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Effectiveness and implementation challenges of short-course all-oral BPaL and BPaLM regimens for drug-resistant tuberculosis: A systematic literature review

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Abstract

Background: Drug-resistant tuberculosis (TB-RO), including MDR and XDR forms, remains a major global health burden due to prolonged, toxic, and often ineffective conventional regimens. The introduction of short-course all-oral therapies BPaL (*bedaquiline*, *pretomanid*, *linezolid*) and BPaLM (with *moxifloxacin*) has offered a promising alternative, with evidence of superior efficacy, safety, and patient adherence. However, implementation across countries continues to face challenges, including limited access to pretomanid, insufficient laboratory capacity, and scarce evidence for special populations.

Purpose: To synthesize global evidence on the effectiveness, implementation challenges, and supporting factors associated with BPaL and BPaLM regimens for drug-resistant tuberculosis.

Method: A Systematic Literature Review (SLR) following the PRISMA protocol was conducted to identify, screen, and include relevant studies published from 2016–2024. Data sources consisted of clinical trials, operational studies, cost-effectiveness analyses, bibliometric reviews, and qualitative stakeholder assessments. Thematic analysis was applied to summarize findings on treatment outcomes, adverse effects, operational barriers, and socio-economic influences that shape implementation across different health system contexts.

Results: Regimens BPaL and BPaLM demonstrated high treatment success rates ranging from 84% to 97.6%, with rapid sputum culture conversion. Linezolid-related toxicities—such as neuropathy and myelosuppression—were common but manageable through dose adjustment and active monitoring. Cost-effectiveness analyses indicated up to a 25% reduction in per-patient expenditure compared with conventional regimens. Supporting factors included patient-centred care, psychosocial support, strengthened pharmacovigilance, and international technical collaboration. Key barriers comprised limited pretomanid access, inadequate laboratory capacity for drug-susceptibility testing, variable readiness of health systems, and limited evidence in special populations (children, pregnant women, and extrapulmonary TB cases).

Conclusion: The global adoption of BPaL and BPaLM regimens marks a significant advancement in the treatment of drug-resistant tuberculosis by enabling shorter, safer, and more cost-effective therapy with consistently high treatment success and improved operational feasibility across diverse settings.

Keywords: BPaL, BPaLM; Drug-Resistant; Implementation Challenges; Tuberculosis.

INTRODUCTION

Tuberculosis (TB) remains a major global public health challenge. Each year, approximately 10 million people are infected with TB, and 1.5 million die from the disease. As part of the Sustainable Development Goals (SDGs), the WHO targets TB

elimination by 2030 (Otto-Knapp, Edwards, Kuchukhidze, Kröger, Häcker, Bivol, & Yedilbayev, 2024). Despite various prevention and treatment efforts, social stigma against TB patients remains a serious barrier. This stigma not only limits patient

access to healthcare but also negatively impacts early detection and treatment adherence, increasing the risk of transmission and slowing the decline in TB incidence (Horter, Stringer, Gray, Parpieva, Safaev, Tigay, & Achar, 2020).

In addition to drug-sensitive tuberculosis (TB SO), a new challenge has emerged in the form of drug-resistant tuberculosis (TB-RO), including MDR-TB (Multi-Drug Resistant) and XDR-TB (Extensively Drug Resistant). Conventional treatment regimens for TB-RO are often long, toxic, costly, and unsuccessful in many patients, creating a burden on health systems and patients themselves. Therapeutic innovations such as the shorter BPAL regimen (*bedaquiline*, *pretomanid*, *linezolid*) and BPALM (with the addition of *moxifloxacin*) have emerged as more effective, safer, and patient-friendly options (Vanino, Granozzi, Akkerman, Munoz-Torrico, Palmieri, Seaworth, & Tadolini, 2023).

Drug-resistant tuberculosis (TB-RO) remains a critical global health challenge (World Health Organization, 2022). Multidrug-resistant tuberculosis (MDR) and extensively drug-resistant tuberculosis (XDR) threaten progress toward TB elimination. Standard TB-RO treatment prior to the BPAL and BPALM era required long treatment durations, caused severe adverse drug effects, and often demonstrated low treatment success rates (Vanino et al., 2023). The recommendation of a shorter, all-oral regimen with fewer drugs—namely BPAL (*bedaquiline*, *pretomanid*, *linezolid*) and BPALM (with *moxifloxacin*)—has introduced a new revolution in TB-RO therapy, offering promise for improved effectiveness, safety, and patient adherence (Burhan, Sugiharto, Soemarno, Juan, Runtu, Yuvensia, & Gebhard, 2025; Gupta, Juneja, Babawale, Majidovich, Ndjeka, Nguyen, & Sahu, 2024). This review summarizes global experiences with the implementation of BPAL and BPALM regimens for TB-RO treatment, highlighting their clinical effectiveness and implementation challenges across countries.

Although BPAL and BPALM regimens have shown promising results in clinical trials, implementation across countries continues to face major challenges. These include limited access to pretomanid, inadequate laboratory capacity,

insufficient data in special populations (children, pregnant women, extrapulmonary TB patients), as well as socio-economic and operational barriers influencing treatment success. There has yet to be a comprehensive review that integrates global implementation experiences, clinical effectiveness, and both facilitating and constraining factors in real-world practice.

A six-month BPALM regimen produced better outcomes than the standard of care in MDR/RR TB cases, reducing the risk of unfavorable outcomes such as death, treatment failure, or loss to follow-up (Silva, Fernandes, Ferreira, Bernando, Dalcolmo, Johansen, & Mello, 2024). However, of the 3,668 studies evaluated, only one randomized controlled trial (RCT) met the inclusion criteria, indicating that direct experimental evidence remains very limited, thereby weakening the generalization of findings to broader contexts. Meanwhile, real-world operational research found that the BPAL regimen yielded treatment success rates of up to 95.3% in MDR/RR TB patients and 90.4% in pre-XDR TB patients, demonstrating that this therapy is effective and relatively safe even outside controlled clinical trial environments (Sinha, Klebe, Rekart, Alvarez, Skrahina, Yatskevich, & Saunders, 2025). Furthermore, an individual patient data meta-analysis study showed that the BPAL regimen was more tolerable when the linezolid dose was reduced to 600 mg/day compared with higher doses, decreasing the incidence of severe adverse events without compromising effectiveness (Hasan, Medcalf, Nyang'wa, Egizi, Berry, Dodd, & Fox, 2024).

Nevertheless, existing literature still highlights important gaps: very few high-quality clinical trials, fragmented real-world evidence, and limited analyses of cost, program sustainability, and socio-economic factors in scaling up BPAL/BPALM implementation. Therefore, comprehensive studies that integrate clinical evidence, real-world findings, economic and operational considerations, and variations in health system contexts and population characteristics are still needed to provide a stronger foundation for policy and practice.

This study is significant because it employs a Systematic Literature Review (SLR) using the PRISMA protocol to synthesize global evidence on

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the effectiveness, implementation, barriers, and supporting factors of BPaL and BPaLM regimens. The findings are expected to offer clearer insights into best practices, strategies to mitigate challenges, and policy recommendations to expand access to TB-RO therapy, improve treatment success, and strengthen global efforts toward TB elimination. These results are particularly relevant for policymakers, healthcare practitioners, and researchers seeking to optimize the implementation of these innovative regimens across countries with varying resources and challenges.

RESEARCH METHOD

A systematic literature review approach was employed to evaluate relevant literature on the implementation of the BPaL and BPaLM regimens. The research process began with data collection from various literature sources, including clinical studies, real-world implementation reports, and cost analyses published between 2016 - 2024. The literature selection process followed the PRISMA protocol, which consists of three main stages: identification, screening, and inclusion. The identification stage involved searching for articles using relevant keywords, while the screening stage included assessing the eligibility of articles based on inclusion and exclusion criteria such as relevance to the topic, publication period, and source credibility. Articles that passed the screening stage were then included for more in-depth analysis.

Literature searches were conducted in the Google Scholar database using the keywords: "BPaL," "BPaLM," "Drug-Resistant Tuberculosis," "MDR-TB," and "XDR-TB," for publications between 2016–2025. During the article selection stage, 153 articles were initially identified. Of these, 32 articles were inaccessible, leaving 121 articles. Subsequently, 28 articles were excluded due to irrelevance to clinical tuberculosis or public health topics, reducing the number to 93 articles. Another 43 documents were excluded because they were not research articles, leaving 50 articles. Twelve articles were excluded because they were not written in English, resulting in 38 articles. Ultimately, 9 articles

were selected for thematic analysis following the PRISMA protocol, focusing on treatment success, adverse effects, operational strategies, systemic barriers, and socio-economic factors.

After gathering the relevant literature, thematic analysis was conducted to highlight key emerging themes, such as treatment success rates, drug-related adverse effects, operational strategies, systemic barriers, and socio-economic factors influencing regimen implementation. This analysis allowed the researcher to systematically organize complex data, synthesize findings from previous studies, and identify research gaps that require further exploration. Through this approach, the study provides a comprehensive understanding of the effectiveness, implementation challenges, and supporting factors of the BPaL and BPaLM regimens, while offering a robust evidence base to inform health policy decision-making at both national and global levels.

This review compiles findings from several types of data sources, including operational research such as implementation reports, adverse drug event documentation, and programmatic adjustments in countries such as Indonesia, Kyrgyzstan, Nigeria, and Ukraine; economic analyses including cost-effectiveness studies and budget impact assessments in South Africa, the Philippines, Georgia, and Nigeria (Evans, Hirasen, Casalme, Gler, Gupta, & Juneja, 2024; Gomez, Siapka, Conradie, Ndjeka, Garfin, Lomtadze, & Vassall, 2021); bibliometric reviews analyzing research trends, international collaboration, and knowledge gaps (Sridharan, & Sivaramakrishnan, 2025); systematic reviews and meta-analyses comparing the relative effectiveness and safety of BPaL/BPaLM versus standard regimens (Silva et al., 2024); and stakeholder and feasibility studies assessing qualitative insights on acceptability, feasibility, and barriers among healthcare workers and patients (Van de Berg, Pelzer, Van der Land, Abdrakhmanova, Ozi, Arias, & Van den Hof, 2021; Khan, Ismail, Ghafoor, Khan, Muzaffar, Zafar, & Shahid, 2024).

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RESEARCH RESULTS

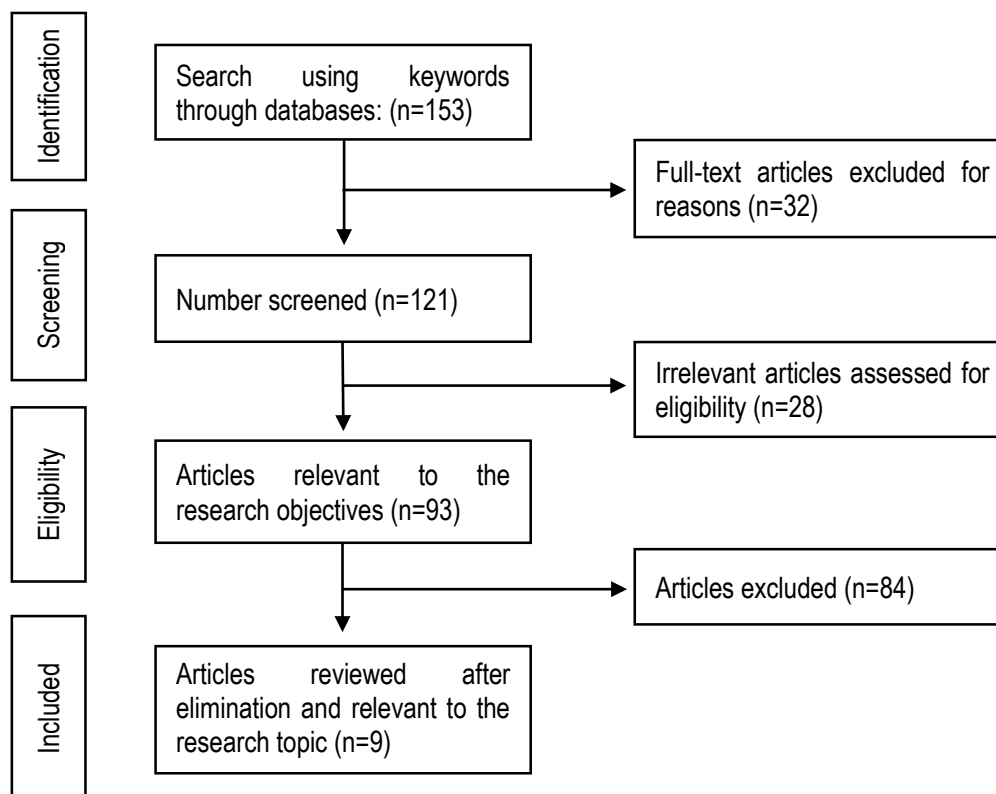


Figure 1. Prisma Flow Diagram

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Table 1. Characteristic of the articles reviewed

(Author, Year) (Country)	Purpose	Study Design	Subjects	Finding
(Sangsayunh et al., 2024) (Thailand)	To evaluate the real-world effectiveness, side effects and challenges associated with the implementing of the groundbreaking BPaL-containing regimen in Thailand.	Case series, single group	28	Success 82%; lung cavitation affected culture conversion
(Myrzaliev et al., 2024) (Kyrgyzstan)	This report presents experiences and results from the BPaL operational research under the LIFT-TB project in Kyrgyzstan.	Prospective cohort	50	Success 84%; adverse effects 34%
(Burhan et al., 2025) (Indonesia)	To assess treatment success rate (TSR) and time to sputum culture conversion (TSCC).	Prospective cohort	84	Success 97.6%; 100% sputum culture conversion at 3 months
(Ikpe et al., 2025) (Nigeria)	This study focused on the outcomes of patients managed with this regimen in the southeastern zone of Nigeria.	Cross-sectional	212	Success 89%
(Feshchenko et al., 2023) (Ukraine)	To study the programmatic results of efficacy and tolerability of the standard combination of the BPaL REGIMEN (NIX-TB, zeNIX-TB, TB Practecal, Simplici TB) for patients with pre-extensively drug-resistant tuberculosis and treatment failures of multidrug-resistant tuberculosis treatment in an operational study.	Prospective cohort	142	Success 91.5%
(Connors et al., 2023) (Canada)	We highlight significant implementation challenges and make recommendations for what needs to be addressed to ensure safe programmatic use of BPaL in Canada.	Case report	1	Cured; regimen recommended

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(Author, Year) (Country)	Purpose	Study Design	Subjects	Finding
(Haley et al., 2023) (United States)	To report the real-world management and outcomes of US patients treated with BPaL in 2019–2022.	Retrospective cohort	70	Success 97.1%
(Rashitov et al., 2024) (Kazakhstan)	We report safety and effectiveness of three 9-month all-oral regimens containing bedaquiline (Bdq), linezolid (Lzd), and levofloxacin (Lfx) and reinforced with cycloserine (Cs) and clofazimine (Cfz), delamanid (Dlm) and pyrazinamide (Z), or Dlm and Cfz.	Prospective cohort	510	Success 97.1%
(Sinha et al., 2025) (Belarus & Uzbekistan)	To estimate the effectiveness (cured or treatment completed) and safety (the occurrence of serious adverse events) of BPaL-based regimens.	Prospective cohort	677	Success 95.3%

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The analysis of the selected articles showed that treatment success rates for BPaL and BPaLM ranged from 84% to 97.6%, with rapid sputum culture conversion. Adverse effects particularly those associated with linezolid—were manageable through dose adjustments and active monitoring, while cost analyses demonstrated reductions of up to 25% per patient compared with conventional regimens. Several major clinical trials also provide evidence of the effectiveness of these regimens. The Nix TB study in South Africa, involving a single cohort of 109 participants, showed that 26 weeks of BPaL achieved a 90% treatment success rate with sputum culture conversion to negative (Conradie, Diacon, Ngubane, Howell, Everitt, Crook, & Spigelman, 2020). The Zenix TB trial focused on determining the optimal linezolid dose, with 600 mg found to be effective while minimizing risks of peripheral neuropathy and myelosuppression (Conradie, Bagdasaryan, Borisov, Howell, Mikiashvili, Ngubane, & Spigelman, 2022). Additionally, the TB-PRACTECAL randomized controlled trial demonstrated that the 26-week BPaLM regimen achieved an 89% success rate—substantially higher than the 52% observed with the previous standard regimen—along with a more favorable safety profile (Nyang'wa, Berry, Kazounis, Motta, Parpieva, Tigay, & Fielding, 2022). These findings confirm the high clinical effectiveness and improved safety of BPaL and BPaLM for treating drug-resistant tuberculosis.

The implementation of the BPaL and BPaLM regimens across various countries shows differing levels of effectiveness and challenges, largely influenced by the capacity of national health systems. India, as the country with the highest burden of drug-resistant TB, has reported improvements in treatment effectiveness and patient adherence due to the shorter treatment duration. However, these successes are not yet uniform. India continues to face major obstacles in pharmacovigilance, particularly regarding the risk of emerging bedaquiline resistance and the high incidence of linezolid-related adverse events such as peripheral neuropathy and myelosuppression. In addition, disparities in healthcare quality across states result in uneven adoption of these new regimens (Gupta et al., 2024). A different situation is seen in South Africa, the first country to implement

BPaL on a national scale, which has demonstrated high efficacy even among patients co-infected with HIV. This success is supported by a relatively well-prepared MDR-TB care system, although the considerable rate of linezolid toxicity necessitates dose adjustments and long-term monitoring (Conradie et al., 2020).

Eastern European countries, such as Russia, face different challenges. Complex drug resistance patterns (XDR) make BPaL an important option, but adoption is hindered by stricter regulatory policies and lengthy bureaucratic processes. Common comorbidities such as alcoholism and hepatitis C further increase the risk of hepatotoxicity, requiring stricter monitoring strategies. In the Philippines, early outcomes show improved treatment completion rates, yet structural barriers arise from inadequate laboratory capacity, high levels of social stigma, and limited pharmacovigilance documentation. This suggests that the effectiveness of the new regimens is not determined solely by drug quality but also by the readiness of diagnostic infrastructure and adverse event reporting systems (Evans et al., 2024).

Bangladesh shows a smoother transition to BPaL due to its prior experience with shorter regimens, but still faces classic challenges related to unsystematic linezolid monitoring, particularly in rural healthcare facilities. Heavy reliance on donor funding also raises concerns about the long-term sustainability of regimen implementation. Indonesia, although having incorporated BPaL and BPaLM into its national program, remains in the expansion phase of implementation. The most critical challenges lie in service inequities between urban areas and remote 3T regions, limited capacity for detecting drug-resistant TB, and suboptimal documentation of linezolid-related adverse events linezolid (Burhan et al., 2025). Overall, cross-country findings show that the BPaL/BPaLM regimens consistently demonstrate high effectiveness, but the quality of pharmacovigilance and the preparedness of health systems remain key determinants of success.

The SLR findings indicate several research gaps that require further investigation. Long-term bedaquiline resistance remains rarely reported despite the rapid global scale-up of its use. Country-specific cost-effectiveness evaluations are also

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limited, even though drug procurement and the need for intensive monitoring are major concerns for low- and middle-income countries. Similarly, few studies assess the regimens' impact on patients' quality of life, despite the importance of this aspect given that shorter therapy should ideally reduce psychosocial burdens. Furthermore, implementation studies on special populations—such as HIV patients with severe immunosuppression, pediatric patients, and individuals with chronic comorbidities—are still scarce. Overall, this critical analysis underscores that the success of the BPaL and BPaLM regimens relies not only on their pharmacological superiority but also on the readiness of health service systems, strengthened pharmacovigilance, and a deep understanding of social contexts and health policies in each country.

DISCUSSION

This study affirms that the BPaL and BPaLM regimens represent transformational therapeutic options for drug-resistant TB, offering high effectiveness, manageable safety profiles, and cost efficiency. Findings from clinical trials and operational research demonstrate consistent success across several high-burden countries, underscoring the potential for global adoption of these regimens.

SLR findings indicate that the implementation of the BPaL/BPaLM regimens across countries is strongly influenced by health system factors, facility readiness, and social support. Key enabling factors include patient-centered care approaches, psychosocial support, and active monitoring of drug safety. In many countries, the presence of specially trained nurses and psychological counselling systems has improved patient adherence and led to higher treatment success rates. Additionally, international collaboration through WHO technical assistance, the harmonization of national guidelines, and operational research networks has strengthened countries' capacity to adopt the regimens.

Nevertheless, several significant barriers remain. Access to pretomanid is still limited, particularly in Europe and several lower-middle-income countries (LMICs), hindering the equitable expansion of BPaL/BPaLM. Laboratory capacity for conducting second-line drug susceptibility testing (DST) also remains insufficient in some settings, resulting in delays in determining appropriate treatment regimens. Furthermore, uneven provider training has slowed the implementation process in many regions. Overall, although the BPaL/BPaLM regimens are clinically and economically effective, their success depends heavily on health system readiness, drug availability, and laboratory capacity.

A systematic review of clinical trials shows that the BPaL/BPaLM regimens have high effectiveness in curing drug-resistant TB. The Nix-TB trial in South Africa, involving 109 patients, demonstrated that 26 weeks of BPaL therapy achieved a 90% success rate in sputum culture conversion. This provided early evidence of the high effectiveness of the regimen based on bedaquiline, pretomanid, and linezolid. Subsequently, the ZeNix-TB trial aimed to determine the safest linezolid dose without compromising efficacy. Key findings indicated that a dose of 600 mg daily significantly reduced the risk of peripheral neuropathy and myelosuppression, allowing BPaL to be used more safely and tolerably. Another clinical trial, TB-PRACTECAL, a randomized controlled trial comparing BPaLM with the conventional standard regimen, showed an 89% treatment success rate for BPaLM, significantly higher than the 52% achieved with standard therapy. The new regimen also demonstrated a more favorable safety profile. Taken together, the clinical evidence confirms that BPaL/BPaLM regimens are effective, safe, and shorter in duration than previous therapies. The implementation experiences of BPaL/BPaLM across countries provide a comprehensive picture of real-world effectiveness, operational challenges, and programmatic relevance.

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Table 2. Implementation of the BPaL/BPaLM regimen

Country	Study Design / Context	Key Outcomes (Effectiveness)	Enabling Factors	Challenges / Notes
Indonesia	Prospective cohort study of 84 patients	97.6% success; 100% culture conversion within 3 months	Strict patient selection; intensive nurse-led monitoring; adverse event management; patient-centered care.	Minimal major barriers; regimen highly accepted by the health system.
Kyrgyzstan	Implementation with WHO support	84% success	Psychological counseling; active drug safety monitoring; strict inclusion criteria.	Linezolid-related adverse events remain present but manageable.
Nigeria	Implementation for MDR/RR-TB and pre-XDR TB	89% success (MDR/RR) and 100% success (pre-XDR)	Significant cost-efficiency; projected national savings of 32% over five years.	Suboptimal AE reporting; pharmacovigilance system needs strengthening
Ukraine	Operational study in conflict-affected areas	91.5% success	Acceptable safety profile; regimen suitable for unstable health systems.	Conflict limits long-term follow-up
South Africa & Philippines	Implementation in general population and TB-HIV patients	9–25% reduction in treatment costs; improved survival and culture conversion	Optimized linezolid dosing; integration of TB-HIV services.	Linezolid toxicity remains a primary concern
Europe	Cross-country implementation analysis	No pooled effectiveness reported; high inter-country variability	Strengthening of regional laboratory networks	Limited access to pretomanid; weak laboratory capacity; uneven DST availability; unstable financing

The implementation of BPaL/BPaLM regimens has shown varying outcomes across countries; however, overall performance remains strong in the treatment of drug-resistant TB. Indonesia recorded the most notable results, with a success rate of 97.6% and 100% culture conversion, supported by strict patient selection, intensive monitoring, and a patient-centered care model. Kyrgyzstan achieved an 84% success rate through strategies such as psychological counseling and active drug safety monitoring, although linezolid-related adverse events remain a challenge. Nigeria demonstrated excellent

outcomes 89% for MDR/RR-TB and 100% for pre-XDR TB—along with a projected national cost savings of up to 32%, though improvements in adverse event reporting are still needed. Ukraine reported a high success rate of 91.5%, showing that the regimen remains effective even in conflict-affected health systems. Meanwhile, South Africa and the Philippines reported cost reductions of 9–25% and improved survival rates, particularly among TB-HIV co-infected patients. In contrast, European countries face substantial barriers, including limited access to pretomanid, inadequate laboratory

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capacity, and unstable financing structures, hindering optimal implementation of the regimen.

From the perspective of national TB program macroeconomics, several countries have reported significant cost savings. Nigeria, for instance, is projected to reduce program expenditure by up to 32% over five years if the BPaL regimen is widely adopted. This is largely due to the shorter treatment duration and higher cure rates, which reduce the financial burden associated with retreatment, complications, and productivity loss from prolonged illness. These findings align with modern health-economic principles, particularly value-based healthcare (Porter, 2010) which emphasize that the most efficient interventions are those that produce the greatest clinical benefit with the least resource expenditure. In the context of MDR/XDR-TB, high clinical effectiveness (rapid culture conversion, high cure rates, low toxicity) directly contributes to long-term cost savings.

Although initial implementation costs may appear higher for example, due to the need for strengthened pharmacovigilance systems or expanded access to pretomanid recent evidence indicates that long-term savings far outweigh those associated with older regimens requiring 18–24 months of treatment and often resulting in failure. Nonetheless, challenges in drug procurement, particularly pretomanid, remain a limiting factor in some European countries, underscoring the need for stable and innovative drug-financing mechanisms. Overall, current evidence demonstrates that BPaL/BPaLM regimens are not only clinically superior but also substantially more cost-efficient, making them the most rational therapeutic choice for countries with a high burden of drug-resistant TB.

Despite the growing evidence of the effectiveness of BPaL/BPaLM regimens, several critical areas still require further research. First, linezolid toxicity remains a major concern; emerging oxazolidinone alternatives such as TBI-223 and delpazolid show promise for improved safety profiles. Moreover, long-term data on relapse and real-world safety remain limited. Special populations children, pregnant women, and patients with extrapulmonary TB require additional clinical data. Pediatric formulations and dosing strategies are still under development, while safety data for pregnant women

remain insufficient. Operational research must also be expanded to strengthen laboratory capacity, expedite DST availability, and develop more adaptive decentralized service models.

The BPaL/BPaLM regimens have transformed the approach to treating drug-resistant TB. Shorter treatment duration, higher adherence, and lower toxicity have reduced the burden on health systems and improved patient quality of life. However, global success still depends on strengthening health systems, establishing sustainable financing mechanisms, and ensuring coordinated international efforts for equitable drug access. Patient-centered approaches including psychosocial support, nutritional interventions, and active monitoring are essential components that must be continually reinforced. Innovative financing models and global partnerships are required to close existing gaps in drug access, particularly in countries with limited laboratory capacity.

CONCLUSION

The global adoption of BPaL and BPaLM regimens marks a significant advancement in the treatment of drug-resistant tuberculosis by enabling shorter, safer, and more cost-effective therapy with consistently high treatment success and improved operational feasibility across diverse settings. However, their full impact remains constrained by limited access to pretomanid, uneven diagnostic and laboratory capacity, gaps in evidence for special populations, and ongoing challenges in pharmacovigilance, workforce preparedness, and supply chain stability. Addressing these barriers through coordinated strategies, inclusive research, strengthened health systems, and sustained political and financial commitment is essential to ensure equitable scale-up, optimize real-world effectiveness, and support progress toward global tuberculosis elimination targets.

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