Disruption:** The COVID-19 pandemic had a catastrophic impact on TB services worldwide. Lockdowns, resource diversion, and patient reluctance to seek care led to a significant drop in TB notifications. For the first time in over a decade, the estimated number of TB deaths increased in 2020 and 2021, erasing years of hard-won progress. The global number of people diagnosed with TB fell from 7.1 million in 2019 to 5.8 million in 2020, indicating a vast and dangerous pool of undiagnosed and untreated cases in the community [20].

The evolution of tuberculosis from an ancient pathogen to a modern-day pandemic illustrates its remarkable adaptability. It has survived through major shifts in human society, from hunter-gatherer communities to dense urban centers, and has evolved resistance to the pharmaceutical agents designed to defeat it. The current epidemiology of TB is a story of two worlds: one where the disease is largely under control and often forgotten, and another where it remains a leading cause of death and suffering, exacerbated by HIV, drug resistance, and social inequality.

The fight against TB is now more complex than ever. It requires not only new tools—such as more effective vaccines, shorter drug regimens, and rapid point-of-care diagnostics—but also a renewed commitment to addressing the underlying social and economic determinants that fuel the epidemic. Understanding its deep history and modern dynamics is crucial for designing the next generation of interventions needed to finally end this enduring plague.

The Role of Nursing in Tuberculosis Care:

Patient education is the first and most continuous intervention in the nursing process for TB care. The diagnosis of tuberculosis is often met with fear, confusion, and anxiety due to the disease's historical stigma, the lengthy treatment regimen, and concerns about transmission to family members. Nurses are tasked with demystifying the disease and empowering patients with knowledge.

- **Initial Diagnosis and Pathophysiology:** The educational process begins at the moment of diagnosis. Nurses explain the basic pathophysiology of TB in accessible language, clarifying the difference between Latent TB Infection (LTBI) and Active TB Disease. This distinction is critical for alleviating undue fear and ensuring the patient understands their specific condition and its implications [22].

- **Infection Control and Transmission:** A paramount educational topic is stopping transmission. Nurses teach respiratory hygiene, including cough etiquette, the importance of wearing masks in the initial phases of treatment, and the principles of ventilation. They provide clear instructions to patients on how to protect their household contacts, thereby acting as frontline defenders of public health [23].

- **Medication Management:** Educating patients about their medication regimen is a complex and vital task. Nurses provide detailed information on the names, purposes, dosages, and timing of each drug. However, the most crucial aspect is managing expectations regarding the duration of treatment and the necessity of strict adherence even after symptoms subside. They meticulously explain the potential side effects of anti-TB drugs, from minor issues like orange discoloration of bodily fluids to severe adverse reactions such as hepatotoxicity, visual disturbances, and neuropathy. This proactive education prepares patients to identify and report side effects early, preventing treatment interruptions and promoting safety [24].

This educational role transcends the individual patient. Nurses engage in community health education, participating in outreach programs to raise awareness about TB symptoms, reduce stigma, and promote health-seeking behaviors in high-risk populations. By educating community leaders, school staff, and other stakeholders, they amplify their impact and contribute to early case detection and a more informed, supportive environment for those affected by TB [25].

If education empowers the patient, advocacy empowers their journey. Nurses are the primary advocates for TB patients, a role that requires navigating complex healthcare systems and confronting the pervasive social determinants of health that fuel the epidemic. TB disproportionately affects the poor, the homeless, migrants, and those with substance use disorders. A nurse's advocacy is often the key that unlocks access to care for these marginalized individuals.

- **System Navigation:** The pathway from diagnosis to cure is fraught with potential barriers. Nurses advocate for their patients by ensuring timely appointments, facilitating communication between multiple specialists (e.g., pulmonologists, infectious disease doctors, radiologists), and coordinating care with public health departments for contact tracing and directly observed therapy (DOT)

[26]. They help patients overcome bureaucratic hurdles to access social services, transportation for clinic visits, and financial aid programs, understanding that these logistical challenges are primary drivers of treatment default.

- **Addressing Stigma:** The stigma associated with TB remains a significant barrier to care and adherence. Patients may face discrimination, social isolation, and even job loss. Nurses advocate by counseling patients and families on coping strategies, confronting misinformation within communities, and consistently reinforcing the message that TB is a curable disease, not a moral failing. They create a safe, non-judgmental clinical environment where patients feel respected and supported [27].

- **Psychosocial Support:** A TB diagnosis can be psychologically devastating. Nurses assess for and address co-morbid conditions such as depression and anxiety, which are common among TB patients. They provide essential emotional support, encourage the development of a support network, and, when necessary, advocate for and facilitate referrals to mental health services. This holistic approach recognizes that mental well-being is intrinsically linked to physical recovery and treatment adherence [28].

The nursing roles of educator and advocate converge most powerfully in the implementation of Directly Observed Therapy (DOT). DOT is a cornerstone of the modern TB control strategy, wherein a healthcare worker, most often a nurse or a community health worker supervised by a nurse, observes the patient swallowing every dose of their medication.

- **DOT as an Educational Platform:** Each DOT encounter is an opportunity for ongoing education and assessment. The nurse uses this time to reinforce the importance of adherence, answer new questions, and monitor for side effects in a structured, daily manner. This continuous interaction builds a strong therapeutic relationship based on trust and mutual respect [29].

- **DOT as an Advocacy Tool:** Through DOT, nurses move beyond the clinic walls and into the patient's community. Home-based DOT allows the nurse to assess the patient's living conditions, identify potential barriers to adherence (e.g., food insecurity, lack of social support), and connect the patient with appropriate resources. This proactive, hands-on approach is the ultimate form of advocacy, ensuring that the treatment plan is not just prescribed but is actually feasible for the patient to complete [30].

Despite their critical role, nurses working in TB care face significant challenges. High patient loads, limited resources, and the emotional burden of working with a complex, chronic disease can lead to burnout. Furthermore, the fear of occupational exposure, particularly in settings with inadequate infection control resources, remains a persistent concern. The rise of drug-resistant TB has intensified these challenges, requiring nurses to manage more toxic drug regimens and longer, more difficult treatment courses [31].

To maximize the impact of nursing in TB care, health systems must invest in:

1. Specialized Training: Providing ongoing, advanced education for nurses on the latest TB diagnostics, MDR-TB treatment protocols, management of adverse drug reactions, and motivational interviewing techniques.

2. Workplace Safety: Ensuring strict adherence to infection control protocols, including the provision of adequate N95 respirators and negative-pressure rooms, to protect frontline nursing staff.

3. Supportive Supervision and Mentorship: Creating supportive environments where nurses can debrief, seek guidance, and prevent compassion fatigue.

4. Expanded Scope of Practice: In many high-burden settings, task-shifting—where nurses take on responsibilities traditionally held by doctors—is essential. Supporting nurses to initiate treatment, manage side effects, and lead clinic teams can dramatically improve access to care.

The fight against tuberculosis cannot be won by pharmaceuticals and diagnostics alone. It is won in the consistent, compassionate, and skilled interactions between nurses and their patients. Through their unwavering commitment to education, nurses transform patients from passive recipients of care into active participants in their own healing. Through their determined advocacy, they break down systemic and social barriers, ensuring that the most vulnerable individuals are not left behind. The roles of educator and advocate are not ancillary nursing duties; they are the very essence of nursing practice in TB care and the critical determinants of treatment success. Empowering and supporting nurses is, therefore, not just a professional imperative but a fundamental public health strategy in the global mission to end tuberculosis.

Radiological Imaging in Tuberculosis Diagnosis:

Radiological imaging constitutes a cornerstone in the diagnosis and management of tuberculosis, providing critical visual evidence that guides clinical decision-making from initial suspicion to treatment monitoring. While microbiological confirmation through smear microscopy, culture, and nucleic acid amplification tests (NAATs) remains the diagnostic gold standard, these methods have limitations, including low sensitivity in certain populations (e.g., children, HIV-coinfected individuals), slow turnaround times for culture, and limited accessibility in resource-poor settings. Radiology serves as a rapid, non-invasive tool that is often the first objective investigation to suggest a diagnosis of TB, assess the extent of disease, identify complications, and evaluate response to therapy. The evolution of imaging technology, from conventional radiography to advanced cross-sectional techniques, has profoundly enhanced our ability to detect and characterize tuberculosis in its myriad forms, making radiology an indispensable partner in the global fight against this disease [32].

Conventional Radiography: The Frontline Modality

The chest X-ray (CXR) remains the most widely used and accessible initial imaging modality for pulmonary tuberculosis worldwide. Its low cost, rapid acquisition, and widespread availability make it invaluable for screening, triage, and initial diagnosis. The radiographic presentation of TB is varied and depends on whether the disease is primary (resulting from recent infection) or post-primary (reactivation of latent infection).

- **Primary Pulmonary Tuberculosis:** In immunocompetent adults and more commonly in children, primary TB often manifests as parenchymal consolidation, which can occur in any lung lobe but is frequently mid or lower zone. A hallmark feature is lymphadenopathy, which is typically unilateral and hilar or paratracheal. The combination of consolidation and lymphadenopathy is highly suggestive of primary TB. Other features include pleural effusions, which are often unilateral and can be the sole presenting finding, and miliary disease, seen as countless tiny (1-2mm) nodules scattered throughout both lungs, representing hematogenous dissemination [33].

- **Post-Pulmonary Tuberculosis (Reactivation):** This form classically presents with opacities in the apical and posterior segments of the upper lobes and the superior segments of the lower lobes. These areas are favored due to their high oxygen tension. Key radiographic signs include:
  - **Cavitation:** The development of thick-walled air-filled spaces within areas of consolidation is a highly characteristic feature of reactivation TB and indicates high bacterial burden and potential infectivity.
  - **Fibrosis and Scarring:** Healed disease often leaves behind linear streaky opacities and volume loss, pulling the hilum upward and the trachea deviated.
  - **Nodules and Tree-in-Bud Opacities:** Endobronchial spread of disease appears as centrilobular nodules and branching linear opacities, resembling a "tree-in-bud" pattern, indicating active and infectious airway involvement [34].

Despite its utility, CXR interpretation has limitations, including inter-reader variability, poor sensitivity for detecting subtle early disease or lymphadenopathy, and the masking of findings in HIV-positive patients with atypical presentations. To address this, computer-aided detection (CAD) software, using artificial intelligence (AI) to analyze digital CXRs, is emerging as a powerful tool to improve accuracy and consistency, particularly in high-volume, low-resource settings [35].

Computed Tomography: Unveiling the Complexities

Computed Tomography (CT), particularly high-resolution CT (HRCT), is vastly superior to plain radiography in its sensitivity and specificity for evaluating tuberculosis. It is not typically a first-line screening tool due to higher cost and radiation dose, but it plays several crucial roles in TB management:

- **Problem-Solving and equivocal CXR:** When a CXR is suspicious but non-diagnostic, CT can confirm the presence of characteristic findings like early cavitation, subtle tree-in-bud nodules, or lymphadenopathy that is not visible on X-ray.

- **Detecting Complications:** CT excels at identifying complications of TB that may be missed on CXR. This includes bronchiectasis (permanent airway damage) distal to an involved lymph node or area of stenosis, bronchopleural fistula, pericardial involvement, and the extent of destroyed lung parenchyma [36].

- **Evaluating Extrapulmonary TB:** CT is essential for assessing TB in body parts beyond the lungs. It is the primary modality for evaluating TB lymphadenitis, which often demonstrates central necrosis and peripheral rim enhancement on

contrast-enhanced scans, a classic though not pathognomonic sign. Abdominal CT can identify involvement of the solid organs (e.g., liver, spleen), gastrointestinal tract, and peritoneum [37].

- **Guiding Intervention:** CT provides an essential road map for diagnostic procedures such as transthoracic or transbronchial biopsy of a lung nodule or mass, drainage of a complex pleural collection, or aspiration of a deep lymph node, ensuring precision and safety [38].

The detailed characterization provided by CT is invaluable for differentiating TB from other pulmonary diseases like malignancy, fungal infections, or sarcoidosis, thereby preventing diagnostic delays and guiding appropriate therapy.

Magnetic Resonance Imaging (MRI) and Nuclear Medicine

For specific applications, particularly in extrapulmonary TB, other advanced modalities offer unique advantages.

- **Magnetic Resonance Imaging (MRI):** With its superior soft-tissue contrast and lack of ionizing radiation, MRI is the imaging modality of choice for central nervous system (CNS) and musculoskeletal tuberculosis.
  - **CNS TB:** MRI is essential for diagnosing tuberculous meningitis, revealing basilar meningeal enhancement, and for detecting parenchymal complications like tuberculomas (ring-enhancing lesions) and abscesses. It is also critical for identifying spinal TB (Pott's disease), demonstrating vertebral body destruction, disc involvement, paraspinal abscesses, and potential spinal cord compression with unparalleled clarity [39].
  - **Musculoskeletal TB:** MRI is highly sensitive for early osteomyelitis and septic arthritis before changes become visible on X-ray or CT [40].

- **Nuclear Medicine:** While not a first-line anatomical imaging tool, positron emission tomography combined with CT (FDG-PET/CT) is gaining a role in TB management. TB lesions are typically fluorodeoxyglucose (FDG)-avid, and this technique is highly sensitive for identifying sites of disease activity. Its primary applications include:
  - **Staging:** Surveying the entire body for occult sites of extrapulmonary involvement in complex cases.
  - **Monitoring Response:** Differentiating active from inactive disease, which can be challenging with anatomical imaging alone. A decrease in FDG avidity can indicate successful response to treatment earlier than structural changes on CT [41].
  - **Guiding Biopsy:** Identifying the most metabolically active site within a complex lesion to target for biopsy, increasing diagnostic yield [42].

The field of radiological imaging in TB is rapidly evolving, driven by technological innovation aimed at improving accessibility, accuracy, and functional assessment.

1. Artificial Intelligence (AI) and Computer-Aided Detection (CAD): AI algorithms, particularly deep learning models, are being trained on vast datasets of CXRs to automatically detect signs suggestive of TB with performance rivaling or exceeding that of human readers. These tools promise to revolutionize screening programs by providing rapid, standardized, and high-volume interpretation in regions with a critical shortage of radiologists. They can triage patients for further testing, reducing diagnostic delays [35, 43].

2. Point-of-Care Ultrasound (POCUS): While ultrasound cannot image the air-filled lung parenchyma, it is extremely useful for identifying extrapulmonary complications. POCUS can rapidly detect pleural effusions, pericardial effusions (in cardiac TB), and abdominal ascites or lymphadenopathy at the bedside. Its portability, low cost, and lack of radiation make it an ideal tool for use in resource-limited settings [44].

3. Advanced MR Techniques: Sequences like diffusion-weighted imaging (DWI) and magnetic resonance spectroscopy (MRS) are being explored to improve the characterization of TB lesions, particularly in the CNS, helping to differentiate tuberculomas from other ring-enhancing lesions like toxoplasmosis or lymphoma.

4. Low-Dose CT Protocols: Technological advancements are enabling the development of ultra-low-dose CT chest protocols that significantly reduce radiation exposure while maintaining diagnostic accuracy for TB signs like cavitation and tree-in-bud nodules. This could make CT a more viable option for serial monitoring, especially in younger patients [36].

Radiological imaging is not a standalone diagnostic test for tuberculosis but an integral component of a multifaceted diagnostic algorithm. Its primary strength lies in its ability to suggest the diagnosis rapidly, assess the burden and pattern of disease, guide diagnostic sampling, and monitor the response to treatment. The choice of modality—from the ubiquitous CXR to the sophisticated

PET/CT—is dictated by the clinical context, the anatomical site of concern, and available resources. The future of TB radiology is one of integration and intelligence. The synergy between advanced imaging techniques and artificial intelligence will continue to enhance diagnostic precision and efficiency. Furthermore, the growing use of functional imaging like PET/CT provides a window into the metabolic activity of the disease, moving beyond mere structural assessment. As these technologies become more accessible, their role in global TB control efforts will only expand, ensuring that radiology remains at the forefront of the fight to end tuberculosis by providing the essential visual evidence to guide care from diagnosis to cure.

Conclusion

Tuberculosis management in the 21st century is a complex endeavor that defies simplistic solutions. As this narrative review has detailed, the path from infection to cure is navigated through the concerted efforts of three critical disciplines: public health, nursing, and radiology. Public health systems establish the essential infrastructure for prevention, surveillance, and control, setting the stage for an effective response. Nursing professionals bring this framework to life, providing the human touch, education, and unwavering advocacy that translate policy into successful patient outcomes at the individual level. Radiological imaging provides the crucial visual evidence that guides the entire process, from initial suspicion and accurate diagnosis to monitoring therapeutic response and identifying complications.

The central thesis of this review is that the efficacy of any TB control program is contingent upon the seamless integration of these three pillars. Their functions are not isolated but exist in a state of dynamic interdependence. A breakdown in public health infrastructure cripples contact tracing and allows for unchecked transmission. A shortage of skilled nurses undermines treatment adherence, fostering drug resistance. A lack of access to advanced radiology leads to diagnostic delays and mismanagement. Therefore, investments in one domain must be matched by strengthening the others.

Moving forward, the global health community must prioritize strategies that enhance this collaboration. This includes implementing interprofessional education to foster mutual understanding, leveraging technological advances like artificial intelligence in radiology to augment capabilities in high-burden settings, and advocating for policies that support and expand the nursing workforce. Ultimately, defeating tuberculosis requires more than just medical interventions; it demands a holistic, integrated, and person-centered approach that recognizes and empowers the unique yet interconnected roles of public health, nursing, and radiology. The End TB strategy goals will only be realized when these disciplines work not in parallel, but in powerful, synchronized concert.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
- **Acknowledgement:** The authors declare that they have nobody or no-company to acknowledge.
- **Author contributions:** The authors declare that they have equal right on this paper.
- **Funding information:** The authors declare that there is no funding to be acknowledged.
- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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