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REVIEW

A Call to Action: Empowering Pharmacists in Drug-Resistant Tuberculosis Management

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Abstract: Drug-resistant tuberculosis (DR-TB) continues to be a major global health threat, and while advancements in drug therapies have been made, the role of pharmacists in improving patient outcomes has not been fully optimized. This review aims to describe the types, resistance mechanisms, and management strategies of DR-TB, with a focus on discussing the critical role of pharmacists in optimizing treatment outcomes for DR-TB patients. A narrative review approach was adopted to provide an updated and evidence-based perspective. Additionally, manual review of reference lists from the retrieved articles was performed to identify additional relevant studies. The review identifies types of DR-TB, including mono-, poly-, rifampicin-, multi-, pre-extensively, and extensively-drug resistance. Resistance mechanisms are outlined, highlighting mutations in key genes, such as those involved in rifampicin and isoniazid (INH) resistance, which compromise treatment efficacy. The treatment regimens for DR-TB include the INH-R regimen, Bedaquiline, Pretomanid, and Linezolid (with or without Moxifloxacin) (BPaL(M) regimen, shorter oral regimen, and longer oral regimen, each tailored to the specific resistance pattern and patient condition. The challenges in managing DR-TB include complex treatment regimens and side effects, social barriers such as stigma and adherence issues, and system-related obstacles like limited resources and healthcare infrastructure. The review underscores pharmacists' vital yet underutilized role in addressing challenges. Pharmacists' contributions include patient counseling to improve adherence, and optimizing regimens for vulnerable populations and therapeutic drug monitoring. Addressing DR-TB requires a multifaceted approach, with pharmacists playing a critical role in its management. Their contributions are key to improving patient outcomes and overcoming the challenges associated with DR-TB management.

Keywords: pharmacists, drug-resistant, tuberculosis, medication management, adherence, therapeutic drug monitoring

Introduction

Tuberculosis (TB) is an infectious disease caused by *Mycobacterium tuberculosis*.[1] TB has long been a global health concern, with its impact reverberating across communities and nations.[2] Although substantial progress has been made in combating this infectious disease resulting in high cure rates of drug susceptible TB (DS-TB), a formidable challenge has emerged in the form of drug-resistant tuberculosis (DR-TB).[3,4] The rise of drug-resistant strains of *Mycobacterium tuberculosis* poses a significant threat to public health.[5]

The updated global TB report 2024 describes that around 175,923 individuals are diagnosed and received treatment for multidrug-resistant/rifampicin-resistant tuberculosis (MDR/RR-TB) globally, with most TB cases being reported in South-East Asia (45%), Africa (24%), and the Western Pacific (17%).[6] The estimated number of new TB cases in 2023 for countries with at least 100,000 cases is illustrated in Figure 1, which emphasizes the urgency of addressing this escalating public health crisis. The consequences of DR-TB extend beyond the individual patient and are impacting the healthcare infrastructure and the economic burden and are also posing a significant threat to global health security.[7,8] As

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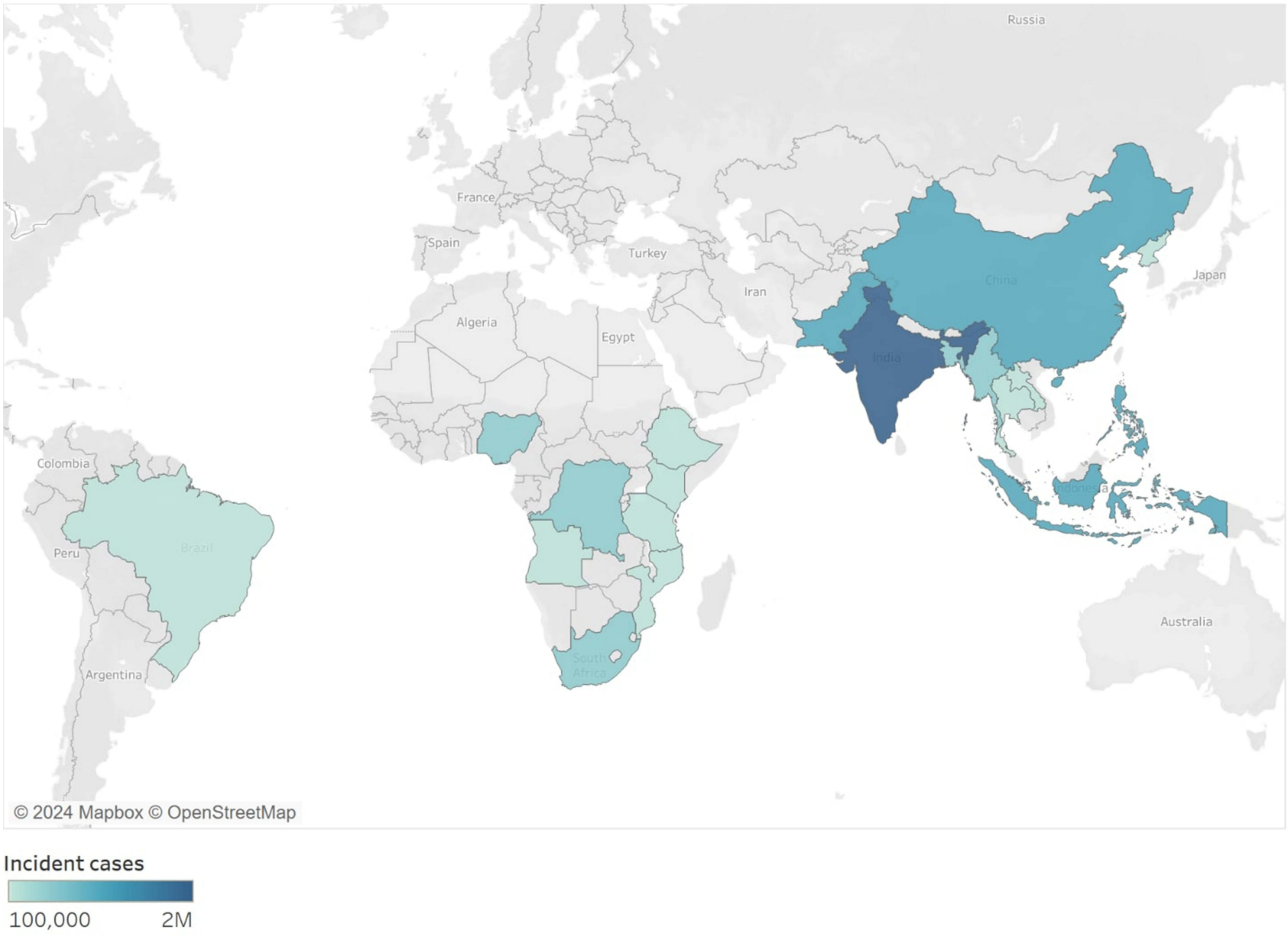

Figure 1 Estimated number of new TB cases in 2023 for countries with at least 100,000 reported cases. Countries are classified into four groups based on the number of cases: 100,000 cases (Brazil, North Korea, Ethiopia, Kenya, Tanzania, Mozambique, Laos, Thailand, and Angola); 500,000 cases (Nigeria, Congo, Bangladesh, Myanmar, and South Africa); 1,000,000 cases (Indonesia, Philippines, China, and Pakistan); and 2,000,000 cases (India). Data source: Recreated from Global Tuberculosis Report 2024 (5) using Tableau (2023.2.1).

the medical community intensifies its efforts to address this growing crisis, the pivotal role of pharmacists in the battle against DR-TB is increasingly recognized.[9]

As a part of a healthcare team, pharmacists can have a role in optimizing therapeutic outcomes by ensuring rational use of medicines, medication adherence and mitigating the risks associated with complex drug regimens.[10] Their expertise in medication management, pharmacokinetics, and drug interactions uniquely positions them to contribute significantly to the comprehensive care of individuals battling DR-TB.[11] Moreover, the different DR-TB treatment regimens, involving shorter regimens like bedaquiline, pretomanid, and linezolid (BPAL) and shorter or longer regimens, demands vigilant monitoring,[12] and management of potential adverse effects.[13] Pharmacists, with their specialized knowledge, are experts at identifying and addressing medication-related problems, thereby enhancing treatment efficacy and outcomes.[14]

Despite these benefits pharmacists' potential contributions to TB care are not fully utilized in practice. The World Health Organization (WHO) and the International Pharmaceutical Federation (FIP) issued a joint statement in 2011 advocating for greater pharmacist involvement.[15] However, the implementation of integrated pharmaceutical programs for TB management remained limited due to challenges such as inadequate funding, lack of coordination between healthcare sectors, and insufficient training for healthcare professionals.[16] Previous studies have highlighted the limited involvement of pharmacists in both community and hospital settings,[17] indicating a missed opportunity to fully integrate their expertise into the management of TB care.[18] To effectively bridge this gap, it is important to highlight the roles of

pharmacists within DR-TB care teams. Additionally, understanding current management strategies, mechanisms of resistance, and the challenges faced in treatment provides strategies for how pharmacists can optimize treatment outcomes in DR-TB care. Therefore, the aim of this narrative review was to describe the resistance of *Mycobacterium tuberculosis* and its resistance mechanism, management of DR-TB and the roles and responsibilities of pharmacists in optimizing DR-TB treatment outcomes through effective medication management in patient care.

Methods

A nonsystematic literature review of English literature was performed in PubMed and EMBASE using the keywords: drug-resistant tuberculosis, pharmacists, medication management, adherence, therapeutic drug monitoring, point of care testing, Bedaquiline, Pretomanid, Linezolid, shorter oral regimen, longer oral regimen, INH-R regimen, resistance mechanisms, mutations, pharmacokinetics, and pharmacodynamics, TB preventive treatment, collaborative care, and treatment outcomes. References of retrieved articles were screened as well. Evidence resulting from the literature search was summarized and recommendations were provided.

Definition and Type of Drug-Resistant Tuberculosis

The emergence of DR-TB has necessitated the WHO to categorize TB strains based on specific resistance patterns to these medications, ie, mono-, poly-, rifampicin-, multi- and extensively-drug resistance. Monoresistant TB is where the bacteria are resistant to only one drug, but it still requires treatment modifications.[19] Polyresistant TB refers to a condition where TB bacteria are resistant to at least two TB drugs, excluding both INH and RIF.[20] Rifampicin-resistant tuberculosis (RR-TB), on the other hand, refers specifically to cases where the TB strain is resistant to RIF but not necessarily to INH.[21] MDR-TB is defined as TB that is resistant to at least INH and RIF, the two most effective first-line anti-TB drugs.[22] Pre-XDR-TB represents a more severe form of MDR-TB that is also resistant to fluoroquinolones and XDR-TB has additional resistance to bedaquiline or linezolid.[23] XDR-TB is particularly concerning, as these patients may face limited therapeutic alternatives, resulting in higher morbidity and mortality rates.[24] Overall, with increasing level of resistance TB treatment is more complex and requires prolonged treatment regimens, resulting in more side effects, and higher treatment costs compared to DS-TB.[25–28]

Mechanism of Drug Resistance

Drug resistance in TB is defined as the ability of *Mycobacterium tuberculosis* to survive and multiply despite the presence of anti-TB medications that would typically eliminate the infection.[29] Resistance to anti-TB drugs is primarily a consequence of inadequately managed TB care, encompassing issues like improper drug prescription practices, substandard drug quality, erratic drug supply, pharmacokinetic variability and patient non-adherence.[30,31] The mechanisms underlying resistance primarily involve chromosomal mutations, with occasional involvement of structural factors, such as the permeability barrier of the cell wall leading to low-level resistance.[32] The dominant process for the development of DR-TB entails the serial selection of a drug-resistant organism. The probability of a patient carrying a resistant mutation is directly linked to the mycobacterial load.[11] In addition to genetic mechanisms, *Mycobacterium tuberculosis* can evade treatment by going into dormancy, which is a non-replicating status of the bacteria that tolerate antibiotics, and are called persistors.[33] Table 1 provides an overview of these resistance mechanisms.

Selection of Treatment Regimen

Effective TB management encompasses various key components, starting with early detection through robust screening programs of latent TB, especially in high-risk populations. Recent advancements in biosensor technologies have shown potential to enhance early TB diagnosis, particularly in resource-limited settings.[57] Following diagnosis of latent TB, TB preventive treatment (TPT) is an essential component, with the WHO recommending a 6-month daily regimen of levofloxacin for individuals exposed to MDR/RR-TB to prevent the development of TB.[58] Once active TB is confirmed, timely initiation of appropriate treatment is critical. The WHO has updated its guidelines for managing DR-TB with several regimen options.[59] Further details on these regimens can be found in Table 2.

Table 1 Anti-Tuberculosis Drugs and the Genetic and Enzymatic Mechanisms of Drug Resistance in Mycobacterium Tuberculosis

Medication	Mechanism of Resistance	Enzyme	Gene	Reference
Rifampicin	Substitution of a single nucleotide	B-subunit of RNA polymerase	rpoB	[34–39]
Isoniazid	Introduces a point mutation, leading to altered protein function	Catalase-peroxidase	katG	[38–44]
Isoniazid-Ethionamide	Substitution of a purine with a pyrimidine or vice versa	Enoyl-ACP reductase	inhA	[38,39,44]
Pyrazinamide	Various mutations, including changes in nucleotide sequence, insertions, deletions, and premature termination.	Amidase	pncA	[45–47]
Ethambutol	Genetic changes and increased expression of the EmbB gene.	Arabinosyl transferase	embCAB	[48]
Streptomycin	Substitution of a single nucleotide in the S12 and 16S ribosomal RNA genes	NA	rpsL, rrs	[38,39,44,49–52]
Fluoroquinolone	Halts DNA replication	DNA gyrase	gyrA	[53]
Bedaquiline	Inhibition of ATP synthase	ATPase	pepQ, Rv0678	[54]
Pretomanid	Inhibition of mycolic acid synthesis	F420	ddn, fgd1, fbiA, fbiB, fbiC, fbiD	[55]
Delamanid	Inhibition of methoxy-mycolic and keto-mycolic acid synthesis			[56]

Notes: This table presents a summary of major anti-tuberculosis medications alongside the molecular mechanisms by which Mycobacterium tuberculosis develops resistance. For each drug, the associated resistance mechanism is described, along with the specific gene typically mutated or altered and the corresponding enzyme or molecular target impacted. The table demonstrates how point mutations or structural alterations in genes or enzymes interfere with the drug's action, ultimately conferring resistance. References indicate the primary studies supporting each mechanism.
Abbreviation: NA, not applicable.

Table 2 Anti-Tuberculosis Regimens and Durations for People with Drug-Resistant tuberculosis[59]

Regimen	Composition	Duration	Eligible Patients
INH-R Regimen	Rifampicin, Ethambutol, Pyrazinamide, Levofloxacin	6 months	1. Individuals with confirmed rifampicin-susceptible, isoniazid-resistant tuberculosis
BPaL(M) Regimen	Bedaquiline, Pretomanid, Linezolid (600 mg), Moxifloxacin	6 months	1. Individuals with MDR/RR-TB or MDR/RR-TB with fluoroquinolone resistance (pre-XDR-TB). 2. Individuals with confirmed pulmonary TB and all forms of extrapulmonary TB, except CNS, osteoarticular, and disseminated (miliary) TB. 3. Adults and adolescents aged 14 years and older. 4. All individuals, regardless of HIV status. 5. Patients with less than 1 month of previous exposure to bedaquiline, linezolid, pretomanid, or delamanid. If exposure exceeds 1 month, they may still receive these regimens if resistance to the specific medicines has been ruled out.

(*Continued*)

Table 2 (Continued).

Regimen	Composition	Duration	Eligible Patients
Shorter Oral Regimen	Linezolid, Bedaquiline, Clofazimine, Moxifloxacin, Pyrazinamide	9 months	1. Individuals with MDR/RR-TB who do not have resistance to fluoroquinolones. 2. Patients with non-extensive TB and without severe extrapulmonary TB. 3. Patients with less than 1 month of exposure to bedaquiline, fluoroquinolones, ethionamide, linezolid, and clofazimine. If exposure exceeds 1 month, they can still receive the regimen if resistance to those medicines is excluded. 4. All individuals, regardless of HIV status. 5. Children (and patients in other age groups) without bacteriological confirmation of TB or resistance patterns, but who are highly likely to have MDR/RR-TB based on clinical signs, symptoms, and history of contact with someone with confirmed MDR/RR-TB.
Longer Oral Regimen	**Group A**: (Bedaquiline – Linezolid – Moxifloxacin -Levofloxacin) **Group B**: (Clofazimine – Cycloserine – Terizidone) **Group C**: (Ethambutol – Delamanid - Pyrazinamide – Imipenem –cilastatin or Meropenem - Amikacin (or streptomycin) - Ethionamide or prothionamide - P-aminosalicylic acid)	18–20 months, or 15–17 months after culture conversion	1. In individuals with MDR/RR-TB, all three Group A agents and at least one Group B agent should be included to ensure treatment starts with at least four likely effective TB agents, and at least three agents are included if bedaquiline is stopped. 2. If only one or two Group A agents are used, both Group B agents should be included. 3. If the regimen cannot be composed with agents from Groups A and B alone, Group C agents should be added to complete the regimen.

Notes: This table outlines the major treatment regimens recommended for managing drug-resistant tuberculosis. Each regimen is presented with its drug composition, recommended duration, and eligibility criteria based on TB resistance profile, patient characteristics, and prior drug exposure. The regimens are categorized according to current WHO guidelines to aid in individualized treatment planning.
Abbreviations: MDR-TB, multidrug-resistant tuberculosis; RR-TB, rifampicin-resistant tuberculosis; XDR-TB, extensively drug-resistant tuberculosis; BPaLM, Bedaquiline, Pretomanid, Linezolid, and Moxifloxacin; TB, tuberculosis; CNS, central nervous system.

Challenges in Drug-Resistant Tuberculosis Treatment

Challenges in managing DR-TB are multifaceted, encompassing systemic, clinical, and social dimensions that collectively hinder effective control and treatment.[60–62] Addressing these barriers of each dimension could improve patient outcomes and reduce the global burden of DR-TB.[63]

Diagnostic delays in the timely and accurate identification of DR-TB pose a significant challenge, delaying treatment initiation and increasing transmission risks.[64] In regions with a high prevalence of DR-TB, gaps in healthcare infrastructure hinder patient care, surveillance, and treatment access.[64] While GeneXpert remains the recommended initial diagnostic tool for detecting TB and rifampicin resistance, incorporating chest X-rays as a complementary diagnostic aid can further enhance sensitivity and support early detection, particularly in cases where GeneXpert access is limited or where radiological findings can guide clinical decisions.[65,66] Staffing shortages in community health centers exacerbate these challenges, with healthcare workers overwhelmed by high patient loads and additional program responsibilities, impacting TB case management.[67] Moreover, the inappropriate use of anti-TB drugs remains a significant challenge, as it contributes to the emergence of resistance.[68]

DR-TB treatment remains a significant challenge due to the reliance on a limited range of medications, their potential for severe adverse effects, and the need for intricate treatment regimens.[69,70] A major contributing challenge has been the extended period during which TB drug development was neglected globally, with no new TB drugs approved for over 40 years

following the introduction of rifampicin in 1966, until the approval of bedaquiline in 2012, delamanid in 2014, and pretomanid in 2019, resulting in decades of reliance on outdated medications and delayed availability of effective drug combinations.[71–73] Moreover, the protracted nature of DR-TB treatment regimens, often extending over several years, poses difficulties in patient adherence and elevates the risk of treatment interruptions.[74,75] Integrating second-line drugs into DR-TB treatment adds additional challenges and intricacies, as these medications may induce adverse drug reactions (ADRs) ranging from gastrointestinal issues to ototoxicity and psychiatric disturbances as well as they are expensive.[76] These ADRs can impact on quality of life and lead to non-adherence, as patients may skip doses or discontinue treatment to avoid severe side effects.[77] Furthermore, the prolonged duration of treatment, often lasting months to years, exacerbates the risk of cumulative toxicity.[78] The management of latent TB also presents a challenge, as individuals with latent infection may not seek treatment, yet they remain at risk of developing active disease and transmitting it later.[79]

Stigma surrounding TB, exacerbated by drug resistance, significantly hinders early diagnosis and treatment-seeking behavior, leading to delayed care and increased transmission risks.[80,81] Additionally, social isolation and financial strain, resulting from stigma in the family, community, and workplace, further hinder TB management, making it more difficult for patients to access treatment and adhere to care regimens.[82] Furthermore, socioeconomic factors such as poverty, limited education, and inadequate access to healthcare create barriers to effective TB management.[83,84] Poverty restricts access to nutritious food, increasing the risk of malnutrition and TB development.[85] Limited education can lead to misconceptions about the disease and non-compliance with treatment regimens,[86] while inadequate healthcare access causes delays in diagnosis, treatment, and adherence, ultimately resulting in poorer health outcomes.[87]

Pharmaceutical Care for Drug-Resistant Tuberculosis

Pharmacists play an essential role in the prevention, treatment, and management of DR-TB, contributing significantly to improved patient outcomes.[10] Beyond simply dispensing medications, pharmaceutical care involves a proactive, patient-centered approach where pharmacists ensure the safe and effective use of medications, address potential adverse effects, and monitor for drug interactions.[88] By working closely with the healthcare team, pharmacists provide essential support in medication management, patient counseling, education and therapeutic drug monitoring (TDM).[89,90] These activities by pharmacists included in pharmaceutical care significantly contributes to patient adherence.[91] A recent systematic review of 13 studies assessing pharmacist-led interventions demonstrated the potential of pharmaceutical care in enhancing treatment outcomes among patients with pulmonary tuberculosis.[92] Key interventions—including patient education, counseling on adverse drug reactions, and resolution of drug-related problems—were linked to improved clinical outcomes and increased treatment completion rates. By educating patients about their treatment, potential side effects, and the importance of completing the full course, pharmacists help maintain treatment continuity and reduce the risk of resistance development.[93] Moreover, their collaborative role within the healthcare team ensures that patients are supported through every stage of their treatment journey, from initial diagnosis to follow-up care, ultimately improving the chances of a successful outcome in the fight against complex conditions like DR-TB.[94] Key characteristics of studies evaluating pharmacist-led interventions in TB and DR-TB management are summarized in Table 3.

Table 3 Summary of Studies Examining the Role of Pharmacists in Optimizing Treatment Outcomes for DR-TB

Study	Country	Study Design	Pharmacist Role	Outcome	Ref. No.
Nasir et al (2019)	Pakistan	Observational study	Patient education	Improved adherence	[10]
Awad et al (2024)	Multiple	Systematic review	Patient education and counselling	Improved clinical outcomes	[92]
Jakeman et al (2023)	USA	Prospective pilot study	Collaboration with health departments	Improved treatment delivery	[95]

(*Continued*)

Table 3 (Continued).

Study	Country	Study Design	Pharmacist Role	Outcome	Ref. No.
Pradipta et al (2023)	Multiple	Systematic scoping review	Patient detection and adherence support	Improved detection and outcomes	[18]
Khan et al (2023)	Pakistan	RCT	Patient monitoring, education	Enhanced quality of life	[96]
Clark et al (2007)	Turkey	Prospective, randomized, case–control study	Patient education	Improved adherence	[93]
Schmitz et al (2017)	Multiple	Systematic review	Patient education	Improved adherence	[97]
Iskandar et al (2023)	Multiple	Systematic review	Medication management	Supportive evidence of impact	[98]
Wong et al (2023)	Multiple	Systematic review	Patient detection and adherence support	Improved detection and outcomes	[99]
O'Brien & Downey (2017)	Peru	Qualitative study	MDR-TB program delivery management	Positive patient perceptions	[100]
Karuniawati et al (2019)	Indonesia	Quasi-experimental	Patient counseling and leaflet	Improved adherence	[101]

Abbreviations: MDR-TB, multidrug-resistant tuberculosis; RCT, randomized controlled trial; USA, United State of America.

Collaborative Care

The essence of effective DR-TB management lies in collaborative care, and pharmacists are integral components of multidisciplinary teams.[95] A recent systematic review reported that pharmacists contribute their specialized knowledge to create comprehensive treatment plans when working seamlessly within healthcare teams, particularly in areas like patient detection, medication adherence, managing adverse drug reactions, and optimizing treatment outcomes.[18] This collaboration extends beyond traditional healthcare boundaries, as pharmacists engage in interprofessional communication with physicians, nurses, public health specialists, and other healthcare professionals.[102] The establishment of cohesive multidisciplinary teams facilitates a holistic approach to DR-TB care, allowing for real-time adjustments to treatment plans, timely identification of emerging challenges, the implementation of patient-centered strategies, and improvement of patients' quality of life.[96] Pharmacists, through their adept communication skills and pharmacotherapeutic insights, bridge gaps between disciplines, ensuring that the collective efforts of the healthcare team are synergized for optimal patient outcomes in the challenging landscape of DR-TB.

Medication Management

Pharmacists have an important role in the intricate landscape of DR-TB by spearheading medication management strategies. Their expertise ensures that patients receive effective and safe drug combinations.[93] Given the limited array of medications available for DR-TB treatment and the complex nature of drug interactions, pharmacists collaborate closely with healthcare teams to optimize treatment regimens. These regimens are tailored to each patient's drug resistance patterns, comorbidities, and tolerance, ensuring both efficacy and adherence.[103] Furthermore, in the complex landscape of DR-TB therapy, pharmacists play a crucial role in monitoring and managing the side effects experienced by patients undergoing MDR/RR-TB treatment.[104,105] While clinicians typically rely on laboratory tests to track treatment progress, community pharmacists engage more directly with patients, discussing and addressing the side effects they report, thereby providing valuable support in optimizing patient adherence and ensuring treatment efficacy.[100,106] This vigilance not only contributes to treatment adherence but also ensures the overall well-being of patients navigating the challenges of prolonged and intensive drug regimens. Pharmacists can also play an active role in Directly Observed

Treatment (DOT) programs by assisting patients in taking their medication daily, thereby ensuring adherence to the prescribed treatment regimen.[11] The WHO delineates five essential components of DOT, encompassing political commitment and sustained financing, case detection utilizing quality-assured bacteriology, standardized treatment with supervision and patient support, effective drug supply and management systems, and reliable monitoring and evaluation systems.[107]

Therapeutic Drug Monitoring

TDM is recognized as an effective strategy for optimizing TB treatment in particular situations like absorption issues, guiding dose adjustments, preventing toxicity (eg, cycloserine, linezolid), and ensuring effective drug levels, particularly in patients with poor response, malabsorption, or co-morbidities like HIV and diabetes.[108] The WHO handbook mentions that for medications such as fluoroquinolones and linezolid which have narrow therapeutic windows TDM can be considered when available.[105] However, its implementation remains limited in many settings, with pharmacists typically playing a role in TDM in specialized TB hospitals, while community pharmacists are not involved in TDM.[109] The introduction of point-of-care saliva tests for TDM may create opportunities for pharmacists to offer such tests in the community.[110–112]

In specialized TB hospitals and other well-resourced settings, pharmacists play a significant role in managing DR-TB by applying their expertise in pharmacokinetics and drug interactions to optimize treatment outcomes.[113] When TDM is available, pharmacists assess patient factors such as age, weight, and metabolic profile to tailor dosing, ensuring optimal drug concentrations.[114] By adjusting doses based on TDM data, pharmacists minimize the toxicity of DR-TB drugs, which carry risks such as nephrotoxicity and hepatotoxicity, and collaborate with TB doctors to prevent resistance and improve treatment success.[115]

Patient Education and Counseling

Pharmacists serve as linchpins in patient education and counseling, playing a transformative role in enhancing adherence to DR-TB treatment regimens.[97,116–119] Beyond the dispensing of medications, pharmacists engage patients in comprehensive discussions about the importance of treatment adherence, explaining the specific role and purpose of each medication in achieving successful outcomes.[98] This educational outreach extends to addressing lifestyle recommendations that complement the therapeutic process.[120] A recent systematic review further underscores the positive impact of pharmacist education on the adherence and completion of prescribed TB medications.[99] Public health promotion is another role for pharmacists, educating the public about TB risk factors and promoting early care-seeking behavior.[100] This is particularly important in settings like homeless shelters and correctional facilities where TB outbreaks have been reported. Counseling by pharmacists showed a crucial role in positively influencing and enhancing patient compliance with TB medication, offering numerous advantages, including ensuring the safety and effectiveness of treatment, providing patients with additional insights into their disease, resolving therapeutic issues in specific situations, minimizing medication errors, enhancing therapy compliance, preventing adverse drug reactions, and optimizing the efficiency of healthcare costs.[101]

Future Direction

Innovative strategies that utilize all available resources should be implemented to strengthen TB management, particularly in high-burden countries. In the contemporary landscape of combating DR-TB, pharmacists can be one of the healthcare teams who are at the forefront of embracing innovative technologies that enhance patient care and contribute to the overall efficacy of treatment strategies.[121]

Enhanced case detection within the community represents a critical area for improvement.[122] Training programs for community pharmacists can equip them to identify individuals presenting with persistent coughs, a key symptom of TB, and refer them for diagnostic testing.[123] Equipped with this knowledge, pharmacists can actively screen patients and refer those showing symptoms for diagnostic testing.[124] This proactive approach can significantly increase early TB detection and reduce transmission within the community, making pharmacists key players in TB control efforts, especially in underserved areas.[125] Additionally, advancements in diagnostic and monitoring technologies, such as point-of-care

testing (PoCT) and TDM using saliva, hold great promise. PoCT offers rapid, portable diagnostic capabilities, particularly valuable in resource-limited settings,[112] while saliva-based TDM provides a non-invasive method to monitor drug levels, enabling personalized dosage adjustments and minimizing adverse effects during treatment.[126] In settings where traditional TDM is not feasible, such as in Tanzania, saliva-based TDM has proven effective. In one case, the saliva test detected suboptimal levofloxacin exposure in 8 out of 9 patients, enabling timely dosage adjustments and minimizing adverse effects, thus enhancing treatment outcomes.[127]

Comprehensive TB training programs with incentives and certification can be developed for pharmacy personnel to improve their skills, with licensing granted after completion, and integrated into continuing education by professional organizations and academic institutions.[18] Additionally, Electronic Health Records (EHRs) represent a pivotal advancement, allowing pharmacists seamless access to comprehensive patient information.[128] This integration could streamline medication management for pharmacists, providing real-time updates on drug regimens, adverse effects, and patient adherence, enabling the identification of potential drug interactions, optimization of dosage adjustments, and facilitating efficient communication with the broader healthcare team.[129]

The integration of telehealth initiatives has emerged as a game-changer in DR-TB care.[130] Pharmacists can use these telehealth platforms to conduct virtual consultations, monitor treatment progress, and provide timely interventions, thereby overcoming geographical barriers and enhancing accessibility to expert pharmaceutical care.[131] Furthermore, future strategies should prioritize integrating telehealth and digital health tools to support patient engagement and enhance treatment adherence, which remains a central challenge in DR-TB management. When combined with pharmacist-led monitoring and EHR access, these technologies can enable early identification of non-adherence, allow for personalized interventions, and ensure continuous support throughout the treatment journey.[132,133] Recent evidence also highlights the promise of combining digital adherence technologies with therapeutic drug monitoring to enable more personalized and effective TB care, particularly in resource-limited settings.[134] Finally, comprehensive guidelines to facilitate collaboration among pharmacies, community health centers, and all TB stakeholders is urgently needed, which are important for improving treatment outcomes.[135]

Conclusion

In conclusion, the management of DR-TB presents significant challenges to public health worldwide, particularly in high-burden countries. Pharmacists play a role in this battle by optimizing treatment outcomes through effective medication management, patient education, and collaborative practice within healthcare teams. Their expertise in pharmacotherapy is essential for ensuring rational use of medicine and medication adherence to complex treatment regimens, managing side effects, and providing vital support to patients throughout their treatment journey. By integrating pharmacists into DR-TB care models, healthcare systems can enhance treatment efficacy, reduce the burden of resistance, and ultimately improve patient outcomes.

Data Sharing Statement

All the datasets generated during this review are provided within this manuscript.

Author Contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis and interpretation, or in all these areas; took part in drafting, revising or critically reviewing the article; gave final approval of the version to be published; have agreed on the journal to which the article has been submitted; and agree to be accountable for all aspects of the work.

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Disclosure

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