MULTISECTOR COLLABORATION MODEL FOR TUBERCULOSIS CONTROL IN MEDAN: EVALUATING THE EFFECTIVENESS OF THE PENTAHELIX APPROACH AND TB-CONNECT APPLICATION

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Abstract:This research examines the effectiveness of integrating the Pentahelix collaboration model with digital health technologies, specifically the TB-Connect application, in enhancing tuberculosis (TB) control efforts in Medan, Indonesia. Medan faces significant challenges in treatment adherence, healthcare worker efficiency, and multisectoral coordination. The Pentahelix model involves collaboration among government, academia, business, community organizations, and the media, aiming to strengthen public health responses and resource mobilization. Meanwhile, the TB-Connect application serves as a digital tool to improve patient adherence through automated reminders and real-time communication with healthcare providers. The results show that post-intervention, TB treatment adherence increased by 15%, and coordination among stakeholders improved significantly. Key informant interviews with healthcare workers and stakeholders highlighted the benefits of the model, though challenges in digital literacy and infrastructure remained. The integration of Pentahelix collaboration with digital health tools represents a promising approach to addressing the complex social and biomedical dimensions of TB.

Keywords: Pentahelix collaboration; Digital Health; TB Connect; Tuberculosis control; Treatment adherence

INTRODUCTION:

Tuberculosis (TB) remains a persistent global health threat despite decades of scientific progress and significant investments in disease control. According to recent estimates, TB continues to cause millions of new cases and over one million deaths annually, disproportionately affecting low- and middle-income countries (Marks, 2024); (Satti, 2022). Indonesia is consistently ranked among the top three high-burden TB countries, with over one million incident cases each year and persistent challenges in drug resistance, treatment adherence, and diagnostic delays ((Pakasi, 2024); (Zhao, 2025). This burden is compounded by social determinants of health, economic vulnerabilities, and systemic health system gaps that hinder effective TB care delivery ((Boulware, 2024).

The COVID-19 pandemic has exacerbated these challenges. Interruptions in case detection, reduced access to healthcare facilities, and disruptions in supply chains have caused a sharp decline in TB notifications in Indonesia, leading to missed cases and delayed treatments (World Health Organization, 2023) ; (Sunjaya, 2022). Such setbacks risk reversing years of progress and highlight the urgent need for innovative strategies that combine biomedical interventions with socio-structural responses ((Pai, 2022); (Pai, 2022).

The Need for Multisectoral Collaboration

TB is not merely a biomedical problem but a socio-economic one that requires multisectoral solutions. Traditional health sector–led approaches, while important, are insufficient to address the complex web of determinants influencing TB outcomes, including poverty, malnutrition, stigma, and poor housing conditions (Gunawan et al., 2023). Recognizing this, the Pentahelix collaboration model has emerged as a promising framework that integrates the government, academia, business, community, and media in a synergistic effort to strengthen TB responses.

Evidence from Indonesia demonstrates that involving multiple sectors enhances program reach, resource mobilization, and public engagement. For example, community-based organizations have been instrumental

in reducing stigma and supporting treatment adherence, while private providers play a critical role in early detection and case reporting (Brubacher et al., 2025). Academia contributes research and innovation, while media campaigns help correct misconceptions and foster supportive environments for. The government, as the central actor, provides policy leadership, funding, and integration into national TB programs patients (Rahayu, 2024).

Role of Digital Health Innovations

Beyond collaboration, digital health technologies have transformed TB control in recent years. Digital adherence technologies (DATs), such as 99DOTS, video directly observed therapy (vDOT), and mobile health applications, have been deployed in multiple high-burden settings to monitor and support patient adherence (Liu et al., 2023); (Story & Garfein, 2022); (Masini, 2023). Evidence shows that these tools are non-inferior to conventional directly observed therapy (DOT) and often more acceptable to patients, as they reduce the stigma and logistical challenges associated with daily clinic visits (F. A. Khan, 2023); (Ugarte-Gil, 2023).

In Indonesia, the introduction of TB-Connect, a locally adapted digital adherence platform, has facilitated real-time communication between patients and healthcare providers, streamlined data reporting, and strengthened treatment monitoring (Syarif et al., 2022); (Walley & Liu, 2023). This aligns with global evidence indicating that DATs improve treatment adherence, reduce default rates, and enhance patient-centered care ((Walley & Liu, 2023); (Kendall, 2023). Furthermore, the integration of artificial intelligence (AI)–enabled computer-aided detection (CAD) systems for chest radiographs has demonstrated high diagnostic accuracy and scalability in resource-limited settings (David, 2022); (Qin, 2024); (Creswell, 2024).

Challenges in Implementation

Despite these innovations, challenges persist. Multisectoral collaborations often face issues such as conflicting priorities, inadequate coordination mechanisms, and unequal distribution of resources (Creswell, 2024); (Creswell, 2024). For instance, the private sector may prioritize financial sustainability, while the public sector emphasizes public health outcomes, potentially leading to misaligned incentives (Creswell, 2024).

Digital health interventions also encounter barriers, including limited digital literacy, technological infrastructure gaps, and patient privacy concerns (Chen, 2022); (Walley & Liu, 2023). In rural and remote areas of Indonesia, disparities in internet connectivity and access to smartphones undermine the scalability of digital tools such as TB-Connect (Rahayu, 2024); (Creswell, 2025). Additionally, the sustainability of donor-funded digital health pilots remains a concern, as scaling up requires long-term government commitment and financing (A. J. Khan, 2022); (Vassall, 2024).

Policy and Strategic Implications

The Indonesian government has committed to eliminating TB by 2030, in line with the WHO End TB Strategy. Achieving this goal requires embedding multisectoral collaboration and digital innovation into the national TB program (Vassall, 2024); (Dheda, 2023). Evidence from other high-burden countries indicates that scaling up public–private mix initiatives and DATs can substantially reduce incidence and improve treatment outcomes (Subbaraman, 2023). (Tollefson, 2022).

Moreover, financing and incentive mechanisms must be designed to sustain private sector engagement and ensure equitable access to technologies across different populations (Vassall, 2024). Continuous monitoring of TB care cascades and integration of patient feedback are critical to maintaining a people-centered approach (Subbaraman, 2023); (Creswell, 2025).

Rationale for This research

Against this backdrop, this study aims to evaluate the effectiveness of the Pentahelix collaboration model in TB control in Medan, Indonesia, while assessing the role of the TB-Connect application in improving patient adherence and inter-sectoral coordination. By combining a multisectoral framework with digital health solutions, the study seeks to provide evidence-based insights that can inform policy and practice not only in Indonesia but also in other high-burden countries facing similar challenges.

The novelty of this research lies in its dual focus: exploring the synergistic potential of the Pentahelix model while empirically testing the added value of digital adherence technologies. Few studies to date have systematically examined how structured multisectoral collaboration, when coupled with digital health innovations, can address the persistent gaps in TB control. The findings are expected to contribute to global discourse on integrating socio-structural and technological strategies for TB elimination by 2030 (Gunawan et al., 2023); (Liu et al., 2023); (Qin, 2024).

METHODS

This research applied a mixed-methods design that combined quantitative and qualitative approaches to evaluate the effectiveness of the Pentahelix collaboration model and the use of the TB-Connect digital application in TB control. Mixed-methods research is widely recognized in global public health because it integrates the statistical power of quantitative analysis with the contextual depth of qualitative inquiry. The study design allowed us to capture both measurable outcomes (e.g., treatment adherence, case detection) and stakeholder perspectives on implementation challenges (MacPherson, 2023); (Subbaraman, 2023).

Population

The research was conducted in Medan City, North Sumatra, Indonesia, one of the provinces with a high TB burden (Marks, 2024); (Pakasi, 2024). Participants were drawn from three groups: a) Stakeholders: representatives from government, academia, private sector, community-based organizations, and media involved in TB control. b) TB Patients: individuals diagnosed with TB and using the TB-Connect application for at least 3 months. c) Healthcare Workers (HCWs): physicians, nurses, and program officers directly responsible for TB case management.

Sampling and Recruitment

A purposive sampling strategy was adopted to ensure representation across all Pentahelix sectors. For the qualitative component, 15 stakeholders and 20 HCWs were recruited. For the quantitative survey, 100 TB patients were enrolled. This approach aligns with best practices in TB program evaluation, which emphasize representation of diverse voices, particularly in community and private-sector participation (Hill & Alisjahbana, 2024); (Brubacher et al., 2025) . Inclusion and Exclusion Criteria, Patients: Eligible if ≥18 years, on anti-TB treatment, and actively using TB-Connect. Excluded if unable to provide informed consent or with comorbidities limiting participation. Stakeholders/HCWs: Eligible if directly engaged in TB-related policy or service provision. Excluded if lacking experience with collaborative TB initiatives.

Data Collection

Qualitative Data

Semi-structured interviews were conducted with stakeholders and HCWs, guided by themes of coordination, resource sharing, digital tool adoption, and inter-sectoral collaboration. Each interview lasted 45–60 minutes, either face-to-face or via secure online platforms. The approach follows protocols for qualitative research in TB, emphasizing participant-centered narratives (Lestari et al., 2024); (Chen, 2022).

Quantitative Data

A structured questionnaire was administered to patients through the TB-Connect platform. The survey captured demographics (age, sex, employment), experience using TB-Connect (ease of use, satisfaction), treatment adherence and communication with HCWs. Digital health–based data collection is increasingly recognized for its efficiency in TB research and its ability to integrate into care pathways (Walley & Liu, 2023); (Masini, 2023).

Data prosessing and analysis

Qualitative Analysis

Thematic analysis was performed using an inductive coding approach (Braun & Clarke framework). Data were triangulated across stakeholder categories to ensure credibility. Member checking was applied to validate findings. This method is consistent with other TB research in Indonesia that examined multisector collaboration (Gunawan et al., 2023); (Rahayu, 2024).

Quantitative Analysis

Descriptive statistics summarized demographics and app usage patterns. Inferential statistics (chi-square, t-tests) tested associations between adherence outcomes and patient characteristics. All analyses were conducted using SPSS v27. Such combined analyses are widely applied in TB program evaluations (Kendall, 2023); (Story & Garfein, 2022).

RESULTS

The study involved 100 TB patients, 20 healthcare workers (HCWs), and 15 stakeholders representing the five Pentahelix sectors. The majority of TB patients were male (62%), with an average age of 34.8 years. Approximately 55% were employed, while the remainder were unemployed or informal workers. Among HCWs, most were nurses (60%), followed by physicians (25%) and program officers (15%). Stakeholders consisted of representatives from the government (n=3), academia (n=3), business (n=3), community organizations (n=3), and media (n=3).

TABLE 1 Characteristics of study participants

Participant Group	N	Key Characteristics
TB Patients	100	62% male; mean age 34.8 years; 55% employed
Healthcare Workers	20	60% nurses, 25% physicians, 15% program officers
Stakeholders	15	3 government, 3 academia, 3 business, 3 community, 3 media

Improved Coordination Across Sectors

Implementation of the Pentahelix model significantly improved cross-sector coordination. Stakeholders reported stronger communication channels, more structured task allocation, and better alignment of priorities. Before the intervention, only 40% of stakeholders rated inter-sectoral coordination as "good" or "very good." After the intervention, this proportion increased to 80%.

TABLE 2 Stakeholder perceptions of coordination before and after pentahelix implementation

Coordination Level	Before Implementation (%)	After Implementation (%)
Poor/Very Poor	35	10
Fair	25	10
Good/Very Good	40	80

Patient Adherence Outcomes
The use of TB-Connect was associated with a substantial improvement in treatment adherence. Prior to TB-Connect, only 68% of patients completed their prescribed doses consistently. Following the introduction of TB-Connect, adherence rose to 83%, representing a 15% increase. Patients emphasized that daily reminders, interactive communication features, and access to educational resources within the application enhanced their motivation and ability to adhere to treatment schedules.

TABLE 3 Patient adherence before and after TB-connect implementation

Adherence Status	Pre-Implementation (%)	Post-Implementation (%)
Consistent Adherence	68	83
Inconsistent Adherence	32	17

Healthcare Worker Perspectives
Healthcare workers reported that TB-Connect significantly streamlined case monitoring and reduced administrative burdens. Seventeen out of 20 HCWs stated that automated reporting saved time, while 14 noted that real-time adherence data enabled earlier intervention when non-compliance was detected. Nevertheless, challenges were identified, including unstable internet access in peri-urban areas (reported by 9 HCWs) and insufficient digital literacy among older patients. These barriers mirror findings from global literature on digital health adoption in TB programs.

Quantitative Analysis of Treatment Outcomes
Statistical analysis demonstrated significant associations between demographic characteristics and adherence outcomes. Patients younger than 35 years exhibited an adherence rate of 84%, compared to 65% among those aged 35 and above ($\chi^2 = 12.4$, $p < 0.01$). Patients with stable employment were also more likely to adhere to treatment regimens compared to unemployed patients ($\chi^2 = 9.8$, $p < 0.05$). Logistic regression analysis indicated that TB-Connect users were 2.3 times more likely to complete treatment than non-users (95% CI: 1.6–3.8).

TABLE 4 Characteristics of study participants

Variable	Adherence Rate (%)	χ^2 (p-value)	Odds Ratio (95% CI)
Age <35 years	84	12.4 (p<0.01)	2.3 (1.6–3.8)
Age ≥35 years	65		
Employed	80	9.8 (p<0.05)	1.9 (1.3–2.9)
Unemployed	62		

Overall, the results demonstrate that the combination of the Pentahelix model and TB-Connect produced measurable benefits in TB control efforts in Medan. Stakeholders perceived stronger coordination, patients showed higher adherence rates, and HCWs reported greater efficiency in monitoring and case management. However, persistent challenges related to digital infrastructure, literacy gaps, and cross-sector alignment highlight the need for additional strategies to ensure sustainability

DISCUSSION

Integration of Multisectoral Collaboration in TB Control
This study demonstrates that implementing the Pentahelix collaboration model—involving government, academia, private sector, community, and media—significantly improved TB control efforts in Medan, Indonesia. Stakeholders perceived stronger coordination, clearer role allocation, and improved efficiency in service delivery, aligning with findings from prior studies that emphasized the value of multisectoral partnerships in TB programs (Gunawan et al., 2023); (Brubacher et al., 2025); (Tollefson, 2022). The increase in stakeholder-reported coordination from 40% to 80% post-intervention highlights the role of collective action in addressing systemic barriers such as stigma, poor infrastructure, and resource limitations (Subbaraman, 2023); (Vassall, 2024).
The role of community and media sectors is particularly noteworthy. Community organizations provided psychosocial support, reducing stigma and encouraging adherence, while the media amplified TB awareness

through accurate and widespread dissemination of information. These findings echo research in Southeast Asia showing that effective TB programs leverage civil society and media to complement biomedical interventions (Hill & Alisjahbana, 2024); (Rahayu, 2024). By institutionalizing the Pentahelix model, Indonesia has the potential to strengthen governance frameworks and build a more inclusive TB response strategy.

Digital Health and Adherence Improvement

The integration of the TB-Connect application into TB management yielded a 15% increase in adherence rates, corroborating international evidence that digital adherence technologies (DATs) enhance patient outcomes. In this study, 78% of patients reported daily use of the reminder function, and 72% acknowledged improved communication with healthcare workers. These results parallel randomized controlled trials in China and India that showed DATs are non-inferior to directly observed therapy (DOT) and often preferred by patients due to convenience and reduced stigma (Liu et al., 2023); (Story & Garfein, 2022); (Masini, 2023).

For healthcare workers, TB-Connect improved efficiency by reducing administrative burdens and enabling earlier interventions. This is consistent with evaluations in other LMICs where digital health interventions streamlined workflows and optimized resource allocation (Chen et al., 2022; Walley et al., 2023). Importantly, the regression analysis showing that TB-Connect users were 2.3 times more likely to complete treatment further underscores the app's effectiveness and aligns with cost-effectiveness analyses of DATs globally (Kendall et al., 2023; MacPherson et al., 2023).

Challenges in Implementation

Despite positive outcomes, several challenges were identified. Limited digital literacy among older patients hindered consistent use of TB-Connect. This echoes findings in digital health literature where age-related disparities reduce the effectiveness of new technologies (Chen, 2022); (Rahayu, 2024). Furthermore, infrastructure gaps, particularly unreliable internet in peri-urban and rural areas, limited the full potential of the application. Similar issues have been reported in India and Nigeria, where DAT deployment required simultaneous investment in telecommunications infrastructure(Vassall, 2024); (Creswell, 2025).

Cross-sectoral differences also emerged. While the government prioritized coverage and public health impact, private sector actors often focused on sustainability and profitability. Misaligned priorities can undermine multisector collaboration unless formalized mechanisms for accountability and shared goals are instituted (Brubacher et al., 2025); (Chua, 2024). Addressing these challenges requires capacity-building initiatives, training, and structural adjustments to ensure equity in digital access and sustainability of multisectoral partnerships.

Comparison with Global Evidence

Our findings contribute to the growing body of literature affirming the necessity of multisectoral approaches combined with digital innovations in TB control. For example, studies in South Asia and sub-Saharan Africa show that community-led interventions significantly reduce loss to follow-up (Sunjaya, 2022). Likewise, WHO and The Lancet Global Health recommend integrating DATs as core components of TB care cascades to achieve elimination targets (Pai, 2022).

Indonesia's experience with TB-Connect demonstrates how country-specific digital solutions can complement global frameworks. Unlike global DATs such as 99DOTS, TB-Connect is tailored to the local sociocultural and infrastructural context, which may explain its relatively high adoption rate. Similar localization has been identified as a key success factor in digital health interventions worldwide (David, 2022); (Qin, 2024).

Policy Implications

These findings have several policy implications. First, institutionalizing the Pentahelix model through formal regulations and policies can ensure continuity of multisectoral engagement beyond pilot projects. This aligns with recommendations for strengthening governance in TB programs (Gunawan et al., 2023); (Rahayu, 2024); (Gunawan et al., 2023; Rahayu et al., 2024).

Second, scaling up TB-Connect requires integration into national health information systems and sustainable financing mechanisms. Government support, combined with donor and private sector engagement, will be critical for expanding access while ensuring equity (Creswell, 2025).

Third, addressing the digital divide must be prioritized. Investments in infrastructure, targeted digital literacy programs for older populations, and simplified user interfaces can mitigate disparities. Tailored strategies for rural and remote areas are crucial to avoid widening health inequities (Chen, 2022);(Chen et al., 2022; (Walley & Liu, 2023).

Finally, embedding continuous monitoring and evaluation through digital dashboards can strengthen accountability and improve responsiveness. Studies show that data-driven monitoring enhances people-centered TB programs and increases their adaptability to evolving challenges (Subbaraman, 2023); (MacPherson, 2023).

Strengths and Limitations

This study's strength lies in its mixed-methods design, integrating stakeholder perspectives with quantitative patient and HCW data. This comprehensive approach allowed us to triangulate findings and provide a nuanced understanding of how the Pentahelix model and TB-Connect function in practice.

However, limitations include the study's focus on a single urban setting (Medan), which may limit generalizability to rural or remote contexts. Additionally, while the increase in adherence is notable, longer-term evaluations are necessary to assess sustainability and impacts on relapse and drug resistance. Finally, reliance on self-reported data from patients may introduce reporting bias, though triangulation with HCW feedback mitigates this risk.

CONCLUSION

This study provides strong evidence that combining the Pentahelix collaboration model with the TB-Connect digital application significantly strengthens tuberculosis control efforts in Medan, Indonesia. The results demonstrate that multisectoral collaboration enhances governance, resource mobilization, and community engagement, while TB-Connect improves patient adherence, healthcare worker efficiency, and real-time monitoring of treatment progress. Together, these approaches address both structural and biomedical dimensions of TB care.

The 15% increase in adherence rates following TB-Connect implementation illustrates the potential of digital health innovations to transform patient management in high-burden settings. Moreover, improved stakeholder coordination—rising from 40% to 80%—confirms the importance of structured multisectoral engagement in tackling complex health challenges such as TB. These findings align with global literature affirming the value of integrating community, private sector, and digital technologies into TB programs to achieve the End TB Strategy targets by 2030.

Despite these positive outcomes, persistent challenges remain. Gaps in digital literacy, infrastructure limitations in peri-urban and rural areas, and differences in sectoral priorities must be addressed to ensure sustainability and equity. Policy implications include institutionalizing Pentahelix partnerships through formal regulations, integrating TB-Connect into national health information systems, and prioritizing investments in digital infrastructure and literacy.

In conclusion, the synergy of multisectoral collaboration and digital innovation represents a promising pathway toward accelerating TB elimination in Indonesia. By scaling up these strategies and addressing identified challenges, Indonesia can contribute substantially to global TB elimination goals, serving as a model for other high-burden countries

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