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REVIEW

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Patient-centered and technology-enabled strategies to improve tuberculosis treatment adherence

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ABSTRACT

Introduction: Tuberculosis (TB) treatment adherence (how regular patients follow the prescribed medication) has a major role in TB control. In high-burden countries such as India, poor adherence contributes to treatment failure, relapse, and the emergence of drug-resistant TB (DR-TB), despite substantial programmatic efforts to improve treatment outcomes.

Areas covered: This review examines a broad range of TB treatment adherence strategies, including digital adherence technologies, behavioral and psychosocial interventions, directly observed therapy models, medication dispensing and monitoring tools, incentive-based support programs, and emerging artificial intelligence and biometric approaches. Evidence from published literature were searched in PubMed and Google Scholar and synthesized.

Expert opinion: This review highlights that digital adherence strategies could reduce cost, travel, and time by making adherence monitoring more efficient and less resource-intensive for both patient and providers. This could complement existing adherence strategies in the programme. Multicomponent strategies that combine real-time adherence monitoring, counseling, community engagement, and social support are likely to be most effective in sustaining adherence, preventing drug resistance, and advancing progress toward TB elimination.

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KEYWORDS
Tuberculosis; treatment adherence; digital adherence technologies; directly observed therapy; video observed therapy; patient centered care; behavioral and psychosocial interventions; National TB Elimination Programme

1. Introduction

Tuberculosis (TB) remains a major global public health problem, with an estimated 10–11 million people developing TB every year worldwide and over 1.2 million deaths. This burden is heavily concentrated in developing countries, particularly in Africa, South East Asia, and Western Pacific regions [1]. Globally, while making notable progress, many low- and middle-income countries including India, still carry the heaviest global TB burden, accounting for one in every four TB cases worldwide. Progress toward the WHO End TB Strategy targets, a 75% reduction in deaths and 50% reduction in incidence compared to 2015, remains far off track. Countries continuously focused on early diagnosis, treatment adherence, multi-drug-resistant TB (MDR-TB) management, and social determinants to accelerate progress toward TB elimination goals.

Completing the full course of therapy ensures bacterial cure, prevents relapse, and interrupts ongoing transmission in the community [2,3]. In TB care, 'treatment adherence' refers to the extent to which a patient takes anti-TB medications as prescribed, in terms of correct dose, timing, and duration, throughout the full course of treatment. Hence, treatment adherence is critical for the successful control and elimination of TB. Poor adherence can lead to treatment failure and emergence of drug-resistant TB (DR-TB), including MDR-TB, which is more difficult, costly, prolonged to treat, and associated with poor treatment outcomes. Treatment adherence also reduces TB-related morbidity, mortality, improves quality of life for patients and optimizes the effectiveness of TB control efforts [4]. Strengthening TB treatment adherence through point of care, patient-centered approach, counseling, treatment supporters, digital adherence technologies, social protection measures play a very important role in achieving sustained TB treatment success rate and advancing toward TB elimination goal.

Several adherence strategies (it refers to approaches designed to help patients regularly take their medications) for TB have been developed and implemented to ensure patients complete the full course of TB treatment. Traditional approach was Directly Observed Treatment (DOT), where a health worker or trained person, who is willing to support, supervises drug intake to improve compliance. Patient-centered, flexible, and digital adherence technology-based models have been experimented. These models have gained prominence as key strategies for improving TB treatment adherence. This manuscript reviews various TB treatment adherence strategy domains (Box 1) such as (i) Digital Adherence Technologies (DATs), (ii) Behavioral and Psychosocial Interventions, (iii) Directly Observed Therapy (DOT) Models, (iv) Medication Dispensing and Adherence Monitoring Technologies, (v) Incentive-Based and Financial Support Programme and (vi) Artificial Intelligence and Biometric-Based Adherence Monitoring.

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Article highlights

- VDOT significantly improved treatment success two fold compared to routine DOT.
- For motivational interviewing for TB, the Health Belief Model had medication adherence 4.5 times higher and treatment success was 3.8 times higher.
- The phone messaging has a modest effect on TB treatment success rate in both high and low TB burden countries (RR 1.04 and 1.06).
- Even modest cash support can significantly improve TB treatment adherence in low-income groups.
- Strengthening TB treatment adherence through point of care, patient-centered approach, counseling, treatment supporters, digital adherence technologies, social protection measures play a very important role in achieving sustained TB treatment success rate.

2. Literature search

A narrative scoping review was conducted using MEDLINE via PubMed, supplemented by a manual search of Google Scholar. Search terms included 'tuberculosis,' 'treatment,' 'adherence,' 'success,' 'cured,' 'outcomes,' 'digital adherence technologies,' 'directly observed therapy,' 'video observed therapy,' 'patient centered care,' 'behavioural' 'psychosocial' and 'interventions.' The review aimed to identify various TB treatment adherence strategies that improve treatment outcomes. The search was restricted to articles published in English between 2020 and early 2026. Studies focusing on TB treatment adherence strategies and its impact were included. Screening was performed independently by two reviewers and 51 full text articles were included for data extraction. The included studies evaluated digital tools such as VDOT-7, 99DOTS-6, SMS/IVR-5, MI-TB-4, MERM-4, Ingestible Sensors-4. HB-DOT-2, CB-DOT-2, FB-DOT-1, Stamp-2, food and nutrition-3, cash and nutrition-3, transport assistance-1, stigma reduction-2 and AI applications-5. The relevant data were synthesized using odds ratio (OR) and risk ratio (RR) with 95% confidence interval (CI).

Box 1. TB treatment adherence strategies.

1. Digital Adherence Technologies (DATs)
   1. 99DOTS
   2. VDOT (Video Directly Observed Therapy)
   3. MERM (Medication Event Reminder Monitor)
2. Behavioral and Psychosocial Interventions
   1. Motivational Interviewing for TB (MI-TB)
   2. SMS & IVR Calls
   3. Stigma Reduction Programs
3. Directly Observed Therapy (DOT) Models
   1. Facility Based DOT (FB-DOT)
   2. Community Based DOT (CB-DOT)
   3. Home Based DOT (HB-DOT)
4. Medication Dispensing and Adherence Monitoring Technologies
   1. STAMP (Support for Treatment Adherence and Medication Protocol)
   2. Ingestible Sensors and Smart Pills
5. Incentive Based and Financial Support Programs
   1. Cash Transfers and Vouchers
   2. Food and Nutrition Support
   3. Transport Assistance
6. Artificial Intelligence and Biometric Based Adherence Monitoring
   1. Mobile Apps for TB Adherence
   2. Telemedicine Support
   3. AI-Powered Chatbots
   4. Facial Recognition and Fingerprint Scans

3. TB treatment adherence strategies

3.1. Digital adherence technologies (DATs)

3.1.1. 99DOTS

99DOTS involves using TB pills that come in a blister pack enveloped by a sleeve with hidden phone codes. Each day a patient pops a pill and calls a toll-free number revealed under the blister, logging that dose on a central server. This low-cost, 'Frugal' Information and Communication Technology (ICT) solution requires only a feature phone and per-day patient input [5]. When a dose is taken, the patient dials the toll-free number from a basic phone and the call is recorded as a proof of dosing. 99DOTS can also send SMS reminders to patients who miss calls and alerts the providers [6]. India pioneered the 99DOTS system nationally in 2015 [6,7]. By 2018, over 500,000 patients had registered on 99DOTS and expanded into other countries [6]. The overall adherence to complete treatment using 99DOTS was 96% in Gujarat [7], 93% in Himachal Pradesh [6] and 86.6% in Uganda (Figure 1) [8]. It was reported that 99DOTS has high acceptability among health care providers in implementation of technology and low acceptance by TB patients due to stigma, lack of cell phone access, and cell phone literacy [9,10]. Overall 99DOTS represents a programmatic, patient-friendly digital solution that has strengthened adherence monitoring and programmatic management of TB in resource-constrained settings. However, it confirms patient engagement by phone call or SMS rather than actual pill ingestion and its effectiveness depends on phone access, network availability, and patient motivation.

3.1.2. VDOT (video directly observed therapy)

VDOT is a technique where patients record themselves taking medication or have live video calls with providers using smartphones or tablets, then transmitting videos to health staff. VDOT can reduce patient travel and increase privacy. A recent meta-analysis found VDOT significantly improved treatment success two fold compared to routine DOT (pooled OR 2.39) (Figure 2) [11]. A systematic review found that VDOT achieves treatment adherence comparable to DOT, while also being more cost-effective, enhancing patient satisfaction, and requiring less time from healthcare professionals for supervision [12]. Another qualitative evidence showed that patients report greater convenience, flexibility, and privacy with VDOT compared with DOT, in terms of reduced travel time and stigma [13]. A systematic review and meta-analysis synthesized evidence about the effects of VDOT on medication adherence, treatment completion showing that VDOT improved medication adherence 2.7 times and with similar treatment completion [14]. A study on feasibility and acceptability of VDOT carried out in South India reported that 84% of participants found the application easy to learn and 52% preferred VDOT over DOT (Figure 3). It was concluded that VDOT was an acceptable alternative to conventional DOT for

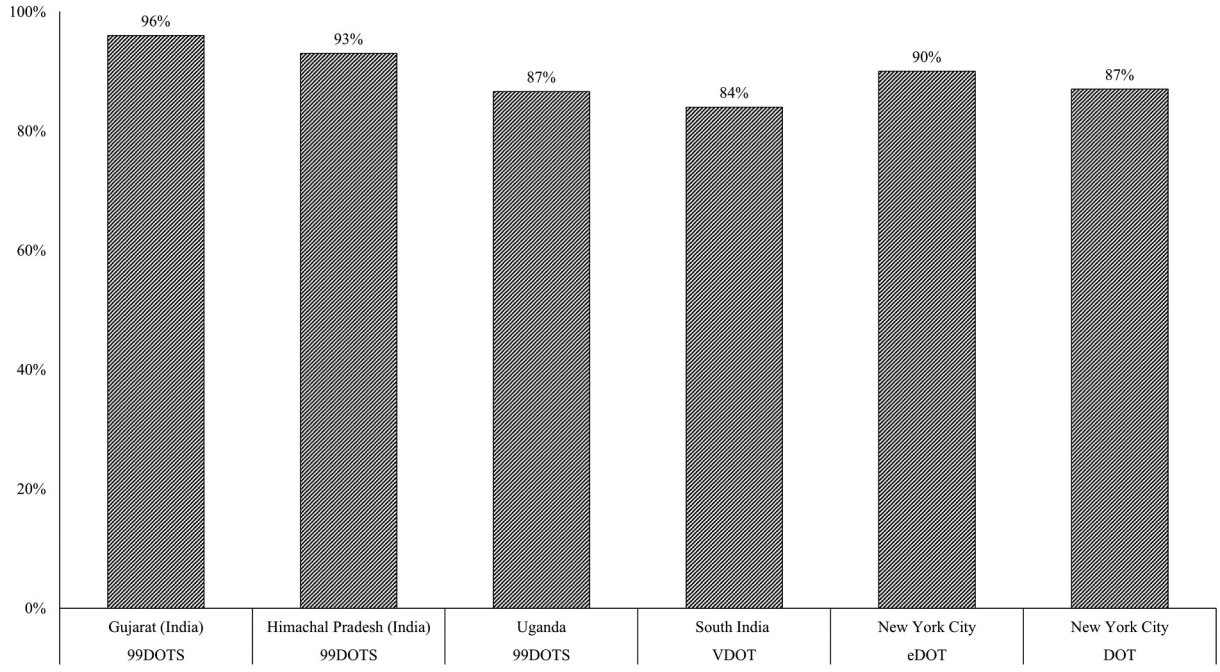

Figure 1. Adherence rate among digital adherence technologies.

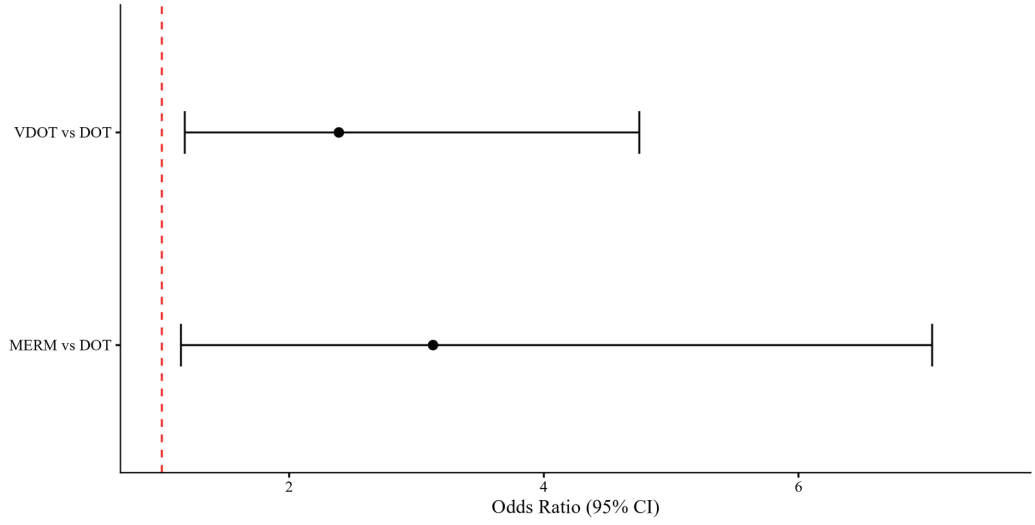

Figure 2. Comparative odds of TB treatment adherence: MERM and VDOT vs DOT.

TB treatment adherence support and monitoring [15]. In high TB burden settings with good mobile penetration, VDOT can support treatment adherence, reduce clinic visits, and empower patients. It also complements other digital adherence technologies such as SMS reminders and 99DOTS by providing direct visual evidence of medication ingestion. New York City Health Department reported that the percentage of completed doses with DOT was 87% with VDOT was 90% (Figure 1). The percentage difference was 3% with a conclusion of non-inferiority that VDOT was as effective as in-person DOT for assuring high levels of TB treatment adherence [16]. A national survey on the use of VDOT for treatment of TB showed that treatment adherence and completion were similar with VDOT compared with the DOT [17]. A systematic review on the cost-effectiveness of VDOT reported that it was consistently associated with cost savings compared to DOT in high-income settings [18].

3.1.3. MERM (medication event reminder monitor)

MERM smart pillbox is a second-generation adherence strategy which uses electronic devices to log dosing using devices like STAMP (smart dispenser). These internet-enabled dispensers record each time they are opened as a proxy for a dose taken [19]. The Wisepill evriMED 1000 is a plastic pillbox holding about one month of pills and uses GPRS or cellular to sync each opening to a cloud system [20]. A randomized controlled trial from Ethiopia among patients with TB, MERM showed non-inferior treatment adherence compared with the DOT

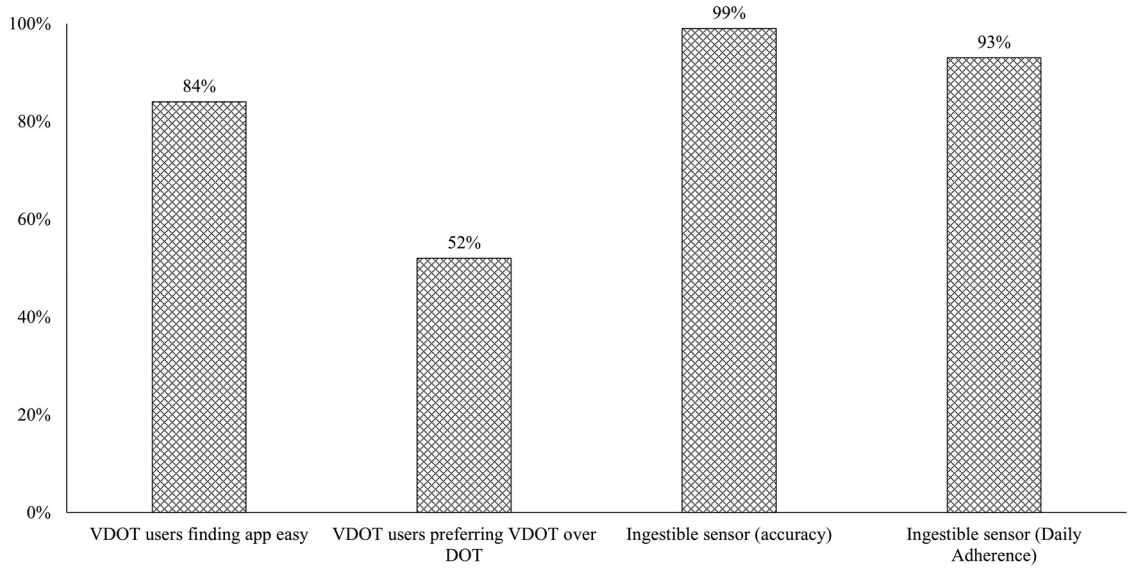

Figure 3. Acceptability of TB treatment adherence strategies among patients.

[21]. Another study from Morocco, North Africa, showed that MERM improved the TB treatment success rates and decreased the loss-to-follow-up. However, this finding is based on a retrospective cohort design which limits the robustness of the results. It was also reported that, over time, the MERM group demonstrated a higher cumulative adherence rate than those receiving standard conventional TB treatment across the six-month period [22]. A recent network meta-analysis found that the TB treatment adherence of MERM was three times higher as compared to DOT (Figure 3) [11]. A systematic review was reported that limitations of the digital adherence technology in accurately capturing dose wise adherence. It was noted that MERM were either over reporting or under reporting adherence which could lead to incorrect prioritization of patient intervention [23].

3.2. Behavioral and psychosocial interventions

3.2.1. Motivational interviewing for TB (MI-TB)

MI-TB is a patient-centered counseling approach used in TB care to strengthen patient's intrinsic motivation and adherence to treatment. This therapeutic approach enhances motivation through goal setting and patient-centered empathy [24]. Compared to usual guidance, MI-TB by nurses increases treatment adherence and cure rate [25]. The other approach involves using trained TB survivors as 'TB Champion' (*TB Vijeta)* to share lived experience and offering motivation to enhance TB treatment adherence. These TB Champions build trust and strengthen patients' intrinsic motivation to complete treatment. Also involving community peer supporters by providing patient-centered peer-based support will increase the TB treatment adherence. A systematic review showed that peer support interventions are associated with improved treatment adherence, reduced loss to follow-up, and better treatment outcomes, particularly among high-risk groups such as patients with prior default or DR-TB [26]. The WHO End TB Strategy and national TB programme, including India's National TB Elimination Programme (NTEP), emphasize community engagement and TB survivor involvement as low-cost, scalable approaches that complement facility-based care and enhance the effectiveness and cost-efficiency of TB control efforts [27]. The Health Belief Model (HBM) based MI-TB communication motivation model experimented in Bali, Indonesia, demonstrated its ability to build a patient-centered relationship by addressing treatment barriers arising from HBM constructs, leading to improved medication adherence and greater treatment success among TB patients. It was estimated that HBM group had medication adherence 4.5 times higher and treatment success was 3.8 times higher (Figure 4) [25]. WHO's consolidated guideline on TB recommendation number 1.1 strongly recommended that health education and counseling on the disease and treatment adherence should be provided to patients on TB treatment. It was reported that the patients who received care and support interventions had higher rates of treatment success, treatment completion, cure, adherence, lower rates of mortality, and less loss-to-follow-up [27].

3.2.2. SMS and IVR calls

Interactive Voice Response (IVR) reminders are mobile health interventions designed to support TB treatment adherence by prompting patients through automated messages or voice calls. A randomized controlled trial conducted in Karachi involving 2,207 patients evaluated daily two-way SMS reminders (Zindagi SMS) compared with routine care and found the treatment success was 83% [28]. A meta-analysis indicated that phone messaging had a modest effect on TB treatment success rate in both high- and low-TB burden countries (RR 1.04 and 1.06) (Figure 5) [29]. It was reported that the impact could be from the growing penetration of mobile phone technology and mHealth initiatives globally [30,31]. When SMS or telephone calls were examined separately, there was

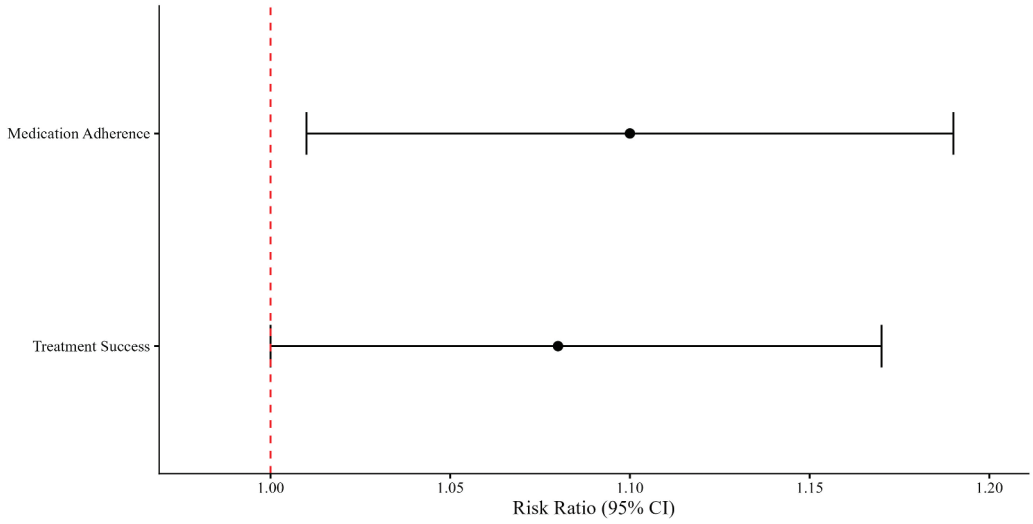

Figure 4. Motivational interviewing and its association with treatment success and medication adherence.

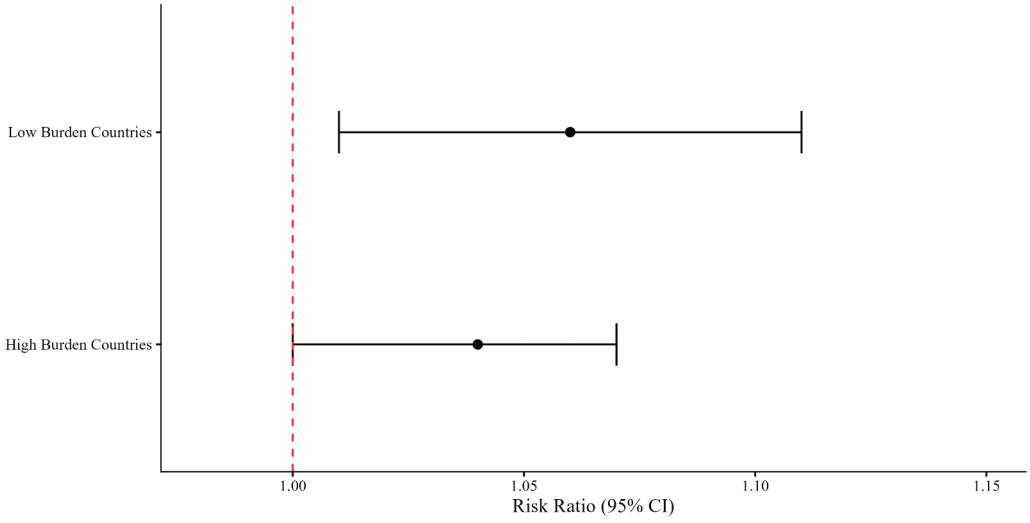

Figure 5. Relative risk of treatment success with SMS Intervention in low and high TB burden countries.

higher rate of treatment success with mobile telephone reminders as compared to standard of care [32].

3.2.3. Stigma reduction programme

Stigma around TB can discourage patients from seeking care or revealing their status, harming adherence. To reduce stigma, mobile and digital platforms-based interventions are used to address fear, misinformation, and social discrimination associated with TB. These programme include SMS, IVR-based education messages, mobile apps, social media campaigns, and video or audio storytelling, that normalize TB as a curable disease and promote supportive attitudes. By delivering confidential, culturally appropriate information in local languages, digital tools help patients better understand their condition, encourage disclosure to trusted contacts and reduce internalized stigma. Digital counseling and peer support platforms further enable anonymous interaction, emotional support, and linkage to care, which can improve treatment adherence, mental well-being, and care-seeking behavior. A systematic review indicated that effective stigma reduction interventions typically integrate educational components, such as community discussions and media messaging, with psychosocial support including peer groups and counseling directed at patients, families, and wider community [33]. Explicitly stigma reduction-focused interventions, when designed with structured educational curricula, psychosocial counseling, digital adherence technologies and peer-led outreach efforts, can help mitigate anticipated stigma and enhance treatment adherence [34].

3.3. Directly observed therapy (DOT) models

3.3.1. Facility-based DOT (FB-DOT)

FB-DOT has been a cornerstone of TB control programme to ensure treatment adherence by requiring patients to visit a health facility where a healthcare provider directly observes medication intake. This approach has been effective in improving adherence and reducing the risk of treatment

failure and drug resistance, particularly during the intensive phase of therapy. However, FB-DOT is often associated with significant patient burdens, including travel costs, wage loss, long waiting times, and stigma related to frequent clinic visits [35]. These barriers can negatively affect adherence, especially among working populations, women and patients in rural or hard-to-reach areas. While FB-DOT provides strong clinical oversight, more patient-centred alternatives, when appropriately implemented, can achieve comparable adherence with lower social and economic costs.

3.3.2. Community-based DOT (CB-DOT)

CB-DOT is a decentralized TB treatment approach in which treatment observation and support are provided within the community rather than requiring patients to visit health facility. In this model trained community members bring treatment support closer to patients to improve access and adherence [36]. This will reduce barriers such as travel time, transport costs, wage loss, and stigma associated with repeated clinic visits, making it especially beneficial for rural, low-income and hard-to-reach populations. A meta-analysis evidence suggested that CB-DOT produced better outcomes than clinic-based DOT [36]. Thus, deaths and loss-to-follow-up were also reduced under CB-DOT. In India, the Accredited Social Health Activist (ASHA) system and TB health workers often serve as community observers [37].

3.3.3. Home-based DOT (HB-DOT)

HB-DOT refers to supervision of TB medication intake within the patient's home, typically by a family member or visiting health worker, to maximize convenience and adherence [36]. Home-based DOT is highly patient-friendly, as it eliminates the need for travel and can be delivered in a family-centered manner. In practice, many programme adopt hybrid models that combine home and community approaches, with DOT initiated at home and later transitioned to a community clinic or vice versa. Home-based care was especially emphasized during COVID-19 to avoid clinic visits [38]. Overall, the aim of any DOT model is to ensure the presence of at least one reliable observer, whether clinical or lay, along with regular patient follow-up. Current Indian TB guidelines allow flexible delivery of DOT in health facilities, community settings or at home, depending on patient preference and programme capacity [27].

3.4. Medication dispensing and adherence monitoring technologies

3.4.1. STAMP (support for treatment adherence and medication protocol)

STAMP is a technology enabled adherence tool that automates TB drug dispensing while digitally monitoring and supporting patient medication intake. STAMP rings an alarm at each scheduled dosing time and dispenses a single pill dose directly into the patient's hand. Simultaneously it transmits a real-time Short Message Service (SMS) confirmation or an automated voice call after four hours to the patient [3]. TB patients using the STAMP dispenser achieved high adherence, attributed to the combined effect of audible alarms, easy dosing, and digital support system [3]. In 2019, WHO recommended STAMP to be a part of TB programme [39].

3.4.2. Ingestible Sensors and smart pills

Ingestible sensor-based digital pills represent a high-technology approach that involves embedding a tiny sensor within a pill and have been evaluated in a few TB trials [40]. The sensor activates on contact with stomach fluid and sends a signal to a wearable patch, which in turn relays ingestion data to a smartphone or server [40,41]. The Proteus Digital Health system demonstrated this for TB meds and its ingestible sensor was 99% accurate at detecting ingestion and yielded 93% daily adherence (Figure 3) [41]. Notably, patients strongly preferred the sensor system over in-person observation. Ingestible tech remains experimental, costly, and requires patients to wear a sensor patch every day [42,43].

3.5. Incentive-based and financial support programme

3.5.1. Cash and nutritional transfers

India's Ni-kshay Poshan Yojana (NPY), launched in April 2018, provides a cash transfer of ₹500 (~US$7) per month to every notified TB patient for nutritional support and it was increased to ₹1000 in 2024 [44]. A national survey found that patients who did not receive NPY had a much higher risk of unfavorable outcomes (death, failure or loss-to-follow-up), almost fivefold higher odds [45]. This suggests that even modest cash support can significantly improve adherence in low-income groups. Internationally, conditional cash transfer (CCT) in Brazil's Bolsa Família programme (a massive poverty-alleviation CCT) was associated with substantial reductions in TB incidence and mortality among beneficiaries [46]. Cash transfers in high-burden settings tend to boost TB treatment completion and reduce catastrophic costs for families [45,46].

3.5.2. Food and nutrition support

In addition to cash, many programme give food baskets or vouchers to TB patients. Undernutrition is a major risk factor for TB in India (estimated to account for ~25% of cases) [45]. Nutritional support, including fortified rations, high-protein foods and micronutrient supplementation has been shown to improve weight gain and treatment outcomes [45]. While NPY is intended as a nutritional support intervention, other models are also implemented, such as linking TB patients to free government food schemes or community kitchens. Ni-kshay Mitra (Patient Volunteer) initiative under NTEP, enables individuals, institutions, corporates, NGOs, and faith-based organizations to voluntarily support people with TB [47]. Registered Ni-kshay Mitras provide nutritional support, diagnostics, vocational assistance, psychosocial care, and other forms of patient-centred aid to TB patients during treatment. The programme aims to reduce financial hardship, improve treatment adherence and outcomes. It also addresses social determinants such as undernutrition and stigma, thereby complementing medical care and strengthening community participation [48].

3.5.3. Transport assistance

Transport assistance for TB patients is a key intervention aimed at reducing financial and access barriers to diagnosis, treatment initiation, and follow-up care. By providing travel reimbursements, travel vouchers or direct cash transfers, transport assistance helps patients attend health facilities for sputum examination, drug collection, monitoring visits, and management of adverse drug reactions. This support is particularly important for patients from rural, tribal, and urban poor settings, where travel costs and distance to health facilities contribute to missed visits and loss-to-follow-up. Evidence shows that transport assistance reduces out-of-pocket expenditure, improves treatment adherence and continuity of care and enhances treatment completion rates. When integrated with national TB programme and other social support measures, transport assistance contributes to patient-centred TB care and better treatment outcomes [49]. India has instituted targeted transport support, under which TB patients from notified tribal areas receive a one-time cash allowance of ₹750 at treatment initiation to cover travel to health facilities [44].

3.6. Artificial Intelligence and biometric-based adherence monitoring

3.6.1. Mobile apps for TB adherence

Adherence apps and digital support tools use smartphone-based platforms to complement TB treatment by supporting medication monitoring, education, and patient engagement. Some hospital-based DOT centers in India now use WhatsApp or dedicated applications to allow patients to report medication intake through photographs or text messages. In addition, the TB Arogya Sathi Android app enables patients to view their treatment schedule, record dose intake, and access educational information on TB [50]. A community-led app, TB Mitra, has also been piloted in India for volunteer support and monitoring. In Malaysia, a gamified video observed therapy application (GRVOTS) achieved a mean adherence of 91%, compared with an 80% guideline benchmark and was associated with significantly higher patient motivation among users [51]. Meta analyses of digital adherence technologies report that smartphone app interventions can significantly improve treatment success, with pooled estimates indicating approximately twofold higher odds of cure in clinical trials [52]. India's National TB Programme has reported rapid uptake of digital tools such as Arogya Sathi and Ni-kshay mobile features, alongside an increase in overall TB treatment success to 89% by 2023 [53]. These interventions are promising for younger or urban patients who use smartphones.

3.6.2. Telemedicine support

Remote monitoring and consultation tools complement mobile applications in supporting TB care, with national helplines and video observed therapy serving as key examples. In India, the multilingual Ni-Kshay Sampark call center (dial 1800–11-6666) provides free counseling and adherence follow-up services seven days a week [50]. Counselors make regular outgoing calls to TB patients, updating the treatment status in the digital registry. Similarly, other programme use telephone or SMS reminders and tele-DOT approaches. During the COVID-19 pandemic, many TB programme globally shifted to VDOT, enabling health workers to remotely verify medication ingestion. Reviews of telehealth interventions report consistent benefits, with telemedicine shown to improve medication adherence, treatment completion, cure rate, and smear conversion among TB patients [54]. In practice, this means higher cure rate and lower loss-to-follow-up rate when video or phone follow-up is used. Call-based support is associated with improved treatment outcomes and is often preferred by patients because of greater convenience and privacy compared with clinic-based DOT [52,54].

3.6.3. AI-powered chatbots

AI chatbots and conversational agents are a novel frontier for TB support. These programmes can interact in natural language (text or voice) to provide education, reminders, and counseling. A South African WhatsApp 'TB Chatbot' has reported high user acceptance and improved patient engagement. Early results noted increased adherence and easier side effect reporting after patients received automated daily prompts and could chat with health staff [55]. In Korea, an 'anti-TB chatbot' app was launched on the Kakao platform to answer questions about TB, treatment and local clinics [56]. Chatbots offer distinct advantages in TB care by operating continuously, delivering content in local languages and multimedia formats that support low literacy users and reducing the time burden on healthcare providers [56]. AI chatbots have the potential to extend TB treatment support into patient's daily lives by delivering reminders, responding to queries and triaging concerns.

3.6.4. Facial recognition and fingerprint scans

Facial recognition and fingerprint scan technologies are emerging digital tools used in TB programme to support treatment adherence and patient verification. Biometric verification systems, such as fingerprint or iris scanning, have been piloted in TB programme to confirm patient identity at the point of drug dispensing [57]. By enabling accurate, real-time monitoring of treatment adherence, biometric authentication strengthens programme accountability and data reliability, particularly in high-burden settings. These digital adherence technologies, improve follow-up of missed doses and support patient--centred TB care while minimizing the need for frequent facility visits. However, facial recognition and fingerprint scan technologies require infrastructure at each clinic (scanners, database) and it needs to be studied further.

4. Conclusion

The measurement of treatment adherence varied across the studies, with outcomes reported across a range of indicators, including treatment adherence, treatment completion, and treatment success. It is important to note that we have highlighted in this manuscript, the various TB treatment adherence strategies and its impact. Innovating new strategies particularly digital adherence strategies played a very important role in addressing persistent challenges such as reducing the need

for daily visits, minimizing travel time, financial hardship by reducing out-of-pocket costs, and social barriers by reducing stigma to patients. In addition, these technologies provided to programme managers with accurate adherence data by monitoring and follow-up and enhancing programme efficiency. Traditional approaches alone are insufficient to reach all segments of the population and ensure consistent treatment completion. Innovation also allows TB programme to adapt technologies that accelerate progress toward TB elimination, improve treatment outcomes, and strengthen health systems. Though several studies report improvements in adherence and treatment outcomes across different interventions, the overall strength of evidence remains variable. There is a need for more robust evidence examining the association between adherence and patient-relevant outcomes.

5. Expert opinion

Technology enabled strategies such as VDOT significantly improved treatment success by twofold compared to routine DOT, while motivational interviewing based on the HBM increased medication adherence by 4.5 times. Phone messaging demonstrated a modest effect on TB treatment success in both high and low burden settings. This finding corroborates with patient-centered approach emphasized by WHO that moves beyond traditional FB-DOT to strategies that empower patients while maintaining treatment supervision. WHO also recommends the use of DATs such as SMS reminders, IVR calls, VDOT, 99DOTS and MERM, which provide real-time monitoring and enable early identification of patients at risk of loss-to-follow-up [58]. Additionally, WHO underscores the importance of community-based support systems, including family members, community health workers, and peer networks to address social, cultural, and economic barriers that may prevent patients from completing treatment [27]. Complementary interventions such as nutritional support, counseling, and psychosocial care are also recommended to enhance patient engagement and improve treatment outcomes. Similarly, the Centers for Disease Control and Prevention (CDC) advocates a multifaceted approach combining direct observation, electronic reminders, and case management to ensure adherence. The CDC emphasizes leveraging adherence data to identify high-risk patients, enabling timely interventions and integrating social support measures such as transportation assistance and nutritional incentives to reduce the likelihood of treatment loss-to-follow-up [59]. The Stop TB Partnership reinforces these recommendations by advocating for differentiated care models tailored to patient risk profiles and local settings, encouraging the adoption of innovative digital tools in combination with community and peer support to maintain adherence while reducing patient burden. In India, the NTEP has operationalized these principles through the Ni-kshay digital platform, which allows real-time monitoring of patient adherence, automated SMS and IVR reminders and tracking of digital adherence technologies such as 99DOTS and MERM devices. Evidence from systematic reviews and Cochrane analyses further supports these approaches, demonstrating that multicomponent interventions, which combine digital monitoring, community engagement, patient education, and social enablers, are most effective in improving adherence and treatment success [28,60]. Across agencies, the consensus is clear that TB treatment adherence cannot rely solely on facility-based supervision or medication provision; instead, it requires patient-centered, flexible and technology enabled strategies that are sensitive to local contexts and individual patient needs. Integrating real-time monitoring, social and nutritional support, and community engagement not only improves adherence and treatment outcomes but also helps prevent the emergence of DR-TB, reduces patient burden and strengthens health systems. By adopting these recommendations, TB program worldwide are better equipped to ensure continuity of care, achieve higher cure rates and move closer to the goal of TB elimination.

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Declaration of interest

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Author contributions

CRediT: **Malaisamy Muniyandi:** Conceptualization, Data curation, Formal analysis, Methodology, Validation, Writing – original draft, Writing – review & editing; **Sahil Abdul Salam:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing; **Karikalan Nagarajan:** Conceptualization, Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing.

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