

BRIDGING THE GAP: TELEMEDICINE AND TB TREATMENT ADHERENCE IN INDIA

Amit Kumar Bardhan*¹, Saad Ashraf²

1. Faculty of Management Studies, University of Delhi, Delhi, India

2. School of Management, Bennett University, Uttar Pradesh, India

*Correspondence: amit-bardhan@fms.edu

ABSTRACT

OBJECTIVE:

This article examines the progress made in utilizing telemedicine for the treatment of tuberculosis (TB), particularly in enhancing patient adherence to treatment regimens. In a case study, the review evaluates the Ni-Kshay platform for health professionals and patients in India, identifying pain points contributing to treatment defaults. It aligns these findings with the country's National TB Elimination Program (NTEP) and offers recommendations to enhance telemedicine's role in TB treatment adherence.

METHODS:

The Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) framework was used to identify articles from two databases: Web of Science, and PubMed. The literature search included terms such as Telemedicine, eHealth, mHEALTH, Digital Health, Mobile Health, Video DOT, along with Tuberculosis and TB. Articles published between January 2021 and June 2024 were selected for the review.

RESULTS:

Out of 948 initially retrieved articles, 94 were reviewed and a final 69 articles included in this review. Except one, all reported positive outcomes from telemedicine. Video DOT and video calls showed superior results among various technologies. Instant messaging apps and smart pillboxes are rising. Mobile app solutions are promising. Telemedicine serves as a complementary tool to in-person clinical supervision, enhancing rather than replacing traditional face-to-face oversight. Integrating successful external interventions by studying local utility and limitations is critical.

CONCLUSION:

The utilization of telemedicine in TB treatment is increasing, highlighting the necessity for documenting best practices and establishing standardized protocols. However, the success of any technology-driven solution hinges on its alignment with user needs and contextual realities. In developing countries, it is crucial to deliberately and pragmatically integrate these solutions to effectively address challenges such as unequal access, high costs, social stigma, comorbidity prevalence, and delivery inefficiencies.

KEYWORDS

Tuberculosis (TB); Medication adherence; Telemedicine; Systematic review; Digital health; SDG goal 3.3

INTRODUCTION

Tuberculosis (TB) remains a major global health challenge, with approximately 10.6 million cases reported in 2022. Southeast Asia (46%), Africa (23%), and the Western Pacific (18%) account for the highest case burdens, where access to continuous, quality healthcare is often limited [1]. TB has consistently been the leading cause of death from a single infectious agent, excluding the recent COVID-19 pandemic [1].

To combat this, the World Health Organization (WHO) introduced the Directly Observed Treatment Short Course (DOTS) program in 1994, standardizing TB treatment across nations. The regimen typically lasts 6–9 months for uncomplicated cases, extending further for multidrug-resistant TB (MDR-TB) [2]. This prolonged treatment period is crucial for complete bacterial eradication and the prevention of drug-resistant strains [3].

Strict adherence to TB medication is critical for effective treatment outcomes. WHO and other organizations have implemented various strategies to support DOTS, including the integration of digital health technologies [4]. However, the absence of standardized tools and protocols hampers the widespread adoption of these technologies [5].

Telemedicine, the use of telecommunications and digital technologies to provide remote medical care, has shown significant potential in TB management. It offers several advantages, such as improved access to healthcare, enhanced patient monitoring, and reduced costs [6,7]. By complementing existing healthcare systems, telemedicine proves especially beneficial for patients requiring long-term treatment, including those with chronic infectious diseases like TB.

Successful implementation of telemedicine for managing TB, hepatitis B and C, and HIV has been documented in several settings [8]. Other telemedicine interventions, including mobile applications, messaging services, and digital adherence technologies (DATs), are also increasingly utilized in TB treatment [9, 10, 11, 12, 13]. However, comprehensive reviews on telemedicine's impact on TB management remain limited [5, 8, 14].

In 2015, WHO launched the "End TB Strategy," targeting an 80% reduction in TB incidence and a 90% decrease in TB deaths by 2030 [1]. India, which carries a significant TB burden, has responded with the National TB Elimination Programme (NTEP), leveraging digital technologies like *Ni-Kshay*, an online platform that aids patient care, monitoring, and management. NTEP offers free diagnosis and treatment and incentivizes private sector participation, which now accounts for 30% of TB case notifications. In 2022, India recorded 2.42 million TB cases, with extensive testing and enhanced treatment efforts, significantly reducing case numbers. *Ni-Kshay* has played a critical role in these improvements.

Nevertheless, patient adherence to TB treatment remains a challenge, with default cases observed in both public and private healthcare sectors [15]. Telemedicine offers a potential solution, as studies indicate that telemedicine-assisted supervision improves medication adherence and reduces default rates compared to traditional, in-person supervision [16, 17].

This article explores recent advancements in TB treatment and evaluates the potential for further integration of telemedicine interventions within the *Ni-Kshay* framework [4, 5]. It aims to achieve this through a comprehensive literature review, assessing global telemedicine interventions for TB and identifying those yet to be implemented in India's NTEP. Furthermore, this article examines the reasons for treatment defaults in India, aligning these with existing NTEP strategies and highlighting untested telemedicine interventions. The paper concludes by recommending enhancements to *Ni-Kshay* to improve medication adherence and TB management in India.

LITERATURE REVIEW

RESEARCH METHODOLOGY

This study systematically reviews telemedicine-based interventions for TB treatment using the PRISMA guidelines [18], with modifications (scoping review and broader set of keywords) to align with the Ni-Kshay framework. This study conducts a PRISMA-informed scoping review with a systematic search and expanded keywords to synthesise evidence on telemedicine-based TB interventions aligned with the Ni-kshay framework. The review covers studies from January 2021 to June 2024, focusing on recent advancements in Telemedicine. Literature searches were conducted on *PubMed* and *Web of Science*. In this study we applied the following definition of Telemedicine, "Any intervention utilizing telecommunication, internet, or information technology for enhancing medication adherence". Both authors conducted the review manually, without bibliographical software. It was agreed between the authors that papers listed under *PubMed* and *Web of Science* databases would be deemed of sufficient quality for the review if they meet the inclusion criteria. Disagreements were resolved through discussion, with adjudication by the first author where consensus could not be reached.

INCLUSION-EXCLUSION CRITERIA

Using the above definition of telemedicine, the final shortlist for the review was created based on specific inclusion and exclusion criteria. Each article had to meet two inclusion criteria with at least one sub-criterion from the second set. Articles were excluded if they met any exclusion criteria.

Inclusion criteria

1. The article discusses a telemedicine-based intervention method for TB medication adherence.
2. At least one of the following was identified:
 - (a) The article studies the implementation of a telemedicine intervention.
 - (b) The article studies a previously implemented telemedicine intervention with a new set of participants in a new geographical setting.
 - (c) The article studies a previously implemented telemedicine intervention to improve or alter the intervention process.

Exclusion criteria

1. The article discusses telemedicine intervention but not for TB treatment.
2. The article uses a telemedicine intervention usually used in TB treatment but for studying its treatment of non-TB diseases.
3. The article references telemedicine intervention for TB treatment but the focus of the article is not on studying its implementation or medication adherence.
4. The article reference telemedicine interventions but its objective is to study in-person TB treatment.

SEARCH PROCESS

Initially a set of keywords were identified for the search process using TB reports by WHO [1] and the Government of India [19], as well telemedicine research [7,14,6]. The identified keywords were used in the following search strings for their respective databases:

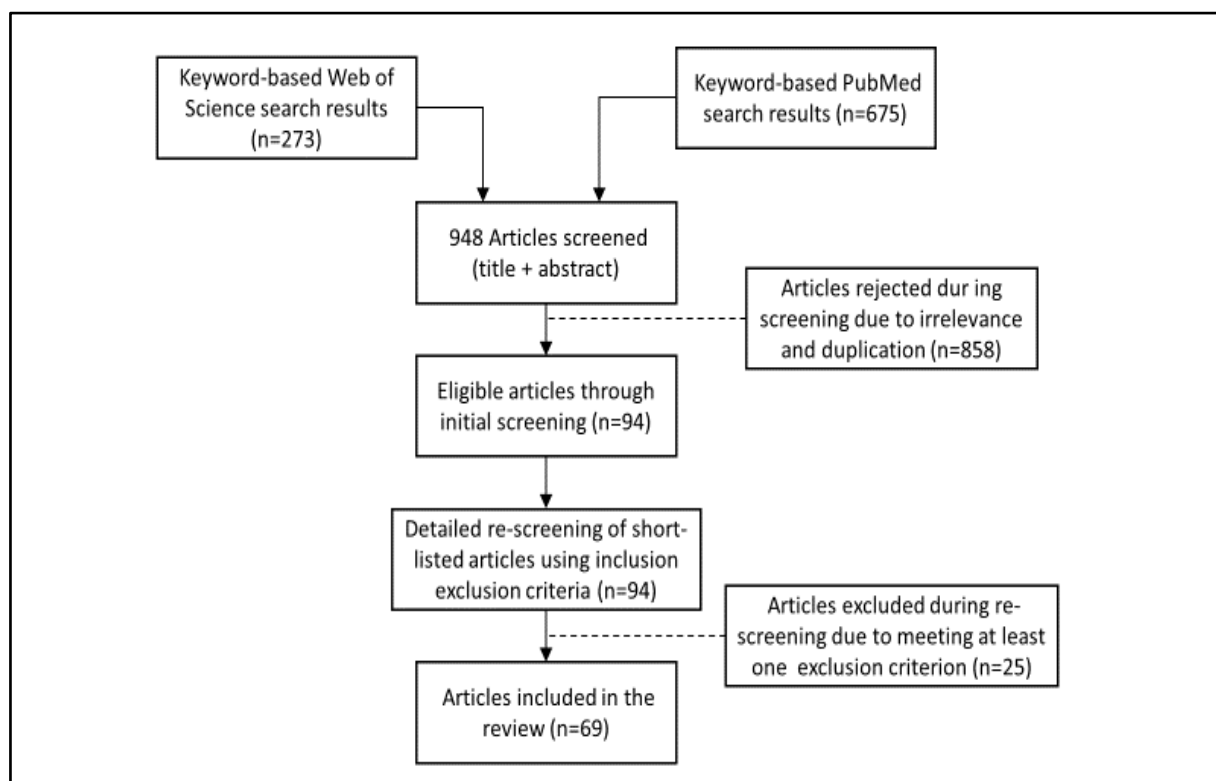
PubMed search string: (((((((((Telehealth) OR (Telemedicine)) OR (EHEALTH)) OR (MHEALTH)) OR (Digital Health)) OR (Mobile Health)) OR (VDOT)) OR (Video DOT)) OR (EDOT)) AND ((Tuberculosis) OR (TB))

Web of Science search string: (Telehealth" OR Telemedicine" OR Tele-health" OR Tele-medicine" OR EHEALTH" OR E-Health" OR MHEALTH" OR Digital Health" OR Mobile Health" OR VDOT" OR Video DOT" OR E-DOT" OR EDOT") AND (Tuberculosis" OR TB")

The *PubMed* and *Web of Science* searches yielded 675 and 273 results, respectively. After reviewing the titles and abstracts of these 948 articles, 94 papers were short-listed. The manuscripts of these 94 papers were rigorously examined based on inclusion-exclusion criteria. Subsequently, 69 research articles, focusing on the implementation of telemedicine-based TB interventions between January 2021 and June 2024, were selected for the review. Each of the 25 articles

excluded during the rescreening fell under at least one of the exclusion criteria. The flow of information for the entire search process is illustrated in Figure 1.

FIGURE 1: FLOW OF INFORMATION FOR THE PRISMA SEARCH PROCESS



RISK OF BIAS ASSESSMENT

The Joanna Briggs Institute (JBI) Critical Appraisal Tools suite was utilized for a risk of bias assessment on the final shortlist [96]. The included articles were first grouped according to their primary study design, following which the appropriate JBI Critical Appraisal checklist(s) were assigned to each group.

Each article was then assessed with the appropriate JBI Critical Appraisal checklist. Subsequently, the articles were analyzed based on their checklist performance and their ability to infer adherence effectiveness of the intervention being studied. These assessments were used to derive a risk of bias categorization at the study design level. Groups (based on study design) were categorized into low, moderate and high risk of bias depending on the overall risk profile of the articles within that group. Categorizing risk of bias at the study design level allowed for comparison of methodological rigor across designs.

The assessment results have been outlined in Table 1. Randomized controlled trials demonstrated lower risk of bias, while quasi-experimental, cross-sectional, qualitative, and textual evidence sources tended to show moderate to high risk, reflecting methodological and inferential limitations.

TABLE 1: RISK OF BIAS BY STUDY DESIGN USING JBI CRITICAL APPRAISAL TOOLS

Study Design	JBI Checklist Used	Studies	Risk of Bias	Notes
Randomized Controlled Trials (including cluster, stepped-wedge, superiority, non-inferiority, pilot RCTs)	JBI Checklist for Randomized Controlled Trials	Majella et al. [55]; Byonanebye et al. [57]; Sahile et al. [58]; Gashu et al. [59]; Kibu et al. [26]; Iribarren et al. [63]; Manyazewal et al. [64]; Burzynski et al. [14]; Kumwichar et al. [67]; Boutilier et al. [27]; Liu et al. [12]; Wei et al. [48]; Cattamanchi et al. [11]; Bao et al. [28]	Low	Randomisation and structured follow-up support internal validity. Completed trials reporting outcomes demonstrate low risk.
Randomized Controlled Trials (cluster and stepped-wedge protocol studies) with no outcome data	JBI Checklist for Randomized Controlled Trials	Sekandi et al. [54]; Tadesse et al. [24]; Iribarren et al. [56]; Ross et al. [32]; Velen et al. [66]; Cheng et al. [79]; Jerene et al. [25]; Foster et al. [46]	Not Applicable	Protocol-only papers with planned but not yet reported outcomes. Risk of bias cannot be formally judged.
Cohort & Longitudinal Studies	JBI Checklist for Cohort Studies	Udwadia et al. [10]; Perry et al. [35]; Lippincott et al. [37]; Bachina et al. [44]; Li et al. [38]; Rodrigues et al. [43]; Wu et al. [69]; Wang et al. [70]; Zhou et al. [81]	Moderate	Good follow-up and real-world adherence measurement, but non-random allocation limits internal validity.
Quasi-Experimental / Pre-Post Studies	JBI Checklist for Quasi-Experimental Studies	Santra et al. [22]; Wijayanti et al. [68]; Saha et al. [16]; Chen et al. [21]	Moderate to High	Useful real-world evidence but absence of randomization increases selection bias. Chen et al. [21] showed reduced outcomes, suggesting implementation uncertainty.
Analytical Cross-Sectional / Comparative Cross-Sectional / Survey Studies	JBI Checklist for Analytical Cross-Sectional Studies	Zhang et al. [17]; Walle et al. [77]; Levine et al. [72]; Kiwanuka et al. [78]; Selvaraju et al. [30]; Htet et al. [74]; Katende et al. [62]; Rahayu et al. [61]	Moderate to High	Good descriptive value, but many rely on self-reported measures. Surveys are exploratory in nature with small samples; outcome causation cannot be inferred.
Qualitative / CFIR / Exploratory / Perception Studies	JBI Checklist for Qualitative Research	Sekandi et al. [40]; Thomas et al. [52]; Mukora et al. [33]; Tumuhimbise et al. [75]; Sekandi et al. [76]; Shah et al. [80]; Milligan et al. [51]; El Joueidi et al. [47]	High	Appropriate for exploring context and experiences; however, do not measure adherence or treatment outcomes.
Mixed-Methods Studies	JBI Checklist for Qualitative Research + Appropriate JBI Quantitative Checklist	Szkwarko et al. [45]; Kim et al. [53]; Maro et al. [34]; Musiimenta et al. [13]; Milligan et al. [51]	Moderate	Comprehensive insight; but, quantitative components often lack randomization, and qualitative rigor is good but not universal.

Pilot / Feasibility / Implementation Studies	Appropriate JBI Quantitative Checklist matched to study design (eg. RCT, Quasi-experimental, Cohort)	Donahue et al. [23]; Marx et al. [29]; Casalme et al. [41]; Katende et al. [62]; Tello-Cajiao et al. [71]	Moderate	Exploratory in nature with small samples; focus is on implementation of the intervention.
Usability / Acceptability / Developmental Studies	JBI Checklist for Qualitative Research and/or JBI Checklist for Analytical Cross-Sectional Studies	Rahayu et al. [61]; Htet et al. [9]; Kumwichar et al. [42]; Abas et al. [36]	Moderate to High	Focus is on the design and testing of the intervention.
Textual Evidence (Narrative, Expert Opinion, Policy / Consensus)	JBI Critical Appraisal Checklists for Textual Evidence (Narrative or Expert Opinion or Policy / Consensus)	Robbiati et al. [39]; Park et al. [50]; Calnan et al. [60]; Yang et al. [65]	Moderate to High	Descriptive nature with focus on providing insights about implementation and not empirical evaluation of interventions.

TABLE 2: CATEGORIZATION OF THE LITERATURE

Author	Type of study	Telemedicine based intervention	Participants	Geography of study	Effectiveness*	Within NTEP / Ni-Kshay	Notes
Santra et al. [22]	Quasi-experimental study	SMS; voice calls	TB patients	Delhi (India)	85.5% - 96.4% (A)	Yes	The intervention duration was 90 days comprising once-daily text message in local language Hindi and once a week real-time two-way 10 minutes voice call.
Sekandi et al. [40]	Exploratory qualitative study	Mobile 'sureAdhere' application	TB patients, nurses, health workers, family member of patient	Kampala (Uganda)	N.A.	Yes	The respondents had no real-life experience using <i>sureAdhere</i> . Still, they identified some critical issues such as cost of internet, the smartphone, and privacy or confidentiality concerns.
Park et al. [50]	Integrated patient management project	Smart pillbox; medication monitoring system	TB patients	Morocco	N.A. - 90% (only end-line %)	No	The smart pillbox sends medication updates of patients to the system. The medication monitoring system operates similarly to the health worker interface of the <i>Ni-Kshay</i> platform.

Szkwarko et al. [45]	Mixed methods study	Mobile application	TB patients, health workers, community volunteers	Kenya	10.7% - 16.2% (A)	Yes	The mobile application is used for presumptive TB screening. A tablet device provided to health workers for the same.
Milligan et al. [51]	Mixed methods thematic analysis	Mobile application	TB patients, health workers	Buenos Aires (Argentina)	N.A.	Yes	The mobile application tracks treatment progress, provides disease tailored information, allows interactive communication between patients and health workers, and is linked with a direct adherence drug metabolite test.
El Joueidi et al. [47]	Consolidated Framework for implementation research (CFIR)	Digital platform and mobile application 'WeTel'	TB patients, health workers, nurses, WeTel manager	Kenya, Rwanda and Canada	N.A.	Yes	WeTel allows patients to communicate with health workers via short message service (SMS), voice and video call.
Thomas et al. [52]	Qualitative study	Smart pillbox	TB patients	Chennai and Mumbai (India)	N.A.	No	Probable missed doses would result in automated SMS text messaging notifications prompting health workers to intervene with patients.
Kim et al. [53]	Mixed methods study	Chatbot	TB patients, TB treatment experts	Seoul (South Korea)	N.A.	No	The chatbot was built on an open-source platform and operates within an instant messenger app called Kakao Talk.
Perry et al. [35]	Observational study	Mobile 'emocha' application	TB patients	California (USA)	53.9% vs. 68.4% (B)	Yes	Patients were daily sent two text message reminders in the absence of submitted videos and were prompted to document side effects prior to submissions.
Donahue et al. [23]	Pilot study	Software 'Adobe Connect'	TB patients	Maryland (USA)	N.A. - 100% (only end-line %)	Yes	The software was used to conduct VDOT for TB patients.
Sekandi et al. [54]	Randomized controlled trial	Digital platform and mobile application	TB patients	Kampala (Uganda)	N.A. (protocol)	No	Weekly internet subscription, text message reminders, and incentives for those who adhere to VDOT treatment are part of the intervention.
Majella et al. [55]	Randomized controlled trial	Voice calls	TB patients	Puducherry (India)	13.0% vs. 4.7% (C, measured loss to follow-up)	Yes	The intervention was used to remind patients to register for anti-TB treatment after referral, in order to reduce pre-treatment loss to follow up.
Iribarren et al. [56]	Randomized controlled trial	Web platform and mobile application	TB patients	Buenos Aires (Argentina)	N.A. (protocol)	Yes	A health worker and a direct adherence test strip is assigned to each patient. The application functions similar to Ni-Kshay.
Cattamanchi et al. [11]	Stepped-wedge cluster-randomized trial	Medication label '99DOTS'	TB patients	Kampala (Uganda)	70.5% vs. 86.6% (C, per protocol)	Yes	Patients need to call health workers and provide the label code for each medication so that their adherence can be tracked.

Tadesse et al. [24]	Cluster randomized trial	Web platform `ASCENT`; smart pillbox; medication label	TB patients	Oromia and Addis Ababa (Ethiopia)	N.A. (protocol)	No	Smart pillbox and medication label were used as interventions for different participant groups and their adherence was measured using ASCENT.
Byonanebye et al. [57]	Randomised control trial	Interactive voice response technology	TB patients	Kampala (Uganda)	N.A. (protocol)	Yes	-
Sahile et al. [58]	Randomised control trial	SMS; voice calls	TB patients	Addis Ababa (Ethiopia)	N.A. (protocol)	Yes	-
Gashu et al. [59]	Randomised control trial	Voice calls	TB patients	Gondar (Ethiopia)	66.4% vs. 79% (C)	Yes	The intervention involved weekly pill refilling and daily medication reminders through phone calls.
Udwadia et al. [10]	Cohort study	Digital tools `Skype` and `Zoom`; instant messenger `WhatsApp`	TB patients	Mumbai (India)	27% vs. 68% (B, preference by patients)	Yes	Telemedicine involved providing online consultations to participants.
Lippincott et al. [37]	Retrospective cohort study	Mobile `emocha` application	TB patients	Maryland (USA)	59% vs. 86% (B)	Yes	Patients use <i>emocha</i> application through Smartphone / tablet and the TB clinic uses a web-based dashboard to conduct VDOT.
Bao et al. [28]	Randomized control trial	Instant `WeChat` messenger	TB patients	Harbin (China)	N.A. (measured for self-management)	No	Pharmacists provide health education to TB patients through WeChat.
Marx et al. [29]	Pilot study	Instant messenger `WhatsApp`	TB patients	Cape Town (South Africa)	N.A. (measured response to reminders)	No	WhatsApp based reminders were sent prior to appointment scheduled 2-3 days after the diagnostic visit.
Robbiati et al. [39]	Situation analysis	Digital platform	Health workers and health facility	Luanda (Angola)	N.A.	Yes	The digital platform is used for electronic medical records and functions similarly to the health worker's interface of the <i>Ni-Kshay</i> platform.
Calnan et al. [60]	Government project	Helpline number/call centre	TB patients	Philippines	N.A.	Yes	Intervention is similar to TB helpline <i>Ni-Kshay Sampark</i>
Bachina et al. [44]	Observational cohort study	Mobile `emocha` application	TB patients	Minneapolis, Minnesota (USA)	54.5% vs. 81% (B)	Yes	The study implemented VDOT 7 where Patients were instructed to submit videos documenting ingestion of medications.
Casalme et al. [41]	Feasibility and acceptability study	Web platform and mobile application `sureAdhere`	TB patients, health workers	Cavite (Philippines)	78% vs. 82% (B)	Yes	Patients had to record videos of them ingesting TB medication as part of the VDOT intervention.
Rahayu et al. [61]	Usability study	Mobile `SIKRIBO` application	Health workers	Semarang (Indonesia)	N.A. (measured system usability)	Yes	The SIKRIBO application was developed using design science research methodology.
Htet et al. [9]	Usability study	Mobile application `TB-screen`	TB patients	Mandalay City (Myanmar)	N.A. (measured system usability)	No	The application screens TB risk propensity of participants.

Li et al. [38]	Prospective cohort study	Mobile application 'TB Assistant'; web system and mobile application 'TB Doctor'	TB patients	Tianjin (China)	51.84% - 84.84% (A)	Yes	TB Assistant is the patient side and TB Doctor is the doctor side of the system. Doctors can view medication feedback, respond to questions, communicate with patients and send messages. The framework is similar to Ni-Kshay.
Kibu et al. [26]	Randomized control trial	SMS	TB patients	Buea and Kumba districts (Cameroon)	41.7% - 61.2% (A)	No	Both single way and double way communication through SMS were assessed as interventions individually as well as combined.
Katende et al. [62]	Pilot study	Mobile application	TB patients, health workers	Kampala (Uganda)	66% - 85% (measured adherence port)	No	Voice text mobile application was developed using design science research methodology.
Iribarren et al. [63]	Pilot randomized control trial	Mobile application	TB patients	Buenos Aires (Argentina)	81% vs. 95% (C)	Yes	Patients can interact with health workers assigned to them through the application. Additionally, a urine drug metabolite test is provided as part of the intervention.
Manyazewal et al. [64]	Randomized control trial	Smart pillbox	TB patients	Addis Ababa (Ethiopia)	N.A. - 79% (measured average adherence)	No	-
Burzynski et al. [14]	Randomized non-inferiority trial	Digital tool 'Skype'; mobile application 'sureAdhere'	TB patients	New York City (USA)	87.2% vs. 89.8% (C)	Yes	Patients can either record their videos (sureAdhere) or do live video conferencing (Skype) from their preferred locations for VDOT.
Yang et al. [65]	Project study	Smart pillbox; medication monitoring system	TB patients	Sale (Morocco)	N.A. (measured cost effectiveness using Markov model)	No	The web-based medication monitoring system sends medication reminders to patients. Smart pillboxes only monitor opening of the pillboxes electronically and not ingestion.
Manyazewal et al. [31]	Randomized control trial	Smart pillbox 'evriMED500'	TB patients	Addis Ababa (Ethiopia)	98.97% vs. 99.01% (C, measured geometric mean)	No	-
Selvaraju et al. [30]	Survey study	Instant messenger 'WhatsApp'	Health workers, TB patients	Tamil Nadu (India)	45% - 0% (A, measured loss to follow up)	Yes	WhatsApp was used by health workers to communicate among themselves. The intervention was concerned with improving communication between health workers.
Velen et al. [66]	Randomized control trial	Mobile application	TB patients	Vietnam	N.A. (protocol)	Yes	The mobile application functions similar to the Ni-Kshay application.
Kumwihar et al. [67]	Cluster Randomized control trial	Mobile application 'LINE'	TB patients, health workers	Songkhla province (Thailand)	N.A. (protocol)	Yes	The specific VDOT system 'TH VOT' was used as the intervention.

Kumwichar et al. [42]	Usability study	Mobile application `LINE`	TB patients, health workers	Songkhla province (Thailand)	N.A.	Yes	The specific VDOT system `TH VOT` was used as the intervention.
Boutilier et al. [27]	Randomized control trial	SMS	TB patients	Nairobi (Kenya)	N.A.	No	Patients can use the unstructured supplementary services data (USSD) interface to access educational information about TB and information on their adherence performance compared with other (anonymised) patients.
Wijayanti et al. [68]	Quasi- experimental study	Mobile application `ER-LINA`	TB patients, health workers	Jakarta (Indonesia)	N.A.	No	ERLINA provides audio-visual media, use of straightforward language and communication with assigned health worker. It also allows real-time data monitoring without internet.
Saha et al. [16]	Quasi- experimental study	Mobile application; web-based application; physical device `TMEAD`	TB patients	Nasik, Maharashtra (India)	90% vs. 99% (B)	No	The tuberculosis monitoring encouragement adherence drive (TMEAD) reminds, dispenses, and senses a patient's adherence to the treatment regime. Web-based application provides real-time monitoring with daily updates and patient analytics to health institutions. Mobile application provides instant updates and a quick view for the on-field TB health worker.
Wu et al. [69]	Prospective cohort study	Mobile application; smart pillbox	TB patients	Shanghai (China)	N.A. (measured three for groups)	No	The application provides medication reminders to patients.
Wang et al. [70]	Longitudinal study	Instant messenger `WeChat`; smart pill- box	TB patients	China	83.8% vs. 95.3% vs. 95.7% (C, Control group vs. WeChat group vs. pillbox group)	Yes	WeChat and EMM were studied as separate interventions.
Tello-Cajiao et al. [71]	Implementation study	Instant messenger `WhatsApp`	TB patients	Cal (Colombia)	N.A. vs. 98% (A, only end-line %)	Yes	WhatsApp was used for video calls between patient and health worker to ensure that the patient ingests the medication.
Abas et al. [36]	Development and validation study	Mobile application `GR-VOTS`	IT experts, health workers, health administrators	Malaysia	N.A.	No	Gamified real-time video observed therapies (GR-VOTS) uses gamification of treatment schedule to improve adherence.
Levine et al. [72]	Cross-sectional study	Voice calls; message prompts	TB patients	Connecticut (USA)	N.A. - 94.3% (A, only endline %)	Yes	-

Chen et al. [21]	Pre-post study	Medication label '99DOTS'	TB patients	Himachal Pradesh (India)	93.1% - 92.9% (A, measured favourable treatment outcome)	Yes	The intervention caused a decline in favourable outcome. However, the decline was not statistically significant.
Rodrigues et al. [43]	Cohort study	Mobile application 'v.Cure'	TB patients	Bangalore, Karnataka (India)	94% (measured acceptability of videos)	Yes	v.Cure was used to record medication ingestion videos by patients. It also sent adherence text reminders.
Musiimenta et al. [13]	Mixed methods formative study	SMS; mobile wallet 'Wise-Cash'; smart pillbox 'evriMED1000'	TB patients	Uganda	N.A. (measured financial incentives preference)	No	The My Mobile Wallet intervention is composed of a real-time medication monitor, SMS reminders, and a WiseCash component for sending mobile money incentives. The NTEP also has similar reward systems under its programme.
Foster et al. [46]	Cluster randomised trial	Web platform 'ASCENT'; smart pillbox 'evriMED'; medication label	TB patients	Addis Ababa and Oromia (Ethiopia)	N.A. (protocol)	No	Smart pillbox and medication label were used as interventions for different participant groups and their adherence was measured using ASCENT.
Liu et al. [12]	Cluster randomised superiority trial	Smart pillbox	TB patients	China	10% vs. 9% (C, measured loss to follow up)	No	A monthly review of adherence data was provided to patients, and also used to provide differentiated care for patients with adherence issues.
Zhang et al. [17]	Comparative cross sectional study	Electronic system 'e-PSS'	TB patients	Wuhan (China)	80.33% vs. 84.28% (B)	Yes	The interface of e-Patient Service System (e-PSS) is used by health workers for data collection and data management of patients, similar to Ni-Kshay. This study compares e-PSS with the paper based TB control information system (TCIS).
Manyazewal et al. [73]	Randomised controlled trial	Smart pillbox 'evriMED500'	TB patients	Addis Ababa (Ethiopia)	63.43 vs. 85.78 (C, effectiveness measured using TQSM)	No	Treatment satisfaction questionnaire for medication version 4 (TSQM 1.4) was used to compare effectiveness, side effects and convenience between arms of the study.
Jerene et al. [25]	Pragmatic cluster randomised trial protocol	Web platform 'ASCENT'; smart pillbox 'evriMED'; medication label 99DOTS	TB patients	South Africa, Tanzania, Ukraine and Philippines	N.A. (protocol)	No	Smart pillbox and medication labels to be used as interventions in different facilities and their performance to be measured using ASCENT.
Mukora et al. [33]	Qualitative study	Smart pillbox 'evriMED'; SMS; voice calls	Health workers, stakeholders	South Africa	N.A.	No	Health workers were surveyed and thematic analysis was used to discuss the feasibility and effectiveness of the interventions.
Htet et al. [74]	Survey study	Mobile application	Community members	Mandalay (Myanmar)	N.A.	Yes	Mobile application used to calculate the TB risk propensity of patients by uploading their details.
Tumuhimbise et al. [75]	Qualitative study	Mobile application 'Tuuka'; SMS	Health workers	Mbarara (Uganda)	N.A. (measured usability)	Yes	The module for SMS reminders was also integrated within the application.

Sekandi et al. [76]	Cross-sectional qualitative study	Mobile application	TB patients	Kampala (Uganda)	N.A.	Yes	The application is used for asynchronous monitoring, that is, patients need to record and submit videos of ingesting medicine.
Ross et al. [32]	Randomized controlled trial	Smart pillbox 'Wisepill RT3000'	TB patients	Durban, KwaZuluNatal(South Africa)	N.A. (protocol)	No	Study included four arms, with the pillbox being one of the interventions. Participants using the pillbox could choose a text message reminder from a guided menu, and received weekly messages to encourage adherence.
Walle et al. [77]	Cross-sectional; Structural equation modelling	SMS	Health workers	Ilu Aba Bor and Buno Bedelle (Ethiopia)	N.A.	Yes	Structural equation modelling was used to measure the intention and attitude towards using SMS by health workers.
Kiwanuka et al. [78]	Survey study	Medication label 99DOTS; SMS; voice calls	TB patients	Uganda	N.A.	Yes	-
Cheng et al. [79]	Randomized controlled trial	Mobile application 'Bac Sy Minh (Dr Smart)'	TB patients	Vietnam	N.A. (measured cost effectiveness)	Yes	Participants were provided money to cover the data usage costs.
Shah et al. [80]	Exploratory qualitative study	Mobile application 'Ni-Kshay SETU'	Health workers, stakeholders	Jharkhand and Gujarat (India)	N.A.	Yes	Ni-Kshay SETU is developed by Indian Institute of Public Health, Gandhinagar and follows NTEP protocols. However, it is outside the official Ni-Kshay framework under NTEP.
Abas et al. [49]	Single-arm intervention study	Mobile application 'GR-VOTS'	TB patients	Malaysia	81% vs. 90.87% (B)	No	Gamified real-time video observed therapies (GR-VOTS) uses gamification of treatment schedule
Zhou et al. [81]	Cohort study	Mobile application; smart pillbox	TB patients	Yiwu city, Zhejiang China)	89.6% vs. 94.3% (B)	Yes	Participants had to choose between application used to send reminders and smart pillbox as interventions. A management website was provided for medical staff to monitor patients' medication adherence.
Maro et al. [34]	Mixed methods study	Smart pillbox 'evriMED'; SMS	TB patients	Kilimanjaro (Tanzania)	N.A. (based on demographics)	No	EvriMED is a medication dispenser with internet connectivity that can send real-time SMS reminders.
Wei et al. [48]	Randomized controlled trial	Smart pillbox; mobile application; instant messenger 'WeChat'	TB patients	Tibet	36% vs. 9.8% (C, measured poor adherence to treatment)	No	The pillbox also has audio message reminders. An associated application to facilitate adherence monitoring and communication between patients and healthcare workers and a free smartphone data package was also part of the intervention.

Note: In effectiveness column, (A) is 'baseline adherence % - end-line adherence %'; (B) is 'in-person intervention vs. telemedicine intervention'; (C) is 'control group adherence vs. intervention group adherence'. Details beyond these categories have been specified in parentheses.

TABLE 3: GLOBAL BEST PRACTICES VS NI-KSHAY FRAMEWORK

Domain	Global Best Practices	Current Status in Ni-Kshay	Identified Gap	Feasibility in India	Adaptable Recommendation
Patient Engagement & Support	Patient-centred mobile apps enabling self-monitoring, adherence tracking, education, and communication	Patient information largely managed by healthcare workers; limited active patient-side engagement	System is provider-driven; weak patient empowerment and interaction features	High (apps already exist; patient literacy improving)	Strengthen patient interface with self-monitoring dashboard, educational material, symptom reporting, and structured follow-up prompts.
Tele-Counselling	Counselling delivered by trained TB health professionals; structured behavioural support protocols	Ni-Kshay Sampark provides tele-counselling but via non-medical call agents	Potential misinformation; absence of clinical qualification and expertise in counselling	Moderate (large population, workforce training burden, and policy integration challenges)	Hybrid model with medically trained counsellors for complex cases; standardized counselling scripts; clear escalation process; phased rollout rather than nationwide at once.
Communication Channels	Multi-channel communication: SMS, voice, instant messaging, app notifications, two-way interaction	SMS reminders and telephonic counselling exist; WhatsApp is used informally	No formal integrated messaging platform within Ni-Kshay; limited two-way structured communication	Moderate (significant number of patients are low-tech users)	Integrate app or platform linked two-way messaging system; retain SMS for low-tech users
Digital Adherence Technologies (DATs)	Smart pillboxes (MERM), medication labels, automated tracking dashboards integrated with apps	Smart pillboxes and 99DOTS exist; alerts and reminders are in use	Fragmented integration; underutilisation of real-time analytics	High	Consolidate DATs into unified Ni-Kshay dashboard; real-time adherence monitoring
Video-Supported Treatment (VDOT)	Widely validated VDOT systems improving adherence and reducing burden	No integrated VDOT in Ni-Kshay; limited due to internet coverage challenges	Lack of in-system VDOT functionality; reliance on voice calls	Moderate (selective due to digital divide; realistic mainly for urban, higher-income populations)	Pilot VDOT in urban / connectivity-strong districts
Integrated Telemedicine Ecosystems	Unified platforms integrating app, dashboard, VDOT, messaging, pillboxes, reminders	Ni-Kshay app + Ni-Kshay Sampark operate as separate systems	System fragmentation; parallel telemedicine entities	Moderate	Integrate Sampark into Ni-Kshay ecosystem or create structured interoperability
Data Use & Analytics	Real-time dashboards, predictive analytics, early identification of risk of default	Primarily monitoring and registry functions	Limited analytical analysis for proactive intervention	Moderate	Introduce intervention focussed clustering and risk-flagging processes
Equity & Access	Offline capability, low-data solutions, multilingual design, inclusive design	Internet connectivity challenges; reliance on telephony and SMS for many	Digital divide limits advanced telemedicine reach	High for low-tech tools; Moderate for video	Prioritize SMS/voice + DAT strengthening; selective VDOT rollout; vernacular and low-bandwidth app optimisation

TABLE 4: USER-CENTRIC DESIGN ENHANCEMENTS FOR IMPROVING NI-KSHAY FRAMEWORK

Recommendation	Description of suggestion	Name of application	Integration proposal	Reasoning behind recommendation
Offline function	The application should be able to save changes made in online mode. Later, it should automatically update the information when internet becomes accessible.	Ni-Kshay application and TB Arogya Saathi	-	Internet availability is a huge issue in India. This would reduce the waiting time of health workers when they are Doing field visits.
Health worker forum	The forum is used for communication amongst health workers. Users can post queries in the forum where other health workers can answer. Answers can be upvoted or downvoted based on their usefulness and correctness.	Ni-Kshay application	The forum should be available on the homepage of the Ni-Kshay application.	Instructional and technical issues with the application often need immediate attention. Since updates aren't instant, this forum will offer health workers insights on how others handle such situations, serving as user feedback.
Patient forum	This forum is used for communication amongst TB patients. Similar to the health worker forum, TB patients can post queries in the forum which other TB patients can answer. Answers can be upvoted or downvoted based on their usefulness and correctness to ensure false information is not spread. TB patients can visit archives for useful information.	TB Arogya Saathi	The forum should be available on the homepage of the TB Arogya Saathi application.	TB patients can find the forum helpful regarding side effects, motivation, destigmatization, and a sense of community.
Notepad	A notepad section will help users keep a tab of their progress or manage their daily routine.	Ni-Kshay application and TB Arogya Saathi	The notepad should be available inside the patient/health worker forum since both are text-based tools.	It can be used to create to-do lists, remember medicine names and schedules, and manage appointments for TB patients. Health workers can utilize the notepad to organize their daily workload. It will be useful for recording and sharing information on the forum.
Points and badge rewards (gamification)	Patients are presented with a treatment timeline and milestone indicators. As they progress, they earn points based on adherence, displayed on the app's progress meter. Better adherence results in higher-ranked badges. Milestones include complete adherence for a period, completing TB treatment tutorials, and medication changes.	TB Arogya Saathi	The home page, treatment details page, adherence details page should be used to integrate the suggestion.	Gamifying will improve the motivation of patients. They will be inclined to earn higher rewards and badges on their profile for which they will improve their adherence rates.
Leaderboard (gamification)	The leaderboard ranks patients based on their adherence performance, including points and badges. These leaderboards can be categorized by geography, demographics, type of intervention, and time period. Patients can see their ranking and view the points and badges of others, while maintaining anonymity.	TB Arogya Saathi	The leaderboard shortcut should be available on the homepage of TB Arogya Saathi.	Patients can access these leaderboards to see their adherence performance ranking. This feature motivates them to improve, allows them to compare their progress with others, and helps destigmatize the TB medication process.

RESULTS AND DISCUSSION

The COVID-19 pandemic and the WHO's "End TB Strategy" have accelerated the adoption of telemedicine for TB treatment [20]. Table 2 summarizes the reviewed articles, detailing author information, study type, intervention, participant characteristics, geography, and effectiveness. The studies vary in how effectiveness is assessed: (a) Baseline versus end-line adherence (b) Comparison of in-person and telemedicine interventions (c) Control group versus intervention group adherence. Additional notes are included where effectiveness could not be measured, such as in ongoing studies.

The review categorizes telemedicine interventions used in TB treatment. Most studies, except Chen et al. [21], reported positive outcomes. Video-assisted DOTS (VDOT) and health worker phone calls for medication adherence have demonstrated effectiveness [22,23]. Cost-effective methods like medication labels (e.g., 99DOTS) are widely adopted in high TB-burden countries [11,24,25]. SMS reminders are effective in medication adherence and information dissemination [26,27]. Instant messaging apps, such as WhatsApp and WeChat, are increasingly used for communication between patients and health workers due to their convenience [28,29,30].

Smart pillboxes, such as evriMED and WisePill (also called medication event reminder monitors or MERM), are another important tool. These devices store TB medication and electronically track when opened, transmitting data to a patient management system. They are typically paired with SMS and voice call interventions [31,32,33,34].

Mobile applications designed explicitly for TB medication adherence have emerged as a significant advancement. These apps feature interfaces for patients, health workers, and doctors, enabling schedule management, communication, and treatment monitoring [35,36,37,38,39]. Many are designed to facilitate VDOT [40,41,42,43], with popular apps such as sureAdhere and emocha being widely used [14,44]. Applications are also employed for presumptive TB screening, documenting side effects, and patient-health worker communication [45]. For example, the ASCENT app monitors TB treatment via smart pillboxes and medication labels [24,46], while WelTel facilitates SMS, voice, and video communication between patients and health workers [47].

Mobile applications often integrate with other telemedicine tools, including smart pillboxes, SMS, voice calls, and mobile wallets, yielding positive results [48]. Discussions have also emerged about gamifying TB medication adherence through apps [49]. Before presenting recommendations, this review will examine the reasons for TB treatment defaults in India and the telemedicine initiatives for TB elimination under NTEP.

CASE: TB ELIMINATION IN INDIA

To complement the literature review and ground the findings in practice, this article adopts a case study approach to examine the use of telemedicine for TB treatment in India. Case studies are suitable for public health research as they allow detailed examination of complex health system interventions. India's high TB burden and nationwide implementation of the Ni-kshay platform under the NTEP provide a relevant setting to explore treatment adherence challenges. This approach allows for an assessment of how digital tools interact with social, economic, and health factors contributing to treatment default. It also aids in identifying practical gaps and opportunities to strengthen telemedicine-supported TB care.

DEFAULT IN TB TREATMENT

India's TB eradication program faces multiple challenges, including non-adherence to treatment and delays in testing. Non-compliance is widespread, driven by direct and indirect financial burdens, despite free treatment availability at public facilities [82,83]. Many patients remain unaware of these free services [84]. Social stigma remains a persistent issue, causing treatment default despite efforts to reduce stigma [19,85,86]. Misconceptions about TB and lack of scientific awareness exacerbate the stigma problem [84,85].

Additional factors contributing to treatment default include drug side effects, fear of hospitalization, long waiting times, and lack of family support [84,82]. Patients in the private sector are harder to retrieve due to challenges like treatment

costs, travel, and perceptions of ineffective medications [15,19]. Private providers are incentivized for TB case notifications, even if patients continue private treatment [19].

Certain populations face disproportionate challenges. Low-income households struggle with treatment affordability, delaying care-seeking and reducing adherence. Poverty is both a risk factor and an outcome of TB [19]. Patients with comorbidities like HIV or diabetes are prone to non-adherence due to resistance, stigma, and financial constraints. Geriatric patients face additional challenges, including forgetfulness and comorbidities, which elevate default rates [87]. Migrant TB patients often default due to a lack of employer support and familial pressures [84]. Gender and sexual identity discrimination, along with household responsibilities and limited autonomy, further affect adherence, particularly among women and female sex workers [19,88]. Drug resistance complicates treatment, increasing the likelihood of default, especially in MDR-TB cases [89]. Many patients default prematurely upon feeling better, particularly in MDR-TB cases, despite ongoing efforts to mitigate non-adherence [89,90].

INTERVENTION UNDER NTEP

High treatment default rates challenge India's TB eradication efforts, increasing the burden on government programs. Under the National TB Elimination Programme (NTEP), "Ni-Kshay Diwas" (an observance and community engagement day) is observed on a day every month to retrieve patients lost to follow-up. This involves health officials, community leaders, and healthcare workers across public and private centers [19]. However, retrieving defaulters remains challenging [15], necessitating interventions that target default-causing behaviors during diagnosis and treatment.

To address adherence challenges, the government implements direct benefit transfer (DBT) schemes under NTEP, which provide financial support to patients. Programs like Ni-Kshay Poshan Yojana (NPY) offer nutritional support and transportation incentives for those in remote areas. Economic incentives are also provided to healthcare workers to encourage successful treatment completion. Additionally, community engagement initiatives aim to raise awareness, reduce social stigma, and promote health-seeking behaviors [19].

TELEMEDICINE INTERVENTIONS

Despite efforts to reduce defaults, adherence challenges persist. Telemedicine interventions through the Ni-Kshay framework are critical in mitigating defaults. Ni-Kshay Sampark, a dedicated call center, assists TB patients and healthcare providers daily. It includes an online grievance system and tele-counseling services, which help dispel misconceptions and enhance patient self-care [28].

The Ni-Kshay mobile application and web portal serve as patient information management systems for registered healthcare workers. Patients can be added to the database through public health workers or private practitioners and can track their progress via the app. This has improved treatment outcomes and reduced follow-up losses. Less tech-savvy patients are supported by their healthcare workers, while those more proficient in technology can monitor their treatment independently.

Ni-Kshay Sampark operates separately from the Ni-Kshay app and provides tele-counseling by customer support executives who are not medical professionals. While useful, this can lead to miscommunication if their advice differs from that of healthcare workers. The Sampark service also uses SMS for patient engagement, and smart pillboxes send audiovisual reminders to ensure medication adherence. The "99DOTS" system also alerts patients who miss doses by sending SMS reminders [91].

Telemedicine has proven effective for TB management, especially with Video Directly Observed Therapy (VDOT), which has shown positive results for TB treatment adherence [92]. However, less than 50% of India has internet access [93], making it difficult for low-income patients to benefit from video consultations. Given the high TB burden, providing internet data packs would be costly, and the Ni-Kshay framework currently lacks integrated video-calling capabilities.

Health workers mainly rely on voice calls and in-person visits, occasionally using messaging apps like WhatsApp for communication, though these are not formal telemedicine tools under NTEP. Telephonic counseling has been crucial in ensuring adherence among multi-drug-resistant TB patients [94], while telemedicine has been used to monitor TB patients during the COVID-19 pandemic [20, 95]. Video-assisted telemedicine offers potential, particularly for managing vulnerable groups such as women, elderly patients, and those with limited access to healthcare, but nationwide implementation remains challenging.

STRENGTHENING NI-KSHAY FRAMEWORK

COMPARING WITH GLOBAL TELEMEDICINE EVIDENCE

A comparison of the Ni-Kshay framework with global initiatives in TB elimination highlights several similarities and differences in the use of mobile applications, VDOT (Video Directly Observed Therapy), smart pillboxes, medication labels, and SMS-based interventions. While the Ni-Kshay app supports smart pillboxes and 99DOTS medication labels for adherence management, it lacks support for synchronous or asynchronous VDOT [71].

VDOT has proven highly effective in managing TB treatment adherence globally [44, 41]. However, providing free VDOT to every TB patient in India may not be feasible due to infrastructural challenges, scalability, and patient-specific issues such as internet access, data costs, and familiarity with video technology. Implementing a nationwide VDOT system would be cost-intensive, requiring significant investment in infrastructure and training. Patients who can afford private healthcare or VDOT can still track their adherence through the Ni-Kshay or TB Arogya Saathi applications (Arogya Sathi is a digital support application under NTEP - <https://tbcindia.mohfw.gov.in/tb-aarogya-sathi/>), alongside general-purpose tools like Adobe Connect [23], Skype [14], and Zoom [10]. These digital platforms allow video calls or recordings, though adherence tracking typically occurs through a separate application.

Medication labels and smart pillboxes within Ni-Kshay use SMS or mobile apps to send reminders and track missed doses [34, 48]. SMS is also employed for awareness campaigns and reminders [26]. In the Ni-Kshay framework, SMS and voice calls are common tools for communication, though SMS functions outside of the Ni-Kshay app and are not automated. Only one reviewed application had integrated SMS functionality [75]. Nonetheless, updating a patient's profile in Ni-Kshay can trigger SMS notifications, and healthcare workers can use voice calls when necessary [19]. A chatbot is not part of Ni-Kshay [53]; instead, Ni-Kshay Sampark and informal communication through voice calls or messaging apps between patients and healthcare workers fulfill this role.

Mobile wallets have been used to distribute financial incentives to TB patients [13]. Through the TB Arogya Saathi app, patients can link their accounts to the DBT (Direct Benefit Transfer) schemes under NTEP. However, this feature is unavailable in the Ni-Kshay app [19].

IMPLICATIONS AND RECOMMENDATIONS

The Ni-Kshay framework constitutes a comprehensive 'technology + human' integrated system supporting TB elimination in India. It encompasses a wide range of telemedicine interventions, implemented variably across different socio-economic contexts, in accordance with feasibility and implementation constraints. We compared individual telemedicine components of the Ni-Kshay framework with the global best practices evidenced in the literature. As comprehensive as it is, some gaps remain in the Ni-Kshay framework. These gaps are listed in Table 3, along with their potential feasibility for India, and potential recommendations to commence their integration into the Ni-Kshay framework. Furthermore, closing each identified gap is an enormous challenge considering the sheer scale at which TB elimination needs to be addressed in a country like India. A clear example of this is the implementation of VDOT. Literature demonstrates VDOT as an effective intervention for TB treatment adherence and outcomes [23, 40, 41, 42, 43, 44]. Pilot studies conducted in India for VDOT also show encouraging results [22]. However, VDOT is not feasible nationwide. While it can be used in urban settings with strong internet connectivity, such accessibility represents a very small fraction of

India's population [19, 83]. A substantial digital and financial divide exists, especially in the rural and socio-economically disadvantaged settings [15, 82, 83, 84, 86].

The infrastructural requirements, internet dependency and associated implementation costs make nationwide implementation of VDOT into the Ni-Kshay framework highly difficult. In contrast, voice calls as an alternative to VDOT remains practical and cost-effective [22, 55]. Other countries like Ethiopia and Uganda have also adopted voice calls over VDOT due to the costs and challenges associated with the latter [58, 59, 78]. Thus, understanding the context in which VDOT, despite being a global best practice, is not integrated within the Ni-Kshay framework becomes important. Recommendations towards closing the gaps in the Ni-Kshay framework cannot always be to adopt the global best practice.

On the other hand, it is pragmatic to identify opportunities of improvement in the interface design and features of the Ni-Kshay application and TB Arogya Saathi. Since these applications are already in use, they do not require additional infrastructure investments. Moreover, health workers are provided training for using these applications and patients are also familiar with them. At the same time, it is not advisable to integrate every identified feature into Ni-Kshay, as this may introduce unnecessary complexity and reduce the app's usability.

Several mobile apps were identified in the literature that are used for monitoring and analyzing medication adherence. Upon comparison, the Ni-Kshay app covers most of the essential features offered by these apps. For example, the calendar view that visualizes patient progress, is a common approach in adherence applications [43, 36]. Both Ni-Kshay and TB Arogya Saathi offer a user-friendly interface that is easy to navigate and avoids clutter. Some missing interventions are already covered through alternative methods. For instance, Ni-Kshay Sampark and informal communication between patients and healthcare workers lessen the need for a chatbot.

Ultimately, we finalize a set of meticulous, actionable design and UX improvements that can improve the utilization of Ni-Kshay application and TB Arogya Saathi, as detailed in Table 4. The focus of these recommendations is to potentially enhance workflow connectivity and interoperability without hindering existing processes.

THEORETICAL AND PRACTICAL CONTRIBUTIONS

THEORETICAL CONTRIBUTIONS

This review also asserts that global standards in telemedicine interventions for TB medication adherence and outcomes do not represent universally transferable solutions. By systematically comparing the current Ni-Kshay framework with research evidence, the review argues for a pragmatic and context-appropriate framework, wherein adoption of telemedicine interventions must be balanced against infrastructural realities, cultural contexts, and socio-economic constraints.

This research also helps in conceptualizing the telemedicine infrastructure as a hybrid ecosystem, wherein health workers and technological tools play an equally important role. This helps in reinforcing the perspective that telemedicine policies and infrastructure for TB elimination need to consider the human intermediaries involved in the process.

Furthermore, it identifies that the gaps in Ni-Kshay framework as compared to global standards are not always system deficiencies. Some of these occur due to policy constrained by economic and social constraints, offering the interpretation that selective non-adoption of certain tools, such as VDOT, is strategic in nature rather than a system failure. Finally, it contributes to the discussion on patient-centered versus provider-centered digital health systems. While research evidence increasingly prioritizes patient empowerment and self-engagement, the Ni-Kshay framework is largely provider-driven. The recommendations provided in this research for adoption into the Ni-Kshay framework considers a balance between these two approaches.

PRACTICAL CONTRIBUTIONS

This research demonstrates why strengthening low-bandwidth, cost-effective tools, such as voice calls, SMS-based reminders, and digital adherence technologies already embedded within Ni-Kshay framework, represents a sustainable and context-responsive approach. It also contributes a set of pragmatic recommendations for improving the Ni-Kshay and TB Arogya Saathi applications without imposing additional infrastructural burden.

The recommendations for offline functionality, structured messaging systems, interoperability improvements, unified dashboards, and workflow-supporting design features are grounded in the realities of daily field operations of health workers. These suggestions reinforce system usability and reduce friction for health workers. They also enable smoother workflow in rural and low-connectivity environments. Moreover, the proposed design enhancements with respect to health worker forums, notepad utilities, and analytics dashboard can contribute to worker empowerment by fostering peer learning and providing real-time decision support.

Patient-facing forums, self-monitoring dashboards, educational components, and carefully designed gamification features have the potential to enhance motivation, promote adherence behavior, reduce stigma, and cultivate a sense of shared patient community. Finally, and importantly, this study contributes to practice by not only recommending what should be enhanced, but also clarifying what should not be prioritized at present.

CONCLUSION

This article analyzed the Ni-Kshay framework under NTEP, India's initiative to eliminate TB, focusing on addressing medication non-adherence. India presents a unique case where in-person supervision has shown positive results, while telemedicine is more effective when combined with face-to-face interventions. Telemedicine complements in-person methods, helping to reduce TB rates across the country.

A systematic literature review, following PRISMA guidelines, compared the Ni-Kshay framework with global telemedicine approaches for TB management. The current framework is well-structured and has contributed to TB elimination in India. However, several areas for improvement were identified, though these require further study in the Indian context before implementation. These findings, together with the recommendations outlined in this study, highlight the importance of context-appropriate, scalable, and user-centered enhancements to strengthen the Ni-Kshay ecosystem. Operationally, tuberculosis elimination programs operating in volatile and resource-constrained environments encounter significant challenges, including demand uncertainty, variable patient volumes, and fluctuating healthcare resource availability. The integration of telemedicine with artificial intelligence (AI) can function as a flexible and adaptive resource, enhancing programmatic resilience by supporting personalized adherence interventions, and optimized treatment strategies in unstable settings [97, 98]. One limitation of this study is the lack of consideration of potential delays due to increased system load from integrating new features.

Telemedicine can also play a crucial role in reducing the stigma surrounding TB, a significant issue in India. Future research should explore the use of gamification and technology-based tools for raising awareness and fostering open communication, which could help destigmatize the disease at both individual and societal levels.

ACKNOWLEDGEMENTS

The work was supported by a grant from the Indian Council of Social Science Research (ICSSR) through a research grant to the first author. Grant no. 02/1919/GN/2021 22/ICSSR/RP/MJ.

CONFLICT OF INTEREST STATEMENT

The Author(s) declare(s) that there is no conflict of interest.

ETHICAL APPROVAL AND INFORMED CONSENT

This research did not involve human participants. Publicly accessible documents were used for this systematic review, and ethical approval is not required.

SOURCE OF DATA AND AVAILABILITY STATEMENT

The data for this systematic review has been derived from publicly available, peer-reviewed articles. Reference for each included article is provided in the references section.

References

1. WHO. Global tuberculosis report, world health organization, 2023. URL: <https://www.who.int/teams/global-tuberculosis-programme/tb-reports/global-tuberculosis-report-2023> Accessed 2024 Sep 10.
2. Farmer P. DOTS and DOTS-Plus: Not the Only Answer. *Annals of the New York Academy of Sciences*. 2001 Dec;953(1):165-84.
3. Vanino E, Granozzi B, Akkerman OW, Munoz-Torrico M, Palmieri F, Seaworth B, Tiberi S, Tadolini M. Update of drug-resistant tuberculosis treatment guidelines: A turning point. *International Journal of Infectious Diseases*. 2023 May 1;130:S12-5.
4. WHO. Recommendations on digital interventions for health system strengthening. World Health Organization. 2019:2020-10. URL: <https://www.who.int/publications/i/item/9789241550505> Accessed 2024 Sep 10.
5. DeMaio J, Schwartz L, Cooley P, Tice A. The application of telemedicine technology to a directly observed therapy program for tuberculosis: a pilot project. *Clinical infectious diseases*. 2001 Dec 15;33(12):2082-4.
6. Lees J, Bearman M, Risor T, Sweet L. Technology complements physical examination and facilitates skills development among health sciences clerkship students: An integrative literature review. *Perspectives on Medical Education*. 2023;2(1):109.
7. Hjelm NM. Benefits and drawbacks of telemedicine. *Introduction to Telemedicine, second edition*. 2017 Dec 21:134-49.
8. Parmar P, Mackie D, Varghese S, Cooper C. Use of telemedicine technologies in the management of infectious diseases: a review. *Clinical Infectious Diseases*. 2015 Apr 1;60(7):1084-94.
9. Htet KK, Phyu AN, Thwin T, Chongsuvivatwong V. Mobile health app for tuberculosis screening and compliance to undergo chest x-ray examination among presumptive cases detected by the app in Myanmar: usability study. *JMIR Formative Research*. 2022 Jun 7;6(6):e37779.
10. Udhwadia ZF, Sharma S, Mullerpattan JB, Gajjar I, Pinto L. Effective use of telemedicine in Mumbai with a cohort of extensively drug-resistant "XDR" tuberculosis patients on bedaquiline during COVID-19 pandemic. *Lung India*. 2021 Jan 1;38(1):98-9.
11. Cattamanchi A, Crowder R, Kityamuwesi A, Kiwanuka N, Lamunu M, Namale C, et al. Digital adherence technology for tuberculosis treatment supervision: A stepped-wedge cluster-randomized trial in Uganda. *PLoS Med*. 2021;18(5):e1003628.
12. Liu X, Thompson J, Dong H, Sweeney S, Li X, Yuan Y, et al. Digital adherence technologies to improve tuberculosis treatment outcomes in China: a cluster-randomised superiority trial. *Lancet Glob Health*. 2023;11(5):e693-e703.
13. Musiimenta A, Tumuhimbise W, Atukunda E, Mugaba A, Linnemayr S, Haberer J, et al. Digital adherence technologies and mobile money incentives for management of tuberculosis medication among people living with tuberculosis: Mixed methods formative study. *JMIR Form Res*. 2023;7(1):e45301.
14. Burzynski J, Mangan JM, Lam CK, Macaraig M, Salerno MM, deCastro BR, et al. In-person vs electronic directly observed therapy for tuberculosis treatment adherence: A randomized noninferiority trial. *JAMA Netw Open*. 2022;5(1):e2144210.
15. Dey A, Lahiri A, Jha SS, Sharma V, Shanmugam P, Chakrabartty AK. Treatment adherence status of the TB patients notified from private sector and its associated factors: Findings of a secondary data analysis from West Bengal, India. *Indian J Tuberc*. 2022;69(3):334-340.

16. Saha S, Saxena D, Raval D, Halkarni N, Doshi R, Joshi M, et al. Tuberculosis monitoring encouragement adherence drive (TMEAD): Toward improving the adherence of the patients with drug-sensitive tuberculosis in Nashik, Maharashtra. *Front Public Health*. 2022;10:1021427.
17. Zhang M, Wang G, Najmi H, Yaqoob A, Li T, Xia Y, et al. Digitizing tuberculosis treatment monitoring in Wuhan City, China, 2020-2021: Impact on medication adherence. *Front Public Health*. 2023;11:1033532.
18. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. *Int J Surg*. 2021;88:105906.
19. Government of India. India TB report. India TB Report 2023, 2023. URL <https://tbcindia.mohfw.gov.in/2023/06/06/india-tb-report-2023/> Accessed 2024 Sep 10.
20. Udhwadia ZF, Vora A, Tripathi AR, Malu KN, Lange C, Raju RS. Covid-19-tuberculosis interactions: When dark forces collide. *Indian J Tuberc*. 2020;67(4):S155-S162.
21. Chen AZ, Kumar R, Baria RK, Shridhar PK, Subbaraman R, Thies W. Impact of the 99DOTS digital adherence technology on tuberculosis treatment outcomes in North India: a pre-post study. *BMC Infect Dis*. 2023;23(1):504.
22. Santra S, Garg S, Basu S, Sharma N, Singh MM, Khanna A. The effect of a mHealth intervention on anti-tuberculosis medication adherence in Delhi, India: A quasi-experimental study. *Indian J Public Health*. 2021;65(1):34-38.
23. Donahue ML, Eberly MD, Rajnik M. Tele-TB: using telemedicine to increase access to directly observed therapy for latent tuberculosis infection. *Mil Med*. 2021;186(Suppl 1):25-31.
24. Tadesse AW, Mohammed Z, Foster N, Quaife M, McQuaid CF, Levy J, et al. Evaluation of implementation and effectiveness of digital adherence technology with differentiated care to support tuberculosis treatment adherence and improve treatment outcomes in Ethiopia: a study protocol for a cluster randomised trial. *BMC Infect Dis*. 2021;21:1-11.
25. Jerene D, Levy J, van Kalmthout K, van Rest J, McQuaid CF, Quaife M, et al. Effectiveness of digital adherence technologies in improving tuberculosis treatment outcomes in four countries: a pragmatic cluster randomised trial protocol. *BMJ Open*. 2023;13(3).
26. Kibu OD, Siysi VV, Legrand SEA, Tanue EA, Nsagha DS. Treatment adherence among HIV and TB patients using single and double way mobile phone text messages: A randomized controlled trial. *J Trop Med*. 2022;2022.
27. Bouillier JJ, Yoeli E, Rathauer J, Owiti P, Subbaraman R, Jónasson JO. Can digital adherence technologies reduce inequity in tuberculosis treatment success? Evidence from a randomised controlled trial. *BMJ Glob Health*. 2022;7(12).
28. Bao Y, Wang C, Xu H, Lai Y, Yan Y, Ma Y, et al. Effects of an mHealth intervention for pulmonary tuberculosis self-management based on the integrated theory of health behavior change: Randomized controlled trial. *JMIR Public Health Surveill*. 2022;8(7):e34277.
29. Marx FM, Meehan SA, Jivan D, Dunbar R, Hoddinott G, Hesselning AC, Osman M. Use of interactive messaging to reduce pre-diagnosis loss to follow-up for TB care. *Int J Tuberc Lung Dis*. 2022;26(1):26-32.
30. Selvaraju S, Malaisamy M, Dolla CK, Murali L, Karikalani N, Saravanan B, et al. Application of mobile phone technology as intervention for the management of tuberculosis patients diagnosed through community survey. *Indian J Med Res*. 2022;155(2):301.
31. Manyazewal T, Woldeamanuel Y, Holland DP, Fekadu A, Marconi VC. Effectiveness of a digital medication event reminder and monitor device for patients with tuberculosis (selfTB): A multicenter randomized controlled trial. *BMC Med*. 2022;20(1):310.
32. Ross J, Perumal R, Wolf A, Zulu M, Guzman K, Seepamore B, Reis K, Nyilana H, Hlathi S, Narasimulu R, Cheung YK. Adaptive evaluation of mHealth and conventional adherence support interventions to optimize outcomes with new treatment regimens for drug-resistant tuberculosis and HIV in South Africa (ADAP-TIV): study protocol for an adaptive randomized controlled trial. *Trials*. 2023 Dec 1;24(1):776.
33. Mukora R, Maraba N, Orrell C, Jennings L, Naidoo P, Mbatha MT, Velen K, Fielding K, Charalambous S, Chetty-Makkan CM. Qualitative study exploring the feasibility of using medication monitors and a differentiated care approach to support adherence among people receiving TB treatment in South Africa. *BMJ open*. 2023 Mar 1;13(3):e065202.
34. Maro RA, Mtenga A, Mtesha B, Wilhelm K, Lekashingo N, Sumari-de Boer M, Ngowi K. Implementation bottlenecks of real time medication monitoring (evriMED) for improving adherence to anti-TB drugs among people with tuberculosis in Kilimanjaro, Tanzania. *Journal of Clinical Tuberculosis and Other Mycobacterial Diseases*. 2024 Feb 1;34:100409.

35. Perry A, Chitnis A, Chin A, Hoffmann C, Chang L, Robinson M, et al. Real-world implementation of video-observed therapy in an urban TB program in the United States. *Int J Tuberc Lung Dis.* 2021;25(8):655-661.
36. Abas SA, Ismail N, Zakaria Y, Ismail I, Mat Zain NH, Yasin SM, et al. A gamified real-time video observed therapies (GRVOTS) mobile app via the modified nominal group technique: Development and validation study. *JMIR Serious Games.* 2023;11:e43047.
37. Lippincott CK, Perry A, Munk E, Maltas G, Shah M. Tuberculosis treatment adherence in the era of COVID-19. *BMC Infect Dis.* 2022;22(1):800.
38. Li X, Pang X, Zhang F. Evaluation of mobile application for the management of tuberculosis patients in Tianjin during 2019-2020. *Patient Prefer Adherence.* 2022;321-329.
39. Robbiati C, Tosti ME, Mezzabotta G, Dal Maso F, Sachicola OML, Tienabe PS, et al. Improving TB surveillance and patients' quality of care through improved data collection in Angola: Development of an electronic medical record system in two health facilities of Luanda. *Front Public Health.* 2022;10:745928.
40. Sekandi JN, Kasiita V, Onuoha NA, Zalwango S, Nakkonde D, Kaawa-Mafigiri D, et al. Stakeholders' perceptions of benefits of and barriers to using video-observed treatment for monitoring patients with tuberculosis in Uganda: Exploratory qualitative study. *JMIR Mhealth Uhealth.* 2021;9(10):e27131.
41. Casalme DJO, Marcelo DB, Tonquin M, Frias MVG, Gler MT, et al. Feasibility and acceptability of asynchronous VOT among patients with MDR-TB. *Int J Tuberc Lung Dis.* 2022;26(8):760-765.
42. Kumwihar P, Chongsuvivatwong V, Prappre T, et al. Video-observed therapy with a notification system for improving the monitoring of tuberculosis treatment in Thailand: Usability study. *JMIR Form Res.* 2022;6(5):e35994.
43. Rodrigues R, Varghese SS, Mahrous M, Kumar AA, Ahmed MN, D'Souza G. Feasibility and acceptability pilot of video-based direct observed treatment (VDOT) for supporting antitubercular treatment in South India: A cohort study. *BMJ Open.* 2023;13(5).
44. Bachina P, Lippincott CK, Perry A, Munk E, Maltas G, Bohr R, et al. Programmatic adoption and implementation of video-observed therapy in Minnesota: Prospective observational cohort study. *JMIR Form Res.* 2022;6(8):e38247.
45. Szkwarko D, Amisi JA, Peterson D, Burudi S, Angala P, Carter EJ. Using a mobile application to improve pediatric presumptive TB identification in Western Kenya. *Int J Tuberc Lung Dis.* 2021;25(6):468-474.
46. Foster N, Tadesse AW, McQuaid CF, Gosce L, Abdurhman T, Assefa D, et al. Evaluating the equity impact and cost-effectiveness of digital adherence technologies with differentiated care to support tuberculosis treatment adherence in Ethiopia: Protocol and analysis plan for the health economics component of a cluster randomised trial. *Trials.* 2023;24(1):1-12.
47. El Joueidi S, Bardosh K, Musoke R, Tilahun B, Abo Moslim M, Gourlay K, et al. Evaluation of the implementation process of the mobile health platform 'WelTel' in six sites in East Africa and Canada using the modified consolidated framework for implementation research (MCFR). *BMC Med Inform Decis Mak.* 2021;21(1):1-15.
48. Wei X, Hicks JP, Zhang Z, Haldane V, Pasang P, Li L, Yin T, Zhang B, Li Y, Pan Q, Liu X. Effectiveness of a comprehensive package based on electronic medication monitors at improving treatment outcomes among tuberculosis patients in Tibet: a multicentre randomised controlled trial. *The Lancet.* 2024;403(10430):913-923..
49. Abas SA, Ismail N, Zakaria Y, Yasin SM, Ibrahim K, Ismail I, et al. Enhancing tuberculosis treatment adherence and motivation through gamified real-time mobile app utilization: A single-arm intervention study. *BMC Public Health.* 2024;24(1):249.
50. Park S, Moon N, Oh B, Park M, Kang K, Sentissi I, et al. Improving treatment adherence with integrated patient management for TB patients in Morocco. *Int J Environ Res Public Health.* 2021;18(19):9991.
51. Milligan H, Iribarren SJ, Chirico C, Telles H, Schnall R. Insights from participant engagement with the tuberculosis treatment support tools intervention: Thematic analysis of interactive messages to guide refinement to better meet end user needs. *Int J Med Inform.* 2021;149:104421.
52. Thomas BE, Kumar JV, Periyasamy M, Khandewale AS, Mercy JH, Raj EM, et al. Acceptability of the medication event reminder monitor for promoting adherence to multidrug-resistant tuberculosis therapy in two Indian cities: Qualitative study of patients and health care providers. *J Med Internet Res.* 2021;23(6):e23294.
53. Kim AJ, Yang J, Jang Y, Baek JS. Acceptance of an informational antituberculosis chatbot among Korean adults: Mixed methods research. *JMIR Mhealth Uhealth.* 2021;9(11):e26424.

54. Sekandi JN, Onuoha NA, Buregyeya E, Zalwango S, Kaggwa PE, Nakkonde D, et al. Using a mobile health intervention (DOT selfie) with transfer of social bundle incentives to increase treatment adherence in tuberculosis patients in Uganda: Protocol for a randomized controlled trial. *JMIR Res Protoc.* 2021;10(1):e18029.
55. Majella MG, Thekkur P, Kumar AM, Chinnakali P, Saka VK, Roy G. Effect of mobile voice calls on treatment initiation among patients diagnosed with tuberculosis in a tertiary care hospital of Puducherry: A randomized controlled trial. *J Postgrad Med.* 2021;67(4):205.
56. [56] Iribarren S, Milligan H, Goodwin K, Aguilar Vidrio OA, Chirico C, Telles H, et al. Mobile tuberculosis treatment support tools to increase treatment success in patients with tuberculosis in Argentina: Protocol for a randomized controlled trial. *JMIR Res Protoc.* 2021;10(6):e28094.
57. Byonanebye DM, Mackline H, Sekaggya-Wiltshire C, Kiragga AN, Lamorde M, Oseku E, et al. Impact of a mobile phone-based interactive voice response software on tuberculosis treatment outcomes in Uganda (C-TB): A protocol for a randomized controlled trial. *Trials.* 2021;22:1-13.
58. Sahile Z, Perimal-Lewis L, Arbon P, Maeder AJ. Protocol of a parallel group randomized control trial (RCT) for mobile-assisted medication adherence support (MA-MAS) intervention among tuberculosis patients. *PLoS One.* 2021;16(12):e0261758.
59. Gashu KD, Gelaye KA, Lester R, Tilahun B. Effect of a phone reminder system on patient-centered tuberculosis treatment adherence among adults in Northwest Ethiopia: A randomised controlled trial. *BMJ Health Care Inform.* 2021;28(1).
60. Calnan M, Moran A, AlMossawi HJ. Maintaining essential tuberculosis services during the COVID-19 pandemic, Philippines. *Bull World Health Organ.* 2022;100(2):127.
61. Rahayu SR, Zainafree I, Merzistya ANA, Cahyati WH, Farida E, Wandastuti AD, et al. Development of the SIKRIBO mobile health application for active tuberculosis case detection in Semarang, Indonesia. *Healthc Inform Res.* 2022;28(4):297-306.
62. Katende KK, Amiyo MR, Nabukeera S, Mugisa I, Kaggwa P, Namatovu S, et al. Design, development, and testing of a voice-text mobile health application to support tuberculosis medication adherence in Uganda. *PLoS One.* 2022;17(9):e0274112.
63. Iribarren SJ, Milligan H, Chirico C, Goodwin K, Schnall R, Telles H, et al. Patient-centered mobile tuberculosis treatment support tools (TB-TSTS) to improve treatment adherence: A pilot randomized controlled trial exploring feasibility, acceptability and refinement needs. *Lancet Reg Health Am.* 2022;13.
64. Manyazewal T, Woldeamanuel Y, Fekadu A, Holland DP, Marconi VC. Effect of digital medication event reminder and monitor-observed therapy vs standard directly observed therapy on health-related quality of life and catastrophic costs in patients with tuberculosis: A secondary analysis of a randomized clinical trial. *JAMA Netw Open.* 2022;5(9):e2230509.
65. Yang J, Kim HY, Park S, Sentissi I, Green N, Oh BK, et al. Cost-effectiveness of a medication event monitoring system for tuberculosis management in Morocco. *PLoS One.* 2022;17(4):e0267292.
66. Velen K, Nguyen VN, Nguyen BH, Dang T, Nguyen HA, Vu DH, et al. Harnessing new mHealth technologies to strengthen the management of multidrug-resistant tuberculosis in Vietnam (V-SMART trial): A protocol for a randomised controlled trial. *BMJ Open.* 2022;12(6).
67. Kumwihar P, Chongsuvivatwong V, Prappe T, et al. Tuberculosis treatment compliance under smartphone-based video-observed therapy versus community-based directly observed therapy: Protocol for a cluster randomized controlled trial. *JMIR Res Protoc.* 2022;11(7):e38796.
68. Wijayanti E, Bachtar A, Achadi A, Rachmawati UA, Sjaaf AC, Eryando T, et al. Mobile application development for improving medication safety in tuberculosis patients: A quasi-experimental study protocol. *PLoS One.* 2022;17(9):e0272616.
69. Wu Z, Lu L, Li Y, Chen J, Zhang Z, Ning C, et al. Effect of mobile health reminders on tuberculosis treatment outcomes in Shanghai, China: A prospective cohort study. *Front Public Health.* 2023;11:923319.
70. Wang X, Fu Q, Zhou M, Li Y. How integrated digital tools can improve tuberculosis medication adherence: A longitudinal study in China. *Telemed E-Health.* 2024 Feb;30(2):490-498.

71. Tello-Cajiao ME, Mosquera-Hernández JC, Ardila-Giraldo S, Romero-Rosas N, Parra-Lara LG, Niño-Ramírez Y, et al. Synchronous video-supported treatment for tuberculosis in Cali, Colombia: An implementation study. *Health Policy Technol.* 2023;12(2):100747.
72. Levine S, Fraulino D, Krupka P, Velamakanni S. Latent tuberculosis infection in the outpatient general medicine clinic: Efficacy of a nurse-run electronic directly observed treatment program. *Prev Med Rep.* 2023;35:102321.
73. Manyazewal T, Woldeamanuel Y, Getinet T, Hoover A, Bobosha K, Fuad O, et al. Patient-reported usability and satisfaction with electronic medication event reminder and monitor device for tuberculosis: A multicentre, randomised controlled trial. *EClinicalMedicine.* 2023;56.
74. Htet KKK, Phyu AN, Zayar NN, Chongsuvivatwong V. Active tuberculosis screening via a mobile health app in Myanmar: Incremental cost-effectiveness evaluation. *JMIR Form Res.* 2023;7(1):e51998.
75. Tumuhimbise W, Atwine D, Kaggwa F, Musiimenta A. Acceptability and feasibility of a mobile health application for enhancing public-private mix for TB care among healthcare workers in southwestern Uganda. *BMC Digit Health.* 2023;1(1):1-11.
76. Sekandi JN, McDonald A, Nakkonde D, Zalwango S, Kasiita V, Kaggwa P, et al. Acceptability, usefulness, and ease of use of an enhanced video directly observed treatment system for supporting patients with tuberculosis in Kampala, Uganda: Explanatory qualitative study. *JMIR Form Res.* 2023;7:e46203.
77. Walle AD, Hunde MK, Demsash AW. Healthcare professionals' intention to adopt mobile phone-based SMS and its predictors for adherence support and care of TB patients in a resource-limited setting: A structural equation modelling analysis. *BMJ Open.* 2023;13(12):e070813.
78. Kiwanuka N, Kityamuwesi A, Crowder R, Guzman K, Berger CA, Lamunu M, et al. Implementation, feasibility, and acceptability of 99DOTS-based supervision of treatment for drug-susceptible TB in Uganda. *PLOS Digit Health.* 2023;2(6):e0000138.
79. Cheng Q, Dang T, Nguyen TA, Velen K, Nguyen VN, Nguyen BH, et al. mHealth application for improving treatment outcomes for patients with multidrug-resistant tuberculosis in Vietnam: an economic evaluation protocol for the V-SMART trial. *BMJ Open.* 2023;13(12):e076778.
80. Shah H, Patel J, Yasobant S, Saxena D, Saha S, Sinha A, et al. Capacity building, knowledge enhancement, and consultative processes for development of a digital tool (Ni-kshay Setu) to support the management of patients with tuberculosis: Exploratory qualitative study. *J Med Internet Res.* 2023;25:e45400.
81. Zhou L, Zhou Y, Peng Y, Wang W, Chen B, Liu K. Digital tool assessment for the community management of patients with pulmonary tuberculosis in Yiwu City, China: evidence from real world data in 2020. *Front Public Health.* 2024;11:1320904.
82. Samal J. Health seeking behaviour among tuberculosis patients in India: a systematic review. *J Clin Diagn Res.* 2016;10(10):LE01.
83. Sinha P, Carwile M, Bhargava A, Cintron C, Acuna-Villaorduna C, Lakshminarayan S, et al. How much do Indians pay for tuberculosis treatment? A cost analysis. *Public Health Action.* 2020;10(3):110-117.
84. Jayachandran V. A case study on tuberculosis treatment defaulters in Delhi: Weak health links of the community with the public sector, unsupported migrants and some misconceptions. *Ann Trop Med Public Health.* 2014;7(2).
85. Uplekar M, Rangan S. Tackling TB: the search for solutions. Bombay: The Foundation for Research in Community Health; 1996.
86. Chakrabartty A, Basu P, Ali KM, Ghosh D. Tuberculosis related stigma attached to the adherence of directly observed treatment short course (DOTS) in West Bengal, India. *Indian J Tuberc.* 2019;66(2):259-265.
87. Talukdar T, Rathi V, Ish P. Geriatric tuberculosis in India-challenges and solutions. *Indian J Tuberc.* 2022;69:S209-S212.
88. Kulkarni PY, Akarte SV, Mankeshwar RM, Bhawalkar JS, Banerjee A, Kulkarni AD. Non-adherence of new pulmonary tuberculosis patients to anti-tuberculosis treatment. *Ann Med Health Sci Res.* 2013;3(1):67-74.
89. Tola HH, Azar T, Shojaeizadeh D, Garmaroudi G. Tuberculosis treatment non-adherence and lost to follow up among TB patients with or without HIV in developing countries: a systematic review. *Iran J Public Health.* 2015;44(1):1.
90. Kanwal S. Tuberculosis in India. *Tuberculosis in India.* 2022. Available from: <https://www.statista.com/study/85366/tuberculosis-in-india/>.
91. Rai S. 99 DOTS and MERM boxes. 2024. Available from: <https://ntep.in/node/2252/CP-99-dots-and-merm-boxes> Accessed 2024 Sep 10.

92. Guo P, Qiao W, Sun Y, Liu F, Wang C. Telemedicine technologies and tuberculosis management: a randomized controlled trial. *Telemed e-Health*. 2020;26(9):1150-1156.
93. Basuroy T. Internet usage in India - statistics & facts. 2023. Available from: <https://www.statista.com/topics/2157/internet-usage-in-india/> . Accessed 2024 Mar 17.
94. Tale S, Soibam PM. Care of tuberculosis patients in the times of COVID-19. *Indian J Tuberc*. 2021;68(2):285-286.
95. Iyengar KP, Jain VK. Tuberculosis and COVID-19 in India-double trouble. *Indian J Tuberc*. 2020;7.
96. Aromataris E, Munn Z, editors. *JBIManual for Evidence Synthesis*. Adelaide: Joanna Briggs Institute; 2020.
97. Bera S, Kumar P, Bhattacharya S. A study on how to achieve flexibility in healthcare process: a simulation-based approach. *International Journal of Productivity and Performance Management*. 2023 Oct 30;72(8):2292-316.
98. Kumar P. Artificial intelligence and service flexibility in healthcare: Exploring the nexus. *Asia Pacific Journal of Health Management*. 2024 Oct;19(2):147-55.