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Policy Challenges and Structural Barriers to Digital Transformation in Tuberculosis Control in Low- and Middle-Income Countries: A Systematic Review

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ABSTRACT

Digital transformation can strengthen tuberculosis control through adherence monitoring, patient–health worker communication, recordkeeping, and service follow-up. However, its implementation in low- and middle-income countries (LMICs) continues to face policy challenges and structural barriers. This systematic review aimed to identify policy challenges, structural barriers, and strategies supporting digital transformation in tuberculosis control in LMICs. The review followed PRISMA 2020 and was registered with the International Prospective Register of Systematic Reviews (PROSPERO; CRD420261377489). We searched PubMed, Scopus, ScienceDirect, and Springer Nature Link for peer-reviewed articles published between 2015 and 2025. The database searches initially displayed 859 records, of which 809 were successfully exported and imported into Mendeley. After removing 19 initial duplicates, we screened 790 records using the SPIDER framework. We assessed methodological quality using the JBI Critical Appraisal Checklist for Qualitative Research. Nineteen studies met the inclusion criteria and were thematically analyzed. Policy challenges involved regulation and data governance, policy communication, coordination across sectors and levels of care, and digital program integration. Structural barriers included limitations in the health workforce, technological infrastructure, financing, digital access and equity, health information systems, and service delivery. Recommended strategies comprised stronger regulation, system integration, sustainable financing, workforce development, patient-centered approaches, and monitoring and evaluation. Digital transformation in tuberculosis control requires an integrated, secure, sustainable, equitable, and context-responsive health system. Stakeholders should prioritize data protection, interoperability, sustainable financing, continuous training, and non-digital service options to prevent technology from widening inequalities in access.

INTRODUCTION

Tuberculosis remains one of the most persistent public health challenges, although effective treatment has been available for decades. Mycobacterium tuberculosis causes the disease, which is transmitted through airborne droplets from individuals with active tuberculosis. On a global scale, tuberculosis continues to produce a high burden of morbidity and mortality, particularly in countries where health systems still face resource limitations. Low- and middle-income countries carry a large share of this burden because tuberculosis control depends not only on clinical treatment but also on access to diagnosis, continuity of care, surveillance, and program governance. Countries such as India, Indonesia, the Philippines, China, Pakistan, Nigeria, the Democratic Republic of the Congo, and Bangladesh contribute substantially to global tuberculosis cases. This concentration reflects persistent challenges in service delivery, health system capacity, infrastructure readiness, and tuberculosis program management (Thomas et al., 2021).

Digital transformation has increasingly been promoted as one strategy to strengthen tuberculosis control in health systems with complex service needs. Digital health can support surveillance, program monitoring, patient follow-up, treatment adherence, health education, and communication between patients and health workers. Several digital technologies, including video-observed therapy, medication event reminder monitors, telemedicine, real-time reporting systems, and artificial intelligence-assisted screening, have been introduced in tuberculosis programs (Drabarek et al., 2025). Previous evidence suggests that video-observed therapy may improve treatment success, while medication event reminder monitors may support adherence during tuberculosis treatment (Leddy et al., 2023). Digital information systems may also improve case reporting and program monitoring when they are connected to routine health services. Therefore, digital transformation should be understood not only as technology use but also as part of broader tuberculosis control system strengthening (Mukora et al., 2023).

Secondary evidence also indicates that digital health interventions for tuberculosis serve different functions across the continuum of care. These interventions include mobile applications and SMS reminders, video-observed therapy, medication event reminder monitors, electronic information systems, telemedicine, and artificial intelligence-assisted screening. A scoping review found that these technologies can support treatment adherence, patient self-management, communication with healthcare providers, and routine program monitoring (Lee et al., 2023). Therefore, evidence of effectiveness should be considered together with the organizational and contextual conditions required for implementation.

However, the presence of digital technology does not automatically lead to effective implementation, especially in low- and middle-income countries. Many tuberculosis programs still face policy challenges related to fragmented health policies, weak integration of digital health into national tuberculosis programs, and limited coordination across sectors and levels of care. Regulatory gaps also remain important because data protection, information security, confidentiality, and health data-sharing mechanisms are not always clearly regulated (Haldane et al., 2025). These issues are particularly relevant in tuberculosis care because patient data are sensitive and may expose individuals to stigma when privacy protection is weak. Structural barriers further complicate implementation when health facilities experience unstable internet access, unreliable electricity, limited financing, shortage of trained health workers, and weak technical support. These conditions indicate that digital tuberculosis control requires policy readiness, system capacity, and service design that is sensitive to local implementation contexts (Iribarren et al., 2020).

In practice, digital tuberculosis interventions often operate within health systems that are already under pressure. Health workers may be expected to use digital platforms, monitor adherence signals, assist patients, and solve technical problems while continuing routine tuberculosis service duties. Patients may also face difficulties due to limited access to mobile phones, unstable internet connectivity, low digital literacy, privacy concerns, or limited confidence in using digital tools. These challenges are not merely technical; they are closely linked to financing, human resources, infrastructure, social inequality, and trust in health services. When digital tools are introduced without sufficient support, they may increase workload, create duplicate reporting, or reduce the quality of patient–provider interaction. Thus, digital transformation in tuberculosis control should be examined as a policy and health system implementation issue rather than a standalone technological intervention.

The implementation of digital tuberculosis interventions also depends on the health system's underlying capacity. An assessment of information and communication technology infrastructure in LMICs showed that electricity availability, internet connectivity, device access, and the readiness of health information systems influence whether digital interventions can operate reliably and reach intended users (Hui et al., 2022). These technological requirements interact with health workforce capacity because healthcare workers must operate digital platforms, interpret incoming data, respond to adherence alerts, and integrate new procedures into routine services. A health workforce framework synthesis emphasizes placing health workers at the center of health-system planning because insufficient staffing, unclear roles, and inadequate organizational support can weaken healthcare intervention delivery (Nwankwo et al., 2024). Digitalization must therefore be paired with workforce planning, ongoing training, and technical support.

Policy readiness and institutional governance are equally important for sustaining digital health programs. A systematic review of eHealth policy frameworks in low- and lower-middle-income countries highlighted the importance of national policy direction, institutional coordination, governance arrangements, and alignment between digital initiatives and broader health-system priorities (Mengiste et al., 2023). Data protection and cybersecurity also require attention because healthcare organizations in resource-constrained settings may have limited capacity to prevent, detect, and respond to cyber threats (Hasegawa et al., 2024). Furthermore, digital inequalities can operate at individual, community, and structural levels, meaning that unequal access to devices, connectivity, skills, and institutional support may determine who benefits from digital services (Kan et al., 2023). These considerations reinforce the need to examine digital tuberculosis control as an interconnected policy, equity, and health-system implementation issue.

Previous studies have examined several aspects of digital health implementation for tuberculosis and other communicable diseases. Some reviews have focused on the effectiveness of specific digital technologies, such as video-observed therapy, medication event reminder monitors, and mobile health applications for treatment adherence (Gonçalves Tasca et al., 2024). Other studies have discussed digital adherence technologies, information and communication technology infrastructure, and policy gaps in tuberculosis control across selected countries (Meyer et al., 2020). These studies provide important evidence about technical performance, patient acceptability, infrastructure readiness, and implementation barriers. Nevertheless, the available evidence remains fragmented because it has not centered policy challenges and structural barriers in digital tuberculosis control in low- and middle-income countries. This gap limits policymakers' and tuberculosis program managers' ability to understand why digital health interventions succeed in some contexts but remain difficult to sustain or scale in others.

Based on this gap, this article reviews digital tuberculosis control through a health system and policy implementation perspective. The review links governance, regulation, financing, human resources, infrastructure, health information systems, service delivery, and digital equity as interconnected implementation components. This perspective moves the analysis beyond whether digital tools are useful to how to implement them safely, equitably, and sustainably. The study focuses on literature published between 2015 and 2025, a period marked by the expansion of digital health and growing attention to innovation in tuberculosis control. Therefore, this systematic review aims to identify policy challenges, structural barriers, and recommended strategies for implementing digital transformation in tuberculosis control across low- and middle-income countries. The findings are expected to support the development of more contextual, integrated, ethical, and sustainable digital health policies for tuberculosis programs.

METHOD

This study used a qualitative systematic review design to synthesize evidence on policy challenges and structural barriers to the digital transformation of tuberculosis control across low- and middle-income countries. This design was selected because the review focused on implementation context, policy barriers, health system readiness, and structural constraints rather than clinical effectiveness. The review process followed PRISMA 2020 to support transparency in article identification, screening, eligibility assessment, and reporting. We used the SPIDER framework to guide the formulation of eligibility criteria and the search strategy. We did not conduct a meta-analysis because the included studies varied in design, setting, digital technology, and implementation context. The review protocol was registered in PROSPERO under registration number CRD420261377489.

The article search was conducted systematically through PubMed, Scopus, ScienceDirect, and Springer Nature Link. These databases were selected because they cover publications related to public health, health policy, health systems, tuberculosis, and digital health implementation. The search was limited to peer-reviewed articles published in English between 2015 and 2025. Search terms were developed from five main concepts: tuberculosis, digital health, policy and governance, implementation barriers, and low- and middle-income countries. Boolean operators “AND” and “OR” were used to combine keywords and adjust the search strategy in each database. All search results were then exported and managed using Mendeley.

All database searches were conducted on 23 June 2026. The search strategy was developed using the SPIDER framework, comprising Sample, Phenomenon of Interest, Design, Evaluation, and Research type (Table 1). Search terms covered tuberculosis, digital health technologies, policy and governance, implementation barriers, and low- and middle-income countries. Boolean operators "AND" and "OR" were used, and the syntax was adapted to the search functions and indexing conventions of PubMed, Scopus, ScienceDirect, and Springer Nature Link without changing the core concepts. The complete database-specific search strings, search fields, limits, and numbers of records retrieved are provided in Supplementary Table S1 to ensure reproducibility. Backward citation searching was also conducted by examining the reference lists of eligible and other relevant articles to identify potentially eligible studies not retrieved through the database searches. All records were exported to Mendeley for deduplication and screening. Table 2 presents the initial search results retrieved from each database.

Table 1. SPIDER Framework

Component	Operational Definition
Sample (S)	Patients with tuberculosis, healthcare workers, TB program managers, health facilities, programs, or health systems in low- and middle-income countries
Phenomenon of Interest (PI)	Digital transformation in tuberculosis control, including digital health, eHealth, mHealth, telemedicine, video-observed therapy, 99DOTS, digital adherence technologies, electronic health records, TB information systems, and artificial intelligence-assisted services
Design (D)	Qualitative interviews, in-depth interviews, focus group discussions, observations, qualitative case studies, qualitative program evaluations, and mixed-methods studies from which qualitative findings could be extracted separately
Evaluation (E)	Policy challenges, governance, regulation, implementation or structural barriers, feasibility, acceptability, financing, workforce capacity, infrastructure, digital access and equity, information systems, and service-delivery issues
Research Type (R)	Peer-reviewed primary qualitative studies and mixed-methods studies containing separately extractable qualitative findings, published in English between 2015 and 2025

Source: Author's database search documentation, 2026.

Table 2. Database-specific search strategies

Database	Complete Search String	Limits	Record
PubMed	("tuberculosis" OR "TB") AND ("digital health" OR "eHealth" OR "mHealth" OR "telemedicine" OR "VDOT") AND ("barriers" OR "challenges" OR "implementation")	English; 2015–2025	282
Scopus	TITLE-ABS-KEY("tuberculosis" OR "TB" OR "Mycobacterium tuberculosis") AND TITLE-ABS-KEY("digital health" OR "digital transformation" OR "eHealth" OR "mHealth" OR "telemedicine" OR "video observed therapy" OR "VDOT" OR "99DOTS" OR "digital adherence technology") AND TITLE-ABS-KEY("policy" OR "health policy" OR "regulation" OR "governance" OR "program implementation" OR "implementation barriers" OR "structural barriers" OR "health system barriers" OR "implementation" OR "challenges") AND TITLE-ABS-KEY("LMICs" OR "low- and middle-income countries") AND PUBYEAR > 2014 AND PUBYEAR < 2026	English; 2015–2025	28

Database	Complete Search String	Limits	Record
ScienceDirect	("tuberculosis" OR "TB" OR "Mycobacterium tuberculosis") AND ("digital health" OR "digital transformation" OR "mHealth" OR "eHealth" OR "telemedicine" OR "video observed therapy" OR "VDOT") AND ("policy" OR "health policy" OR "regulation" OR "governance" OR "program implementation" OR "implementation barriers" OR "structural barriers" OR "health system barriers" OR "implementation" OR "challenges") AND ("LMICs" OR "low- and middle-income countries")	Research articles; English; 2015–2025	40
Springer Nature Link	("tuberculosis" OR "TB" OR "Mycobacterium tuberculosis") AND ("digital health" OR "digital transformation" OR "eHealth" OR "mHealth" OR "telemedicine" OR "video observed therapy") AND ("policy" OR "health policy" OR "regulation" OR "governance" OR "program implementation" OR "implementation barriers" OR "structural barriers" OR "health system barriers" OR "implementation" OR "challenges") AND ("LMICs" OR "low- and middle-income countries")	Research articles; English; 2015–2025	509

Source: Author's database search documentation, 2026.

The database interfaces displayed 859 records at the initial search stage. After export and data cleaning, 809 records were successfully imported into Mendeley for the formal PRISMA screening process. This difference occurred because database display results and exported records may not always match after filtering, export limits, and reference-management cleaning. Therefore, the 859 records reflect the initial search coverage, while the 809 records represent those processed in the PRISMA flow. After removing 19 duplicates, 790 records were screened by title and abstract. The remaining articles were then assessed according to the predefined eligibility criteria.

The inclusion criteria were developed using the SPIDER framework. Articles were included if they discussed tuberculosis control policies, programs, services, health workers, patients, facilities, or health systems in low- and middle-income countries. The phenomenon of interest was digital transformation in tuberculosis control, including digital health, eHealth, mHealth, telemedicine, video-observed therapy, digital adherence technology, electronic health records, tuberculosis information systems, and artificial intelligence-assisted diagnosis. Eligible studies included qualitative studies and mixed-methods studies when qualitative findings could be extracted separately. Articles also had to report policy challenges, structural barriers, implementation barriers, feasibility, acceptability, governance, financing, workforce, infrastructure, or service delivery issues. Only full-text, peer-reviewed, English-language articles published between 2015 and 2025 were included.

Articles were excluded if they did not focus on tuberculosis control or did not discuss digital health implementation. Studies conducted only in high-income countries were excluded because they were outside the scope of this review. Studies with a global scope were excluded when they did not provide specific findings for low- and middle-income countries. Purely quantitative studies, clinical trials, effectiveness studies, and surveys without contextual implementation findings were also excluded. Editorials, opinion papers, commentaries, and non-systematic reviews were not included. Articles were further excluded when the full text was unavailable, the publication year was outside the selected period, or the article was not written in English.

The article update process followed the PRISMA 2020 flow, including identification, screening, eligibility assessment, and inclusion. A total of 809 records from PubMed, Scopus, ScienceDirect, and Springer Nature Link were imported into Mendeley after export and data cleaning. After removing 19 duplicate records, 790 records were screened by title and abstract using the SPIDER framework. The screening process identified 54 records as included and 36

records as possibly relevant, while 700 records were excluded because they did not match the review focus. During full-text preparation, 21 additional duplicate records were identified and 11 articles could not be obtained in full text, leaving 58 full-text articles for detailed eligibility assessment. After full-text review, 39 articles were excluded, and 19 articles m*et a*ll inclusion criteria, passed methodological quality appraisal using the Joanna Briggs Institute Critical Appraisal Checklist for Qualitative Research, and were included in the final synthesis.

Data extraction was performed using a structured extraction form developed based on the review objectives. The extracted information included author names, publication year, country, study objective, study design, research setting, participant or program context, and type of digital tuberculosis intervention. The form also recorded findings related to policy challenges, structural barriers, implementation barriers, recommended strategies, and relevant conclusions. Data extraction was conducted systematically to ensure consistency across all included articles. The extracted data were organized in Microsoft Excel. These data were then used as the basis for thematic analysis and narrative synthesis.

This review has several limitations. One reviewer primarily conducted study selection, methodological quality appraisal, data extraction, and thematic synthesis, without independent duplicate assessment by a second reviewer. Although the extracted data were discussed periodically with the supervisors and 20% of the extraction results were cross-checked, these procedures did not constitute independent duplicate review. Therefore, reviewer subjectivity or error may have affected selection decisions, quality assessments, data extraction, and thematic interpretation. Future systematic reviews should involve at least two independent reviewers and use a predefined consensus procedure or third-reviewer adjudication to resolve disagreements.

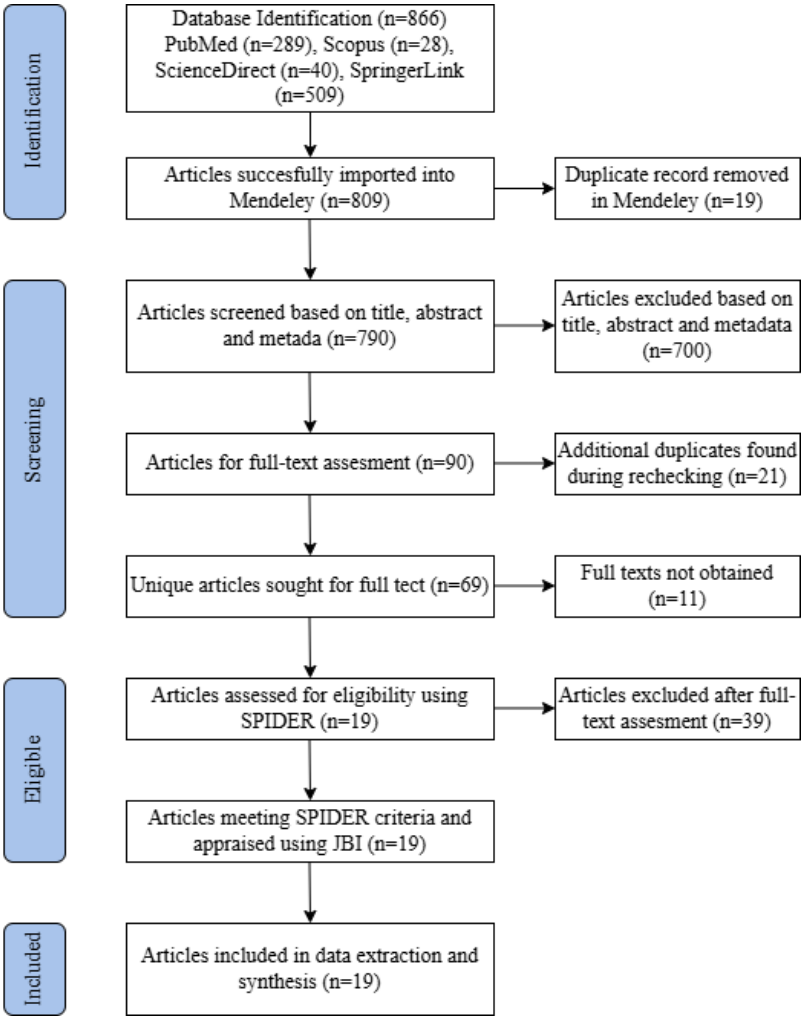

Figure 1. PRISMA flow diagram illustrating the selection process of articles

The methodological quality of the selected articles was assessed using the Joanna Briggs Institute Critical Appraisal Checklist for Qualitative Research. The appraisal examined methodological congruity, data collection, data analysis, interpretation of findings, participant representation, ethical considerations, and the relationship between data and conclusions. Each item was rated as "Yes", "No", "Unclear", or "Not applicable". A minimum score of 6 out of 10 was used as the eligibility threshold. All 19 articles scored above this threshold, so no article was excluded after quality appraisal. The appraisal results showed that the included articles had adequate methodological quality for synthesis.

The methodological quality of the included studies was appraised using the Joanna Briggs Institute Critical Appraisal Checklist for Qualitative Research. The checklist assessed methodological congruity, data collection and analysis, interpretation of findings, researcher reflexivity, participant representation, ethical considerations, and the relationship between the reported data and conclusions. Each item was rated as "Yes", "No", "Unclear", or "Not applicable". The primary reviewer conducted the appraisal without an independent duplicate assessment by a second reviewer.

The review protocol initially specified a score of at least 6 out of 10 as an internal eligibility criterion. However, this threshold was not an official JBI-recommended cut-off and was not treated as a rigid indicator of methodological quality. Greater emphasis was placed on item-level judgments and the specific methodological strengths and limitations of each study. All 19 studies scored between 8 and 10; therefore, none was excluded on the basis of methodological appraisal. Consequently, the appraisal did not function as a study-selection filter but was used to characterize the methodological quality of the included evidence and inform the interpretation of the synthesis findings.

Data were analyzed using thematic analysis and narrative synthesis. Thematic analysis identified recurring patterns related to policy challenges, structural barriers, implementation barriers, and recommended strategies. The first stage involved coding findings related to regulation, data governance, policy communication, coordination, workforce, infrastructure, financing, digital access, information systems, and service delivery. Similar codes were then grouped into descriptive themes. These themes were further compared across different countries and implementation contexts to develop analytical themes. Narrative synthesis explained the relationships between themes and presented the findings systematically.

The analysis produced three main areas of synthesis. The first area focused on policy challenges, including regulation and data governance, policy communication, coordination across sectors and levels of care, and integration of digital health programs. The second area focused on structural barriers, including health workforce limitations, infrastructure constraints, financing barriers, digital access and equity, health information system problems, and service delivery challenges. The third area focused on recommended strategies, including stronger regulation, system integration, sustainable financing, workforce development, patient-centered design, and monitoring and evaluation. This analytical process helped explain digital tuberculosis control as both a policy issue and a health system implementation issue.

RESULTS

A systematic review was conducted using articles retrieved from PubMed, Scopus, ScienceDirect, and Springer Nature Link. After export and data cleaning, 809 records were imported into Mendeley, and 19 duplicate records were removed. A total of 790 records were screened using the SPIDER framework, followed by full-text assessment and methodological quality appraisal. Nineteen articles met the inclusion criteria and were included in the final synthesis. The selected studies were then analyzed thematically based on the three review questions: policy challenges, structural barriers, and recommended strategies for digital tuberculosis control in low- and middle-income countries. The results are presented according to these three areas to maintain consistency with the research objectives.

The database searches initially displayed 859 records, of which 809 were successfully exported and imported into Mendeley. After removing 19 initial duplicates, 790 records underwent title and abstract screening using the SPIDER eligibility criteria. Of these, 700 records

were excluded, while 90 proceeded to full-text retrieval. During this stage, 21 additional duplicate records were identified, and 11 reports could not be retrieved, leaving 58 full-text articles for eligibility assessment. Thirty-nine articles were excluded after full-text assessment, and 19 studies met the inclusion criteria. All included studies underwent methodological quality appraisal, and none were excluded based on the appraisal. Figure 1 presents the study-selection process.

The 19 included studies were conducted across Africa, Asia-Pacific, and Latin America and investigated various digital tuberculosis interventions, including short message service systems, mobile applications, digital adherence technologies, video-observed therapy, electronic medication monitors, and artificial intelligence-assisted remote services. Table 4 summarizes the principal characteristics of the included studies. The findings were subsequently synthesized according to the three review questions: policy challenges, structural barriers, and recommended implementation strategies.

Table 3. Characteristics of the included studies

No.	Study	Country	Design and participants/ data sources	Digital tuberculosis intervention
1	Drabarek et al. (2025)	Vietnam	Qualitative study; 37 in-depth interviews with 25 patients and 12 healthcare workers	Bac Sy Minh application for patients and healthcare workers
2	Ggita et al. (2020).	Uganda	Exploratory qualitative study; semi-structured interviews with 10 household contacts	Automated SMS delivery of TB examination results
3	Gonçalves Tasca et al. (2024)	Tanzania	Qualitative study; 41 interviews with 19 patients and 22 healthcare workers or key stakeholders	Smart pillboxes, medication labels/99DOTS, and the EverWell platform
4	Haldane et al. (2025)	China	Qualitative process evaluation; 62 interviews with patients, caregivers, and healthcare workers	Bluetooth-enabled e-Monitor, online platform, WeChat, and family-supported care
5	Iribarren et al. (2015)	Argentina	Qualitative observational study; 115 days of workflow observation, 2,286 messages, study logs, and stakeholder input	TextTB, interactive SMS, FrontlineSMS, laptop, GSM modem, and SIM card
6	Iribarren et al. (2020)	Argentina	Qualitative study; focus groups, individual interviews, and field testing with seven patients and family input	Mobile/web-based TB support application, adverse-event reporting, adherence monitoring, communication, and self-administered urine metabolite testing
7	Leddy et al. (2023)	Uganda	Qualitative study; in-depth interviews with 30 patients, 12 healthcare workers, and seven TB program staff	99DOTS, toll-free calls, web/application dashboard, and SMS reminders
8	Leung et al. (2024)	Philippines	Qualitative interview study; 25 patients and 20 healthcare workers or key informants	Medication labels, smart pillboxes, digital adherence platform, and differentiated care

No.	Study	Country	Design and participants/ data sources	Digital tuberculosis intervention
9	Meyer et al. (2020)	Uganda	Qualitative implementation case study using visit reports, project-management records, meeting minutes, and community health worker feedback	CommCare application, digital fingerprinting, tablets, and automated SMS
10	Mukooza et al. (2024)	Eswatini	Qualitative study; 18 patients with MDR-TB, 10 healthcare workers, and nine caregivers	Smartphone-based video directly observed therapy and WhatsApp communication
11	Mukora et al. (2023a)	South Africa	Exploratory qualitative study; 62 in-depth interviews with patients across three provinces	Wisepill evriMED, SMS, telephone calls, home visits, and motivational counseling
12	Mukora et al. (2023b)	South Africa	Qualitative study; 25 interviews with 18 staff members and seven stakeholders across three provinces	Wisepill evriMED, monitoring dashboard, SMS, telephone calls, home visits, and counseling
13	Nkala et al. (2025)	Eswatini	Qualitative study; 33 in-depth interviews with patients with drug-resistant TB and healthcare workers across seven facilities	Smartphone-based video-observed treatment
14	Rabinovich et al. (2020)	Cambodia	Cross-sectional qualitative study; six focus groups involving 64 patients in urban and peri-urban settings	VDOT application for treatment videos, messaging, adherence calendar, and potential mobile-money incentives
15	Sekandi et al. (2021)	Uganda	Cross-sectional qualitative study; five focus groups involving 30 participants from four TB clinics	Asynchronous smartphone-based VDOT, encrypted video storage, healthcare-worker dashboard, and SMS reminders
16	Sivashanmugam and Mahendran (2025)	India	Community-based qualitative study; 30 in-depth interviews with patients and healthcare workers at two primary health centers	Digital adherence technologies, mobile phones, SMS/WhatsApp, tablets, NIKSHAY, and direct benefit transfer
17	Thomas et al. (2020)	India	Qualitative study; 62 patient interviews and 31 healthcare-worker interviews	99DOTS, toll-free calls, SMS reminders, and adherence dashboard
18	Thomas et al. (2021)	India	Qualitative study; 65 patients with MDR-TB and 10 healthcare workers	MERM/evriMED digital pillbox with alarms, reminder lights, opening records, and data transmission
19	Wang et al. (2025)	China	Descriptive qualitative study; semi-structured interviews with 25 urban and rural patients	Hypothetical AI-assisted remote service using reminders, symptom tracking, feedback, risk alerts, and text, voice, or video interaction

Source: Author's database search documentation, 2026.

The first review question examined policy challenges in implementing digital tuberculosis control. The synthesis grouped policy challenges into four main aspects: regulation and data governance, policy communication, coordination across sectors and levels of care, and integration of digital health programs. Regulation and data governance issues included limited regulation of privacy, confidentiality, data security, data ownership, access rights, accountability, and patient choice. Policy communication challenges appeared when instructions for digital technology use were unclear, simple, consistent, or aligned with users' language and literacy levels. Coordination problems occurred when the roles of government, health facilities, tuberculosis programs, information technology units, vendors, families, and communities were not clearly defined. Digital program integration also remained weak because some technologies operated separately from routine tuberculosis systems, creating duplicate recording or additional workload.

Table 4. Synthesis of policy challenges in digital tuberculosis control

Aspect	Main findings	Supporting author
Regulation and data governance	Privacy, confidentiality, security, data ownership, access rights, accountability, patient choice, and non-digital service options were not adequately regulated.	Mukooza et al. (2024) Mukora et al. (2023a) Sekandi et al. (2021) Thomas et al. (2021) Wang et al. (2025) Iribarren et al. (2015) Meyer et al. (2020) Mukora et al. (2023b) Wang et al. (2025) Leddy et al. (2023) Mukooza et al. (2024) Nkala et al. (2025) Rabinovich et al. (2020)
Policy communication	Instructions for digital technology use were not always clear, simple, consistent, or aligned with users' language and literacy levels.	Haldane et al. (2025) Iribarren et al. (2020) Leung et al. (2024) Thomas et al. (2020) Wang et al. (2025) Gonçalves Tasca et al. (2024) Leung et al. (2024) Mukora et al. (2023b) Thomas et al. (2020) Ggita et al. (2020) Iribarren et al. (2015) Meyer et al. (2020)
Coordination across sectors and levels of care	Roles among government, facilities, tuberculosis programs, information technology units, vendors, families, and communities were not consistently defined.	Haldane et al. (2025) Meyer et al. (2020) Mukora et al. (2023b) Sivashanmugam & Mahendran (2025) Iribarren et al. (2015) Meyer et al. (2020) Leddy et al. (2023) Mukooza et al. (2024) Rabinovich et al. (2020) Sekandi et al. (2021) Drabarek et al. (2025) Iribarren et al. (2015) Leung et al. (2024)

Aspect	Main findings	Supporting author
Integration of digital health programs	Digital technologies often operated separately from routine tuberculosis systems, causing duplicate recording, additional workload, and weak program continuity.	Drabarek et al. (2025) Haldane et al. (2025) Mukooza et al. (2024) Thomas et al. (2020) Mukora et al. (2023b) Nkala et al. (2025) Sekandi et al. (2021) Thomas et al. (2021)

Source: Author's data processing, 2026.

These findings indicate that policy challenges were not limited to the absence of digital technology guidelines. The more critical issue was how regulation, communication, coordination, and system integration shaped digital tools' ability to function within tuberculosis programs. Weak data governance could increase privacy risks, while unclear communication could reduce user understanding and trust. Poor coordination also made implementation dependent on fragmented actors rather than a clear institutional structure. In addition, weak integration turned digital tools into parallel systems instead of supporting routine tuberculosis services. Therefore, digital tuberculosis control requires stronger policy readiness before implementing technology safely and consistently.

The second review question examined structural barriers that influenced digital tuberculosis control across different LMIC contexts. The synthesis identified six main aspects: health workforce, technological infrastructure, health financing, digital access and equity, health information systems, and health service delivery. Workforce barriers included low digital literacy, staff shortages, staff turnover, training needs, and additional workload. Infrastructure barriers appeared through unstable internet, weak cellular networks, electricity limitations, charging problems, battery constraints, and unreliable devices. Financing barriers included recurring costs for devices, data packages, SMS, internet, maintenance, vendor support, and scale-up. Equity and service delivery barriers showed that digital health could exclude patients with limited access, low literacy, privacy concerns, stigma, or continuing needs for direct human support.

Table 5. Synthesis of structural barriers in digital tuberculosis control

Aspect	Main findings	Supporting author
Health workforce	Low digital literacy, staff shortages, staff turnover, training needs, and additional workload limited implementation.	Haldane et al. (2025) Leung et al. (2024) Nkala et al. (2025) Sekandi et al. (2021) Sivashanmugam & Mahendran (2025) Wang et al. (2025) Drabarek et al. (2025) Leung et al. (2024) Meyer et al. (2020) Mukora et al. (2023b) Sivashanmugam & Mahendran (2025)
Technological infrastructure	Unstable internet, weak cellular networks, electricity limitations, charging problems, battery constraints, and device unreliability disrupted digital service use. Health financing	Gonçalves Tasca et al. (2024) Leung et al. (2024) Nkala et al. (2025) Sekandi et al. (2021) Gonçalves Tasca et al. (2024) Iribarren et al. (2020) Leung et al. (2024) Nkala et al. (2025) Thomas et al. (2021)

Aspect	Main findings	Supporting author
Health financing	Costs for devices, data packages, SMS, internet, maintenance, vendor support, and scale-up were not consistently included in routine budgets.	Iribarren et al. (2015) Meyer et al. (2020) Sekandi et al. (2021) Thomas et al. (2021) Drabarek et al. (2025) Mukora et al. (2023b) Nkala et al. (2025)
Digital access and equity	Phone ownership, internet access, age, gender, income, education, rural location, language, literacy, stigma, and privacy concerns created unequal access.	Leddy et al. (2023) Rabinovich et al. (2020) Sekandi et al. (2021) Wang et al. (2025) Haldane et al. (2025) Rabinovich et al. (2020) Wang et al. (2025) Leddy et al. (2023) Mukooza et al. (2024) Mukora et al. (2023a) Thomas et al. (2020) Thomas et al. (2021)
Health information systems	Data errors, delayed synchronization, duplicate patient identities, low interoperability, and weak data follow-up reduced system reliability.	Iribarren et al. (2015) Meyer et al. (2020) Mukora et al. (2023b) Sivashanmugam & Mahendran (2025) Thomas et al. (2020) Ggita et al. (2020) Mukora et al. (2023b) Thomas et al. (2020)
Health service delivery	Digital monitoring sometimes reduced face-to-face support and added tasks when technology did not fit routine tuberculosis workflows.	Ggita et al. (2020) Mukooza et al. (2024) Rabinovich et al. (2020) Thomas et al. (2020) Drabarek et al. (2025) Leung et al. (2024) Mukora et al. (2023b)

Source: Author's data processing, 2026.

These findings show that structural barriers were interconnected and could not be treated as separate technical problems. Limited workforce capacity affected whether staff could use digital tools properly, while weak infrastructure affected whether the tools could operate consistently. Financing problems also affected sustainability because digital tuberculosis programs required ongoing operational costs, not just initial procurement. Digital inequity mattered because patients did not have the same access to phones, internet, privacy, language support, or digital literacy. Weak information systems and poorly integrated service workflows further reduced the reliability of digital data for follow-up decisions. Therefore, digital tuberculosis control needs health system strengthening, not only technology introduction.

The third review question examined strategies recommended in the literature to overcome policy challenges and structural barriers. The synthesis identified six main strategy areas: stronger regulation and governance, system and workflow integration, infrastructure and financing, human resource capacity development, patient-centered and equitable design, and monitoring, evaluation, and adaptation. Regulation strategies emphasized data protection, privacy, security, algorithm transparency, human oversight, standard operating procedures, role distribution, accountability, and coordination. Integration strategies emphasized connecting applications, digital adherence technologies, dashboards, and tuberculosis information systems with routine service workflows. Infrastructure and financing strategies focused on stable

networks, electricity, devices, data packages, technical support, maintenance, replacement, and routine budg*et al*location. Patient-centered strategies emphasized local language, simple interfaces, voice features, offline functions, human support, non-digital options, and community involvement.

Table 6. Synthesis of recommended strategies for digital tuberculosis control

Aspect	Main findings	Supporting author
Stronger regulation and governance	Policies should regulate data protection, privacy, security, algorithm transparency, human oversight, standard operating procedures, role distribution, accountability, and coordination.	Mukooza et al. (2024) Sekandi et al. (2021) Thomas et al. (2021) Wang et al. (2025) Drabarek et al. (2025) Haldane et al. (2025) Iribarren et al. (2015) Meyer et al. (2020)
System and workflow integration	Digital tools should be integrated with tuberculosis information systems, dashboards, routine workflows, automation, and feedback mechanisms.	Drabarek et al. (2025) Iribarren et al. (2015) Leung et al. (2024) Mukora et al. (2023b) Thomas et al. (2020) Iribarren et al. (2015) Meyer et al. (2020) Thomas et al. (2020)
Infrastructure and financing	Programs should provide stable networks, electricity, devices, data packages, technical support, maintenance, replacement, and routine budget allocation.	Gonçalves Tasca et al. (2024) Leung et al. (2024) Nkala et al. (2025) Sekandi et al. (2021) Thomas et al. (2021) Iribarren et al. (2015) Meyer et al. (2020) Mukora et al. (2023b) Sekandi et al. (2021)
Human resource capacity development	Programs should provide continuous digital training, information technology staff, user support, and adequate workforce capacity.	Haldane et al. (2025) Leung et al. (2024) Nkala et al. (2025) Rabinovich et al. (2020) Sivashanmugam & Mahendran (2025) Wang et al. (2025) Meyer et al. (2020) Mukora et al. (2023b) Sivashanmugam & Mahendran (2025) Drabarek et al. (2025) Iribarren et al. (2020) Rabinovich et al. (2020) Wang et al. (2025)
Patient-centered and equitable design	Technologies should use local language, simple interfaces, voice features, offline functions, human support, non-digital options, and community involvement.	Ggita et al. (2020) Leddy et al. (2023) Mukooza et al. (2024) Rabinovich et al. (2020) Sekandi et al. (2021) Leddy et al. (2023) Mukora et al. (2023a) Sekandi et al. (2021) Thomas et al. (2020) Thomas et al. (2021)

Aspect	Main findings	Supporting author
Monitoring, evaluation, and adaptation	Programs should use iterative evaluation, user feedback, equity monitoring, system reliability checks, and quality monitoring during scale-up.	Drabarek et al. (2025) Iribarren et al. (2020) Meyer et al. (2020) Mukora et al. (2023b) Nkala et al. (2025) Wang et al. (2025)

Source: Author's data processing, 2026.

These strategies show that digital tuberculosis control should be planned as a long-term health system investment. Stronger regulation is needed to protect patients and clarify institutional responsibilities. System integration is necessary to prevent duplicate work and ensure that digital data can support real service decisions. Sustainable financing and workforce development are also required because digital systems need maintenance, training, and user support after implementation begins. Patient-centered design is important to prevent digital tools from widening inequities among patients with different levels of access and literacy. Continuous monitoring and evaluation are needed so digital tuberculosis programs can adapt to local barriers during scale-up.

DISCUSSION

Policy challenges in the digital transformation of tuberculosis control

The findings show that policy challenges in digital tuberculosis control were mainly related to regulation, data governance, policy communication, cross-sector coordination, and program integration. Several studies reported that privacy protection, confidentiality, data security, data ownership, and access rights were not adequately regulated in digital tuberculosis services (Iribarren et al., 2015; Meyer et al., 2020; Mukooza et al., 2024; Mukora et al., 2023a; Mukora et al., 2023b; Sekandi et al., 2021; Thomas et al., 2021; Wang et al., 2025). This condition shows that digital transformation creates new governance demands because tuberculosis data are sensitive and may expose patients to stigma when privacy safeguards are weak. The reviewed studies also indicated that patient choice and non-digital alternatives were not always guaranteed, especially for patients who had limited access to devices or felt uncomfortable with digital monitoring (Leddy et al., 2023; Mukooza et al., 2024; Nkala et al., 2025; Rabinovich et al., 2020). These findings suggest that digital tuberculosis policies should not only regulate technology use but also protect patient autonomy, confidentiality, and equitable access. Policy readiness becomes essential because digital tools cannot operate safely when legal responsibility, data ownership, and accountability remain unclear.

Policy communication also influenced implementation because patients and health workers needed clear instructions to use digital tools correctly. Several studies reported that information about digital technology use was not always simple, consistent, or aligned with users' language and literacy levels (Haldane et al., 2025; Iribarren et al., 2020; Leung et al., 2024; Thomas et al., 2020; Wang et al., 2025). Other studies showed that automated messages or digital adherence signals could differ from patients' actual conditions, creating uncertainty for health workers in interpreting data and deciding follow-up actions (Gonçalves Tasca et al., 2024; Leung et al., 2024; Mukora et al., 2023b; Thomas et al., 2020). Coordination problems appeared when government agencies, tuberculosis programs, health facilities, information technology units, vendors, families, and communities did not have clearly defined roles (Haldane et al., 2025; Leddy et al., 2023; Meyer et al., 2020; Mukooza et al., 2024; Mukora et al., 2023b; Rabinovich et al., 2020; Sekandi et al., 2021; Sivashanmugam & Mahendran, 2025). This pattern explains why digital tuberculosis programs often depend on external vendors or temporary project structures rather than strong local system capacity. The policy challenge is therefore not only the absence of written rules but also the weak translation of rules into coordinated, understandable, and routine service practice.

Structural barriers affecting digital tuberculosis control implementation

The findings show that structural barriers limited health systems' practical capacity to implement digital tuberculosis control. Health workforce limitations were reported across several studies, particularly in relation to low digital literacy, limited training, staff shortages, staff turnover, and additional workload (Drabarek et al., 2025; Haldane et al., 2025; Leung et al., 2024; Meyer et al., 2020; Mukora et al., 2023b; Nkala et al., 2025; Sekandi et al., 2021; Sivashanmugam & Mahendran, 2025; Wang et al., 2025). These barriers appeared because digital tools required health workers to record data, check adherence signals, assist patients, solve technical problems, and conduct follow-up while routine tuberculosis duties continued. Patients also required support when they were older, had lower education, or lacked confidence in using mobile phones and applications (Haldane et al., 2025; Leung et al., 2024; Nkala et al., 2025; Wang et al., 2025). This evidence indicates that digital transformation can increase workload when introduced without sufficient staff, ongoing training, and technical support. Digital tuberculosis programs should treat workforce capacity as a core implementation requirement rather than an additional operational detail.

Infrastructure and financing barriers further explain why digital tuberculosis interventions were difficult to scale and sustain. Studies reported unstable internet, weak cellular networks, unreliable electricity, charging problems, limited battery capacity, low video quality, and device malfunction, especially in rural or remote areas (Gonçalves Tasca et al., 2024; Iribarren et al., 2020; Leung et al., 2024; Nkala et al., 2025; Sekandi et al., 2021; Thomas et al., 2021). Financing barriers also appeared because devices, data packages, SMS, internet access, maintenance, vendor support, and scale-up activities required continuous funding that was not always included in routine tuberculosis budgets (Drabarek et al., 2025; Iribarren et al., 2015; Meyer et al., 2020; Mukora et al., 2023b; Nkala et al., 2025; Sekandi et al., 2021; Thomas et al., 2021). Digital access and equity issues were also important because phone ownership, internet access, gender, age, income, education, language, literacy, stigma, shared phone use, and privacy concerns affected patients' ability to use digital services (Leddy et al., 2023; Mukooza et al., 2024; Mukora et al., 2023a; Rabinovich et al., 2020; Thomas et al., 2020; Thomas et al., 2021; Wang et al., 2025). Health information system barriers, including data errors, delayed synchronization, duplicate patient identities, and weak interoperability, reduced the reliability of digital data for service decisions (Iribarren et al., 2015; Meyer et al., 2020; Mukora et al., 2023b; Sivashanmugam & Mahendran, 2025; Thomas et al., 2020). These findings show that structural barriers are interconnected because infrastructure, financing, digital access, system reliability, and service workflow jointly determine whether technology can support tuberculosis care.

This review has several limitations. First, study selection, methodological quality appraisal, data extraction, and thematic synthesis were primarily conducted by a single reviewer without independent duplicate assessment; although the supervisors periodically reviewed the process and cross-checked 20% of the extracted data, these procedures were not equivalent to an independent second review and therefore did not eliminate the risk of reviewer-related bias. Second, the review included only English-language publications, which may have introduced language bias and excluded relevant evidence published in local languages. Third, the evidence base was geographically and academically concentrated: four of the 19 included studies were conducted in Uganda, and several studies were produced by recurring research groups, including the Iribarren, Mukora, and Thomas groups. This concentration may overrepresent particular implementation settings and limit the transferability of the findings to other LMIC contexts. Fourth, a meta-analysis was not conducted because the included studies were qualitative and heterogeneous in their designs, participants, settings, technologies, and reported outcomes; consequently, the review identifies thematic patterns but does not estimate pooled intervention effects. Fifth, restricting the review to peer-reviewed publications and not conducting a systematic grey-literature search may have introduced publication or dissemination bias. Confidence in the synthesized findings was assessed using the ConQual approach specified in the review protocol (Munn et al., 2014). An additional GRADE-CERQual assessment was not undertaken because it had not been prespecified and would have constituted a post hoc duplication of the confidence assessment; therefore, the findings should still be interpreted in light of the limitations described above.

Strategies and policy recommendations for overcoming implementation barriers

The literature recommends strengthening digital tuberculosis control through regulation, governance, system integration, financing, workforce development, patient-centered design, and continuous evaluation. Several studies emphasized the need for clear rules on data protection, privacy, security, algorithm transparency, human oversight, standard operating procedures, role distribution, accountability, and coordination mechanisms (Drabarek et al., 2025; Haldane et al., 2025; Iribarren et al., 2015; Meyer et al., 2020; Mukooza et al., 2024; Sekandi et al., 2021; Thomas et al., 2021; Wang et al., 2025). System integration was also recommended because applications, digital adherence technologies, dashboards, and electronic records should be connected with routine tuberculosis information systems and service workflows (Drabarek et al., 2025; Iribarren et al., 2015; Leung et al., 2024; Mukora et al., 2023b; Thomas et al., 2020). This recommendation responds directly to findings that parallel systems can create duplicate records, add workload, and weaken follow-up. The literature also highlights the need for stable networks, electricity, devices, data packages, technical support, maintenance, replacement, and routine budget allocation (Tasca et al., 2024; Iribarren et al., 2015; Leung et al., 2024; Meyer et al., 2020; Nkala et al., 2025; Sekandi et al., 2021; Thomas et al., 2021). These strategies suggest that digital tuberculosis control should be planned as a long-term health system investment rather than a short-term technology project.

The reviewed studies also recommend human resource development and patient-centered approaches as essential conditions for equitable implementation. Continuous digital training, sufficient staff, information technology personnel, and user support were recommended to improve the ability of health workers and patients to use digital tools in daily tuberculosis care (Haldane et al., 2025; Leung et al., 2024; Meyer et al., 2020; Mukora et al., 2023b; Nkala et al., 2025; Rabinovich et al., 2020; Sivashanmugam & Mahendran, 2025; Wang et al., 2025). Patient-centered strategies included involving patients in design, using local language, simplifying interfaces, adding voice features, enabling offline functions, maintaining human support, offering non-digital options, and involving families or communities when needed (Drabarek et al., 2025; Ggita et al., 2020; Iribarren et al., 2020; Leddy et al., 2023; Mukooza et al., 2024; Rabinovich et al., 2020; Sekandi et al., 2021; Wang et al., 2025). These strategies are important because tuberculosis patients may face stigma, privacy concerns, limited literacy, and unequal access to digital resources. Monitoring and evaluation should also be iterative because implementation barriers can change when programs move from pilot settings to routine services and wider scale-up (Drabarek et al., 2025; Iribarren et al., 2020; Meyer et al., 2020; Mukora et al., 2023b; Nkala et al., 2025; Wang et al., 2025). Future research should examine long-term sustainability, cost integration, interoperability, data governance, patient safety, and equity outcomes in digital tuberculosis programs across different low- and middle-income country settings.

CONCLUSION

Policy challenges remained central to the digital transformation of tuberculosis control in low- and middle-income countries. This review found that weak regulation, limited data governance, unclear policy communication, fragmented coordination, and poor integration of digital health programs affected implementation. These challenges show that digital tuberculosis control requires more than introducing applications, devices, or monitoring platforms. Health systems need clear rules on privacy, confidentiality, data ownership, access rights, accountability, and patient choice. Policy communication also needs to be simple, consistent, and responsive to users' language and literacy. Stronger governance is needed so digital tools can support tuberculosis services safely, ethically, and consistently.

Structural barriers also limited the use of digital tuberculosis interventions across different low- and middle-income country contexts. This review identified barriers related to health workforce capacity, digital literacy, infrastructure, financing, digital access, health information systems, and service delivery. These barriers were connected because digital tools depend on trained staff, stable internet, reliable electricity, functional devices, sustainable funding, and interoperable data systems. Patients also need fair access to digital services, especially when age, gender, income, education, rural residence, stigma, or privacy concerns affect technology use.

Digital monitoring may also reduce direct human support when it is not properly integrated into routine care. These findings imply that digital tuberculosis control should be designed as part of health system strengthening, not as a separate technical intervention.

The reviewed literature recommended strategies that combine regulation, system integration, infrastructure investment, sustainable financing, workforce development, patient-centered design, and continuous evaluation. Ministries of health, local health offices, and tuberculosis programs should strengthen data protection, interoperability standards, role distribution, routine budgeting, continuous training, and integration between digital tools and tuberculosis service workflows. Programs should also provide non-digital service options, maintain human support, involve families or communities when appropriate, and protect patients from privacy risks and unequal access. Monitoring and evaluation should be conducted regularly so digital systems can adapt to local needs, user barriers, and service capacity. Future research should include broader country coverage, multiple reviewers, and long-term assessment of effectiveness, cost, data security, interoperability, and equity in digital tuberculosis technologies.

AUTHOR'S DECLARATION

Authors' contributions and responsibilities

DY: Conceptualization, methodology, data collection, data extraction, formal analysis, writing-original draft, and manuscript preparation; **FI:** Supervision, validation, review, and editin; **CM:** Supervision, validation, review, and editing.

Competing interests

The authors affirm that no conflicts of interest are present in this study.

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