



NEWER TECHNOLOGY FOR TUBERCULOSIS PREVENTION AND CARE IN RESOURCE-CONSTRAINED SETTINGS: PLANS AND UPCOMING GUIDANCE

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ABSTRACT

Nowadays, one of the leading widespread communicable health determinants of death globally is tuberculosis (TB), which is most prevalent in low-and middle-income nations where health systems consistently struggle with a lack of diagnostic and therapeutic resources (World Health Organization 2024). To address these issues, more digital health solutions are used, such as digital adherence technologies (DATs), video-observed therapy (VOT), artificial intelligence (AI)-enabled chest X-ray computer-aided detection (CAD), electronic surveillance, laboratory connectivity, and mobile financial incentives (Cattamanchi et al., 2021). While solutions like digital adherence technologies (DATs) and video-observed therapy (VOT) significantly enhance patient accessibility and participation in tuberculosis prevention, their efficacy in improving treatment outcomes remains variable (Subbaraman et al., 2018). The World Health Organization (WHO) authorised CAD as a triage method for tuberculosis screening, as it is as precise as radiography (Qin et al., 2021). When used in African contexts, connectivity technologies such as GxAlert reduce the time

between diagnosis and the start of therapy (SystemOne, 2020). Besides, socioeconomic barriers to adherence are addressed through mobile money-based incentives, which have been investigated in TB programs in Africa (Krishnan et al., 2021). Additionally, long-term effectiveness, equity, compatibility, and coordination and regulation of digital health technologies remain enduring issues (Wingfield et al., 2020). The analysis highlights crucial perspectives and insights from current research, demonstrating the primary role of digital health applications in tuberculosis prevention in facilitating patient-focused, comprehensive care, distinct from alternatives to fundamental TB services (World Health Organization, 2024).

1. INTRODUCTION

With roughly an estimated 10 million new cases and resulting in 1.3 million deaths in the year 2023, tuberculosis (TB) remains a global crisis health challenge, with most contamination taking place in countries such as South Asia and Africa (World Health Organization 2024). In areas with limited resources, financial struggles, and inadequate health infrastructure, these factors contribute to persistent treatment disparities, despite progress in diagnosis and treatment (Sahu et al., 2021). The WHO End TB strategy emphasizes technology-based solutions as pivotal for adequate care and promotes their advancement as a cross-cutting catalyst (World Health Organization, 2020). Numerous economically developing countries have shifted from preliminary studies to implementing digital adherence tools, virtual video support services, AI-driven imaging, case-based monitoring, and mobile-based financial transactions over the past few years (Cattamanichi et al., 2021). The study evaluation assesses the contemporary landscape of technology-based TB solutions that are informed by implementation-derived findings to identify future pathways for the equitable and sustainable integration of health systems.

2. METHODOLOGY

This study examined the literature on technology-driven healthcare strategies to reduce the consequences of tuberculosis (TB)

and improve tuberculosis prevention in resource-constrained settings. We used keywords such as "tuberculosis," "digital health," "video-observed therapy," "computer-aided detection," and "social protection." The evidence from 2018 to 2024 was identified in the PubMed, Scopus, and Google Scholar databases. Further evidence came from reports by the World Health Organization (WHO), Stop TB Partnership publications, the Foundation for Innovative New Diagnostics (FINN), and methodological documentation.

With a strong emphasis on lower-resource countries, studies examined technology-enabled interventions in tuberculosis diagnosis, adherence, epidemiological monitoring, or economic protection. Both evidence-based reports and peer-reviewed academic works were chosen. After screening, seventeen considerable sources were identified, and a post-screening process was conducted to ensure that overlapping and comprehensive data were prioritized. Digital adherence technologies (DATs) and video-observed therapy (VOT) were among the six thematic domains into which the evidence was collected. Other domains comprised digital surveillance and connectivity systems, AI-enabled computer-aided detection (CAD), cross-cutting implementation lessons, future directions, and social protection incentives. The outcomes of this methodical approach were specific in representing both the programmatic hurdles and the technological possibilities for extending digital TB therapies.

3. RESULTS

3.1. Digital Adherence Technologies and Video-Observed Therapy

3.1.1. Digital Adherence Technologies (DATs)

DAT utilizes automated techniques to capture notes or instructions with fidelity, thereby eliminating the need for one-on-one DOTs (Subbaraman et al. 2018). The E-medicine holder comes with smart indicators that help count pill intake, while notification alerts remind you to take the prescribed dose. An initial study conducted in Uganda on e-pillboxes and a medication notification system found better compliance but encountered difficulties with internet access and poor connectivity (Thomas et al., 2020). Correspondingly, a performance review in South Africa highlighted the client's

reliability while also drawing special attention to the intermittent roadblocks to access (Krishnan et al., 2021).

3.1.2. Video-Observed Therapy (VOT)

VOT assisted by employing smartphones to experience the patient's presence or to log medication dosage. In economically advanced countries, VOT is statistically equivalent to DOT, with a higher proportion of patients' positive responses (Story et al., 2019). A cost-benefit analysis shows that it minimizes associate and transportation costs (Liu et al., 2021). In an African research study, feasibility projects increase the likelihood of success, while also emphasizing the importance of optimizing digital setups to avoid excluding underprivileged communities (Wingfield et al., 2020).

Table 1. Comparison of Adherence Support Models in TB Care

Approach	Strengths	Limitations	Suitable Contexts
DOT	Reliable observation; familiar with programs	Burden on patients; stigma; resource-intensive	Metropolitan clinics with staff capacity
DATs (SMS, Pillboxes)	Remote monitoring, scalable, real-time alerts	Connectivity or power challenges; risk of false reporting	Semi-urban and rural areas with phone coverage
VOT	Patient-focused; lowers travel; cost-profitable	Require smartphones or internet; privacy concerns	Areas with moderate-to-high technology access

3.2. Artificial Intelligence and Imaging

For TB surveillance, radiography has been used worldwide for several decades. However, there is a shortage of radiologists in low- and middle-income countries (Qin et al., 2021). According to research, AI has introduced a CAD system that automates the analysis of chest X-rays, achieving greater accuracy than

a human specialist (Muyoyeta et al., 2022). (WHO) approved CAD for TB screening in adults in 2021, especially in places where resources are limited (World Health Organization 2021). In parallel, assessments using portable X-ray equipment combined with CAD in many African nations have significantly reduced dependence on

specialists, improved access to TB screening, and expedited triage for confirmatory molecular testing (FIND 2023) as in the study by Wingfield et al. (2020), a minority of the issues that require key consideration involve bias, inequalities in group-specific effectiveness, and the obligation to ensure the fair handling of patient data. This assessment focuses on key strengths derived from contemporary research and global guidelines. It yields evidence on compliance technologies, expanded diagnostics, supervisory infrastructure, and public safety (Subbaraman, 2018; Qin, 2021; Daniels, 2020; WHO, 2024). The arranged results grant a complete overview of how digital health tools support patient-centered TB care in emerging healthcare settings. Increasing peer-reviewed research and reports from organizations such as the WHO, FIND, and the Stop TB Partnership expand the analysis's practical implications.

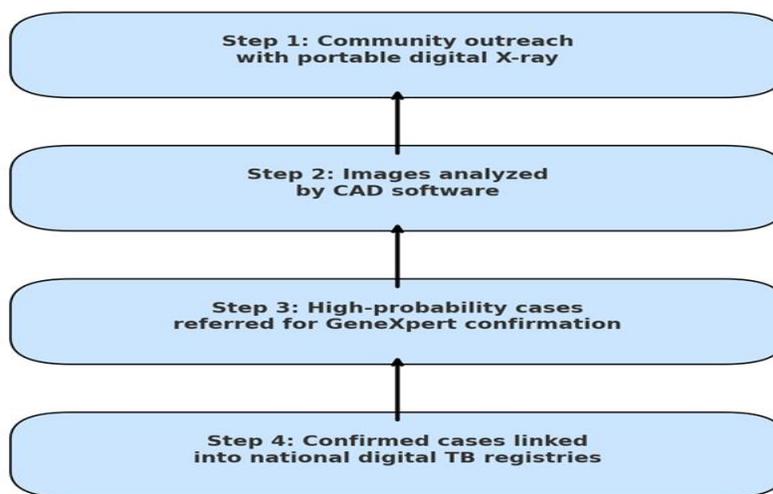
Regardless of the apparent potential of technological advancements for tuberculosis prevention and management, frequent restrictions persist. As reported in studies, these programs tend to adapt poorly and have

unclear long-term sustainability (Daniels, 2020; Wingfield, 2020). However, significant randomized trials have demonstrated the advantages of DATs, VOT, or CAD, with the most cost-effective statistics available (Subbaraman, 2018; Liu, 2021; Qin, 2021). In addition to this study, a major concern arises that equity with patients who lack access to cellphones or electronic devices, consistent internet connectivity, and sufficient literacy may be overlooked. (Sahu 2021; WHO 2020). Moreover, some ethical challenges, such as those concerning data security, transparency, and patient privacy, remain inadequately addressed (Stop TB 2022; WHO 2024). Overall, these gaps suggest that digital health resources are best positioned as supplements to core TB services, rather than replacements for them.

Figure 1. Workflow of CAD-Supported TB Screening

The figure shows how CAD software analyzes portable digital X-rays to identify probable TB cases, which are then confirmed with GeneXpert and linked to national digital registries for timely care and reporting.

Figure 1. Workflow of CAD-Supported TB Screening



summary : figure 1 was created from published evidence on CAD-based TB screening workflows, Qin et al. 2021; Muyoyeta et al. 2022; FIND 2023.

3.3. Digital Surveillance and Laboratory Connectivity

Even though conventional documentation remains the norm in most economically developing countries, effective oversight mechanisms are crucial for outbreak surveillance and governance. (Stop TB Partnership 2022). Several African countries have adopted computerized management systems for TB to enhance the accuracy and

speed of reporting. Platforms like GxAlert link laboratories, registries, and providers by automatically relaying GeneXpert results. In Nigeria, studies have shown that using such systems has shortened the time to commence treatment by approximately 40%. (SystemOne 2020). Furthermore, merging with expanded health information systems, namely DHIS2-based platforms, promotes technical compatibility. (Daniels et al. 2020).

Table 2. Examples of Digital Surveillance and Connectivity Tools

Platform	Country	Functionality	Outcome
GxAlert	Nigeria	Link GeneXpert to registries; SMS reminder	40% reduction in treatment delays
e-TB Manager	Economically developing countries	Electronic or digital case management	Increasing reporting accuracy
DHIS2 Trackers	Africa or Global	Integrates TB data into health information	Improved interoperability and oversight

4. Cross-Cutting Lessons

The structured application of digital TB interventions results in various integrative serious observations. At the initial stage, interventions must be patient-centered, taking action to reduce difficulties, for instance, low literacy competency and sociocultural stigma, and to promote reasonable access as a driver of diversity (Wingfield et al., 2020). Likewise, continued operational sustainability is fundamental, as operating on external donor financing pilots should change into government-administered settings with

consistent resources to confirm permanent results (Daniels et al., 2020). To a greater extent, forceful ethical monitoring is necessary to secure patient information and increase transparency in digitally enabled solutions (World Health Organization 2021). Despite these spreads toward policy-level Compatibility, comprising better-quality compliance methods, CAD competencies, and laboratory associations remain indispensable to cut fragmentation across healthcare pathways and strengthen the distribution of wide-ranging TB services

Figure 2 (Suggested): Digital TB Care Cascade in Low-Resource Settings

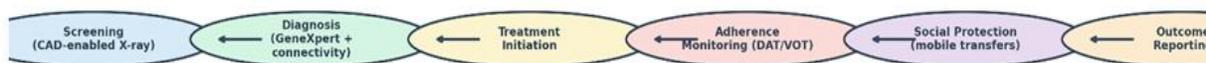


Figure 2: Digital TB Care Cascade in Low-Resource Settings

A stepwise pathway illustrating the integration of digital tools across the tuberculosis (TB) care continuum, from screening with CAD-enabled X-rays through diagnosis, treatment, adherence monitoring, social protection, and outcome reporting.

5. Future Directions

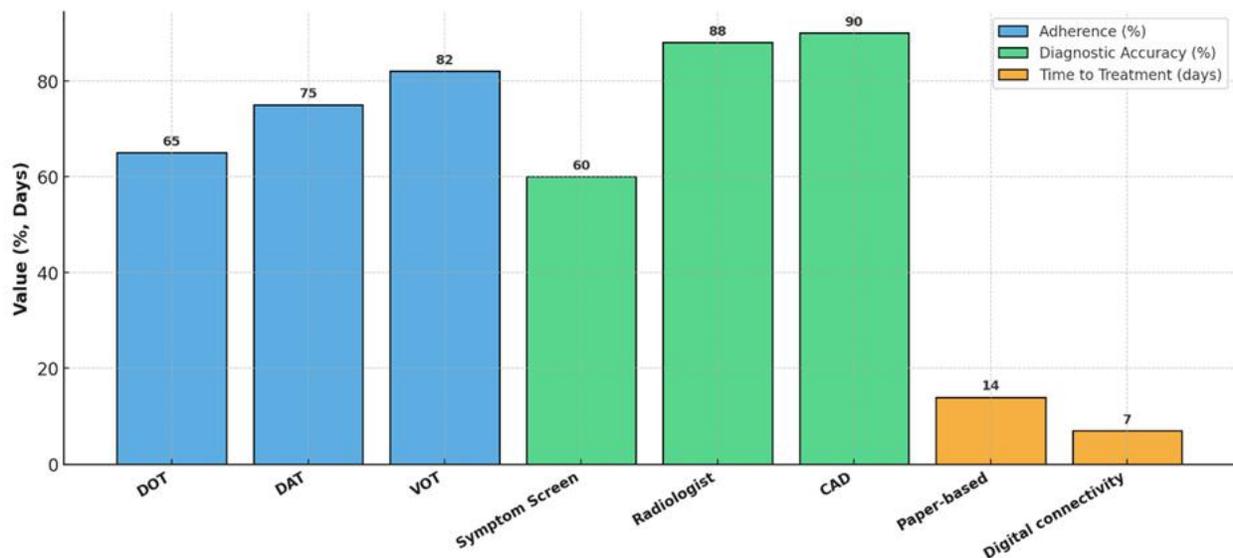
Growing Novel digital tools for TB care, for example, cough-based AI diagnostics and wearable biosensors for synchronous diagnostic-to-treatment pathway surveillance are screening potential, but they endure mostly new and continue In-depth analysis in resource-limited states to regulate their efficacy, and expansion capacity (Qin et al., 2021; Daniels et al., 2020). To achieve tangible progress in TB care, however, there needs to be a clear, well-coordinated collaboration between the government and stakeholders (Cattamanchi et al., 2021; WHO, 2024). Still, empowered leaders should

reinforce TB prevention resources by establishing procedures for integrating digital technologies into broader TB strategies (Cattamanchi et al., 2021; WHO, 2024).

Figure 3. Comparative Impact of Digital Health Interventions on TB Care Outcomes

Bar chart illustrating the effects of digital innovations in TB care. DATs and VOT show higher adherence than DOT, CAD achieves diagnostic accuracy comparable to radiologists and superior to symptom-based screening, and digital connectivity reduces time-to-treatment compared with paper-based reporting.

Figure 3. Comparative Impact of Digital Health Interventions on TB Care Outcomes



summary: figure 3 was created from published evidence Subbaraman, 2018; Thomas, 2020; Krishnan, 2021; Story, 2019; Liu, 2021; Sahu, 2021; Qi,n 2021; Muyoyet, a 2022; FIN, D 2023; SystemOn,e 2020; Daniels, 2020; Stop T, B 2022

6. Social Protection and Digital Incentives

Poverty and lack of nutrition are core determinants of TB vulnerability, which often makes it harder to stick to the given treatment and hence cause delayed recovery (Tanimura et al., 2020). To address these barriers, mobile

financial platforms are being assessed on a small scale to provide social support directly to patients, reducing the need for intermediaries or agencies and increasing transparency. Studies in Uganda and South Africa find that linking small mobile money

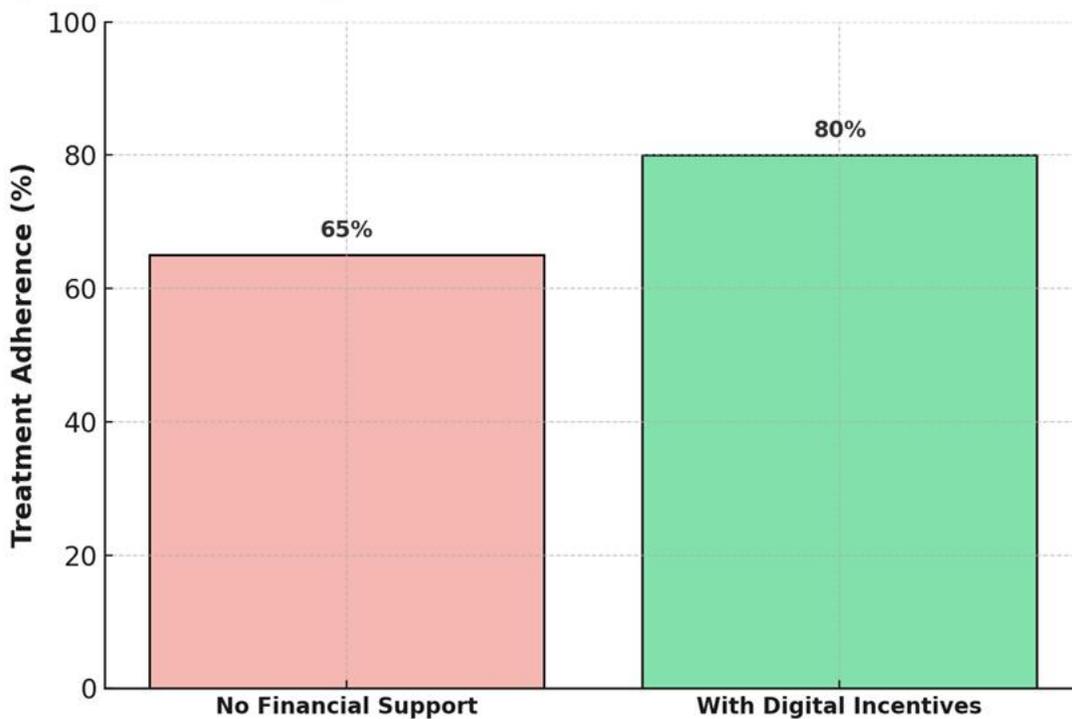
transfers to treatment adherence boosts outcomes. Patients accepted treatment engagement (Krishnan et al., 2021). Correspondingly, supplementary small-scale programs united with newer digital technologies, with uncertain economic sustainability, have demonstrated that reducing social determinants, identical scarcity, can alleviate health service breaches more effectively when combined with financial and clinical interventions (Thomas et al., 2020). Alongside better adherence to the TB treatment regimen, these findings

show that tech-based incentives can advance equity to promote fairness in treatment with patient-centered care by ensuring that innovative approaches reach even the most underserved groups (Wingfield et al., 2020; WHO, 2024).

Figure 4. Effect of Digital Financial Incentives on TB Treatment Adherence

This figure was created from published evidence showing improved adherence when mobile financial transfers were linked to treatment monitoring.

Figure 4. Effect of Digital Financial Incentives on TB Treatment Adherence



summary : figure 4 was created from published evidence from Tanimura 2020; Krishnan 2021; Thomas 2020; Wingfield 2020; WHO 2024.

7. DISCUSSION

Digital health innovation is transforming the care of tuberculosis (TB) within resource-limited settings-constrained environments by solving some of the traditional challenges of care adherence, diagnosis, surveillance, and socioeconomic support. Relative to traditional direct observation therapy (DOT), patient-

centered methods (like digital adherence technologies (DATs) and video-observed therapy (VOT) have proven more acceptable, less burdensome to patients, and better treatment adherence (Subbaraman et al., 2018; Story et al., 2019; Liu et al., 2021; Krishnan et al., 2021). Even though expertise lightens the logistical and economic troubles of DOT,

the value still relies on adopting underlying questions such as connectivity concerns, digital learning, and social bias, notably among underserved populations.

Computer-aided detection (CAD) assisted by artificial intelligence (AI) has become one of the most critical tools for overcoming the diagnostic process bottleneck caused by a shortage of personnel. CAD proves to be as diagnostically effective as radiologists, and a combination with portable X-ray equipment improves the availability of screening and expediency in connecting with confirmatory molecular testing (Qin et al., 2021; Muyoyeta et al., 2022; FIND, 2023). Nonetheless, implementation is associated with algorithmic bias, ethical data management, and population-specific differences, which need close management to guarantee fair implementation (Wingfield et al., 2020). It is also notable that there are digital connectivity platforms that connect laboratories, providers, and registries. GxAlert is among the systems that have significantly reduced time-to-treatment initiation, and it shows that decision-making through the integration of diagnostic reporting into national health information infrastructures can be more robust for surveillance and governance (SystemOne, 2020; Daniels et al., 2020).

Mobile money transfer linked to the monitoring of adherence is viable and acceptable, lowering the rate of treatment non-compliance and enhancing patient attendance (Tanimura et al., 2020; Thomas et al., 2020; Krishnan et al., 2021). These interventions note that digital solutions can go beyond biomedical applications to reinforce equity and patient protection. Despite these increases, considerable disparity remains. There is limited evidence on the cost-effectiveness with small sample sizes and short follow-up periods (Subbaraman et al., 2018; Liu et al., 2021; Daniels et al., 2020). Digital exclusion risks continue to affect patients who do not have smartphones, who

do not have stable Internet access, or who are not sufficiently skilled, which is why equity-oriented approaches are necessary (Sahu et al., 2021; Wingfield et al., 2020). On top of that, ethical issues related to patient privacy, data security, and transparency into how the algorithm functions must be addressed through effective governance systems (Stop TB Partnership, 2022; WHO, 2024).

All these findings underscore the fact that digital health solutions should be regarded as facilitators of traditional TB services, rather than substitutes. They can fast-track the achievement of the End TB Strategy by the World Health Organization by complementing the existing infrastructures and aligning with the overall strategies. To fulfill this vision, however, a long-term investment, cross-sectoral collaboration, and strict assessment are needed to guarantee that these technologies provide patient-centered, equitable results (Cattamanchi et al., 2021; WHO, 2024).

8. Strengths and Limitations

The study analysis highlights the study's strengths by connecting its findings with up-to-date research and globally applied strategies that bring together all the evidence on digital tools that support treatment, enhance diagnostic processes, strengthen monitoring systems, and improve public safety efforts (Subbaraman, 2018; Qin, 2021; Daniels, 2020; WHO, 2024). The arranged results provide a thorough summary of how digital health tools support patient-centered TB care in developing healthcare. Including both peer-reviewed research and reputable reports (such as those from the WHO, FIND, and Stop TB Partnership) increases the practical significance of the analysis.

Despite the evident potential of technological advancements for tuberculosis prevention and management, numerous restrictions persist. Many research efforts rely on tiny pilot programs. These programs have limited adaptability and questionable long-term

viability (Daniels, 2020; Wingfield, 2020). Barely large, randomized trials have confirmed the benefits of DATs, VOT, or CAD. In addition, concerns about data protection, algorithmic transparency, and patient privacy remain inadequately addressed (Stop TB, 2022; WHO, 2024).

9. Conclusion and Future Work

9.1. Conclusion

Based on these results, it was evident that technology-supported health intervention tools play a beneficial accelerator role in TB prevention and treatment strategies. They succeed excellently when corresponding with administration programs sponsored by sustainable capital models and overseen by formidable ethical standards (Daniels, 2020; Wingfield, 2020; WHO, 2024). Then, scaling up helpful tools like digital adherence technologies (DATs), video-observed therapy (VOT), computer-aided detection (CAD), and basic connectivity platforms can improve TB programs. In the meantime, adopting digital public security measures can help reduce socioeconomic disparities and ensure that vulnerable groups have access to care (Tanimura, 2020; Krishnan, 2021; WHO, 2024). While advancing the goals of the End TB Strategy, the incorporation of digital incentives stands out as a practical and rational approach to accelerate progress in low-resource health systems (Cattamanchi, 2021; WHO, 2020).

9.2. Future Work

Although digital interventions showed promising progress, various needs remain unmet. Instead of relying on small trials, the researcher should conduct future studies that focus on large, multi-state trials to better understand how practical, affordable, and flexible digital health solutions really are (Liu, 2021; Story, 2019). Along with this, equity-centered and socially open approaches are required because digital exclusion leaves groups without smartphones, data access, or adequate health education (Sahu, 2021;

Wingfield, 2020). We also need studies that compare TB prediction models with current methods like DOT. These comparisons are essential for developing national policies grounded in practical, proven approaches.

Implementation research is essential to look into how digital innovations fit into public health systems, Academic institutions, and community-integrated health care (Stop TB, 2022; Daniels, 2020). Further evaluation of the newer generation of technology-based diagnostic modules, such as wearable biosensors, AI-generated cough detection, and programs that combine digitalized, socially supported platforms, should focus on understanding their potential for patient-oriented, advanced, fair, and effective management of Tuberculosis in the next phase of innovation.

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