

Digital Health for Tuberculosis Detection, Adherence, and Treatment Outcomes: A Systematic Review

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Digital health technologies are increasingly used across the tuberculosis (TB) care cascade, from case detection to treatment monitoring. However, evidence regarding their effectiveness in improving TB detection, adherence, and treatment outcomes remains inconsistent. This systematic review evaluated the effectiveness of digital health technologies across the TB care cascade and identified intervention characteristics associated with successful implementation. Eleven articles published between 2017 and 2026 met the predefined inclusion criteria and were synthesized narratively. The included studies comprised randomized controlled trials, cluster-randomized trials, diagnostic accuracy studies, and study protocols. Ten studies reported effectiveness outcomes, while one described the development of a digital intervention. Technologies evaluated included computer-aided detection, self-screening applications, electronic medication monitors, 99DOTS, video-observed therapy, ingestible medication sensors, mobile health applications, and digitally delivered economic support. Computer-aided detection showed good performance for TB triage, whereas text message-based self-screening achieved limited user participation. Video-observed therapy and ingestible sensors improved objective verification of medication intake. Electronic medication monitors produced inconsistent clinical outcomes, with greater benefits when integrated with two-way communication, active follow-up, patient support, and adequate connectivity. Mobile health applications and digital cash transfers combined with counselling also improved adherence and treatment outcomes. This review provides an integrated mapping of digital technologies across the TB care cascade while distinguishing technical, behavioural, and clinical outcomes. Digital health technologies may strengthen TB detection and treatment adherence, particularly when digital data trigger timely healthcare-provider responses and individualized patient support.



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Tuberculosis (TB) continues to impose a substantial global health burden despite advances in diagnosis, treatment, and prevention. The World Health Organization estimated approximately 10.7 million incident TB cases and 1.23 million TB-related

deaths in 2024. Indonesia remains among the countries with the highest TB burden, contributing approximately 10% of global cases. These figures highlight the need to strengthen the entire TB care pathway, from early detection and diagnosis to

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treatment initiation, adherence monitoring, and assessment of treatment outcomes [1]

Gaps in case detection remain a major barrier to effective TB control. Limited availability of trained personnel, restricted access to diagnostic services, and delays in seeking healthcare may result in missed diagnoses or delayed treatment initiation. In this context, digital health technologies can support TB screening and triage. The WHO (2021) recommends digital chest radiography with computer-aided detection software as an alternative to human interpretation of chest radiographs for TB screening in adults. Bosman et al. (2024) reported that CAD4TBv7 demonstrated high sensitivity as a triage tool, although positive findings still required bacteriological confirmation [2]. In contrast, Sazali et al. (2023) showed that text message-based self-screening applications had not yet achieved optimal levels of user participation. These findings suggest that the success of digital technologies for TB detection depends not only on diagnostic accuracy but also on their reach, acceptability, and user engagement [3].

Once TB has been diagnosed, treatment adherence becomes a critical determinant of therapeutic success. The long duration of treatment, adverse drug effects, economic barriers, stigma, distance to healthcare facilities, and limited social support may increase the risk of missed doses and loss to follow-up. To overcome the limitations of conventional face-to-face treatment supervision, researchers have developed various digital technologies, including text messaging, mobile health applications, video-observed therapy, 99DOTS, electronic medication monitors, and ingestible medication sensors [4]. Video-based monitoring and digital medication sensors could increase the number of objectively verified doses. However, improvements in recorded or verified adherence have not consistently translated into better clinical outcomes [5].

Earlier systematic reviews have largely focused on the treatment phase. Ngwatu et al. found limited and heterogeneous evidence for SMS, VOT,

and medication monitors. Ridho et al. synthesized randomized trials of digital technologies for medication adherence and treatment outcomes and reported variable effects across intervention types [6]. More recent meta-analyses likewise suggest that digital interventions can improve adherence measures while clinical effects remain heterogeneous and context-dependent [7][8][9]. Reviews of adherence measurement also show that the accuracy of digital signals varies substantially across platforms [10]. These reviews are informative, but they do not fully integrate detection-stage technologies with adherence processes, treatment outcomes, and implementation context within a single care-cascade interpretation.

The present review therefore addresses a different question: how does evidence change when digital technologies are examined across the TB care cascade rather than as isolated tools? The review evaluates digital interventions relevant to case detection, treatment adherence, continuity of care, and clinical outcomes, while distinguishing technical/process outcomes from patient-level clinical outcomes. The review question was: among people being screened, investigated, or treated for TB, how do digital health interventions, compared with usual care or an alternative strategy, affect detection/triage performance, adherence-related processes, and treatment outcomes, and which implementation characteristics appear to modify these effects.

Results and Discussion

The eleven included articles were published between 2017 and 2026 and represented several stages of the tuberculosis (TB) care continuum. Two studies evaluated digital technologies at the case detection stage: one assessed a computer-aided chest radiography analysis system, and another evaluated a text message-based self-screening application. Eight articles assessed interventions designed to support treatment adherence or continuity of care, including electronic medication monitors, 99DOTS, video directly observed therapy (VDOT), mobile applications, ingestible medication

sensors, digital cash transfers, and medication label-based monitoring systems. One additional article presented only a study protocol describing the development of a medication-storage wristband integrated with a smartphone application.

The studies were conducted across diverse settings, including China, Tibet, Uganda, South Africa, Lesotho, the Philippines, Tanzania, Ukraine, and TB care settings in the United States. Jerene et al. (2025) had the broadest geographical scope, reporting findings from four pragmatic cluster-randomized trials conducted in the Philippines, South Africa, Tanzania, and Ukraine. In contrast, Browne et al. (2019) and Sekandi et al. (2025) included smaller sample sizes but evaluated technologies that could directly confirm or observe medication ingestion. Variations in geographical setting, health system capacity, mobile phone access, and models of care contributed to substantial heterogeneity in both the interventions evaluated and the outcomes reported across studies [5].

Effectiveness of Electronic Medication Monitors

Liu et al. (2023) evaluated an electronic medication monitor incorporating daily reminders, monthly review of adherence data, and differentiated care among 2,686 patients with drug-susceptible tuberculosis in China. At 18 months after treatment initiation, the composite unfavorable outcome occurred in 16% of both the intervention and control groups. No significant differences were observed in loss to follow-up, treatment failure, mortality, or recurrence. According to Liu et al. (2023), periodic review of adherence data may not have been timely enough to enable prompt intervention when patients began taking their medication irregularly [16].

In contrast, Wei et al. (2024) reported improvements in both treatment adherence and treatment outcomes among patients with tuberculosis in Tibet. The intervention included not only an electronic medication box but also audio reminders, transmission of medication-box opening data, a patient-provider communication application, treatment supporters, mobile data packages, and

follow-up responses to missed doses. Treatment success was achieved in 133 of 142 patients, or approximately 94%, in the intervention group, compared with 98 of 134 patients, or approximately 73%, in the control group. The adjusted risk difference was 21 percentage points [17].

The contrasting findings reported by Liu and Wei indicate that the same or similar devices may produce different effects depending on how they are integrated into care. In Liu et al. (2023), adherence data did not translate into rapid, individualized responses. In contrast, Wei et al. (2024) incorporated electronic monitoring into an active care package involving digital technology, healthcare providers, treatment supporters, and connectivity support. Therefore, the observed clinical benefit likely stemmed not from the medication box alone, but from the combination of early identification of non-adherence and timely corrective actions [17]

Table 1. Synthesis of reviewed studies on drug receiving in hospital pharmacy services

No	Author, Year	Country / Setting	Population	Intervention / Comparator	Study Design	Outcomes and Effect Estimates
1	Liu, 2023	China (4 prefectures)	Adults ≥ 18 years with GeneXpert-positive, rifampicin-sensitive pulmonary TB; ITT n=2,686.	Intervention: digital medication monitor with daily dosing reminders, monthly provider review of adherence data, and differentiated care for poor adherence. Comparator: routine care with a silent-mode monitor used to measure adherence.	Cluster-randomized superiority trial (24 counties/districts)	Primary composite unfavorable outcome by 18 months: 16% intervention vs 16% control; adjusted RR 1.01 (95% CI 0.73-1.40), no significant benefit.
2	Bosman, 2024	Lesotho and South Africa	Adults ≥ 18 years presenting with ≥ 1 cardinal TB symptom; n=1,392.	Intervention/index test: digital chest X-ray interpreted by CAD4TBv7. Comparator: point-of-care CRP; both assessed against a composite microbiological reference standard (culture or Xpert Ultra).	Prospective multicentre diagnostic-accuracy study.	CAD4TBv7 AUROC 0.87 (95% CI 0.84-0.91) vs CRP 0.80 (0.76-0.84). At thresholds near 90% sensitivity, specificity was 68.2% (65.4-71.0) for CAD4TBv7 vs 38.2% (35.3-41.1) for CRP.
3	Wei, 2024	Shigatse, Tibet, China	Patients with drug-susceptible TB starting standard treatment; n=278 randomized (143 intervention; 135 control).	Intervention: comprehensive EMM package including electronic medication monitor, audio reminders, transmitted opening data, patient-provider app communication, treatment supporters, and connectivity support. Comparator: usual care with a deactivated EMM and no access to the app or trained treatment supporters.	Multicentre randomized controlled trial.	Poor monthly adherence: 10.2% vs 36.5%; adjusted risk difference -29.2 percentage points (95% CI -35.3 to -22.2; $p < 0.0001$). Treatment success: 93.7% vs 73.1%; adjusted risk difference +21.0 percentage points (12.4-29.4; $p < 0.0001$).
4	Cattamanchi, 2021	Uganda (18 health facilities)	Adults initiating treatment for drug-susceptible pulmonary TB; n=1,913 eligible (1,022 control-period; 891 intervention-period).	Intervention: adapted 99DOTS treatment supervision with medication sleeves, daily SMS reminders, toll-free dose reporting, and provider adherence dashboard.	Pragmatic stepped-wedge cluster-randomized trial.	ITT treatment success: 72.7% intervention vs 70.9% control; aOR 1.04 (95% CI 0.68-1.58; $p = 0.87$). Per-protocol: 86.6% vs 70.5%; aOR 2.89 (1.57-5.33; $p < 0.001$).

No	Author, Year	Country / Setting	Population	Intervention / Comparator	Study Design	Outcomes and Effect Estimates
5	Ismail, 2025	Johannesburg, South Africa (9 clinics)	Adults ≥ 18 years undergoing investigation for pulmonary TB; 4,110 randomized; modified ITT n=381 with microbiologically confirmed rifampicin-susceptible pulmonary TB.	Intervention: pre- and post-TB-testing counselling plus conditional digital cash transfer (R150) at treatment initiation and monthly visits for timely attendance. Comparator: standard of care.	Pragmatic, open-label, individual randomized controlled trial.	Successful outcome among participants with available primary-outcome data: 82.0% vs 66.9%. Weighted unsuccessful outcome: 15.9% vs 28.6%; RR 0.52 (95% CI 0.33-0.82); risk difference -14.1 percentage points (95% CI -23.3 to -4.8).
6	Sekandi, 2025	Kampala, Uganda	Adults aged 18-65 years with confirmed drug-susceptible TB receiving daily treatment; n=144 randomized; ITT n=142.	Intervention: DOT Selfie, an enhanced asynchronous video directly observed therapy (VDOT) system using a smartphone app, secure cloud server, and provider review portal. Comparator: usual-care directly observed therapy (UCDOT).	Two-arm, parallel-group, open-label randomized controlled trial.	Primary adherence-monitoring outcome ($\geq 80\%$ expected doses observed): 79% VDOT vs 10% UCDOT; adjusted RR 8.4 (95% CI 4.16-17.0). Treatment completion: 94.4% vs 85.9% (p=0.04); loss to follow-up: 2.8% vs 9.9% (p=0.02).
7	Huang, 2017	Western Hunan, China	Planned adults ≥ 18 years with drug-sensitive pulmonary TB in selected western Hunan counties; protocol described a cohort/evaluation of 400 patients.	Intervention: bracelet- and self-directed observational therapy (BSDOT): medication-storage bracelet, smartphone application, self-photographed dosing, reminders, and remote monitoring. Comparator: traditional TB treatment under DOT without bracelet/mobile application.	Study protocol for a 1:1 cluster randomized controlled trial.	Planned outcomes: WHO-defined TB treatment outcome and adherence ($<5\%$ doses missed), plus self-reported adherence and quality of life. No empirical effect estimate was available because this publication was a protocol only.
8	Jerene, 2025	Philippines, South Africa, Tanzania, and Ukraine	Adults receiving treatment for drug-susceptible TB;	Intervention: smart pillboxes or digital medication labels linked to an adherence platform, with reminders and differentiated responses to adherence data.	Four independent pragmatic cluster-randomized trials.	No reduction in composite poor end-of-treatment outcome: Philippines aOR 1.13 (95% CI 0.72-1.78); Tanzania

No	Author, Year	Country / Setting	Population	Intervention / Comparator	Study Design	Outcomes and Effect Estimates
			n=25,606 enrolled; ITT n=23,483.	Comparator: standard of care.		aOR 1.49 (0.99-2.23); South Africa aOR 1.19 (0.88-1.60); Ukraine adjusted RR 1.15 (0.83-1.59).
9	Qin, 2025	Shanghai, China (7 districts)	Newly diagnosed patients with TB; ITT n=741 (371 intervention; 370 control).	Intervention: WeChat-based mobile health application for medication check-in, education, patient-provider communication, and follow-up support. Comparator: standard of care.	Multicentre, two-arm, open-label, stratified block-randomized controlled trial.	Primary composite unfavorable outcome: 22% vs 28%; adjusted risk difference - 7.04 percentage points (95% CI -13.25 to -1.14; p=0.025). Overall poor adherence: adjusted risk difference -16.39 percentage points (95% CI -22.13 to -9.62; p<0.001).
10	Browne, 2019	San Diego and Orange County, USA	Adults with drug-susceptible TB in the continuation phase; n=77 for accuracy stage; n=61 randomized in stage 2.	Intervention: wirelessly observed therapy (WOT) using an ingestible sensor, wearable patch, paired mobile device, and rapid adherence support when ingestion was not detected. Comparator: maximal in-person DOT (5 days/week).	Prospective two-stage study; stage 2 randomized controlled trial (2:1 allocation).	WOT positive detection accuracy: 99.3% (95% CI 98.1-100). ITT confirmed prescribed doses: 93% WOT vs 63% DOT (p<0.001). After excluding nonworking/held-dose days: difference 2.8 percentage points (95% CI -1.8 to 9.1), supporting non-inferiority.
11	Rich, 2026	Cape Town, South Africa	Adults ≥18 years with valid mobile numbers selected from the Western Cape health database; n=2,500 randomized (1,250/group).	Intervention: unsolicited SMS invitation to use TB Check plus R15 airtime reward for completing self-screening. Comparator: the same SMS invitation without the airtime reward.[15]	Parallel, individual randomized controlled trial.	Primary outcome, completed TB Check self-screening within 1 week: 1.11% vs 0.49% of delivered messages; RR 2.33 (95% CI 0.60-9.09), p=0.342. Screening initiation: 3.2% vs 1.3%; RR 2.50 (1.09-5.73), p=0.035.

Effectiveness of 99DOTS and Program-Level Digital Monitoring Technologies

Cattamanchi et al. (2021) evaluated 99DOTS among 1,913 patients across 18 healthcare facilities in Uganda. In the intention-to-treat analysis, the intervention did not improve treatment success in the overall study population. Only 52% of patients were enrolled in 99DOTS during the intervention period. However, in the per-protocol analysis, patients who actively used 99DOTS were more likely to achieve treatment success, with treatment completion exceeding 85%. These findings should be interpreted cautiously because active users may have been more willing or able to use mobile phones and more engaged with healthcare services from the outset [18].

Jerene et al. (2025) provided the largest body of programmatic evidence. A total of 23,483 participants were included in the intention-to-treat analyses across four cluster-randomized trials evaluating smart pillboxes or digital medication labels combined with differentiated responses. The interventions did not significantly reduce the risk of unfavorable treatment outcomes in the Philippines, Tanzania, South Africa, or Ukraine. Effect estimates across all countries crossed the threshold of statistical non-significance, indicating that these technologies did not demonstrate superiority over standard care when implemented under routine program conditions [19].

The findings of Cattamanchi et al. (2021) and Jerene et al. (2025) highlight a gap between the potential benefits of digital technologies among selected users and their effectiveness at the population level. Digital monitoring systems may be acceptable and beneficial for some patients. Still, their overall impact may be attenuated when enrollment is low, adherence data are not reviewed consistently, healthcare providers do not respond promptly to alerts, or standard care already achieves relatively high treatment success rates [18].

Effectiveness of VDOT and Ingestible Medication Sensors

Sekandi et al. (2025) evaluated DOT Selfie, an asynchronous form of video-observed therapy (VDOT) that allows patients to record themselves taking their medication and transmit the videos to healthcare providers. Among 142 participants included in the analysis, 56 of 71 patients, or 79%, in the VDOT group achieved observation of at least 80% of prescribed doses, compared with only 7 of 71 patients, or 10%, receiving routine directly observed therapy. These findings indicate that VDOT can substantially increase the proportion of doses that can be verified in settings with limited human resources [5].

Browne et al. (2019) used a more direct approach through wirelessly observed therapy (WOT). The system consisted of an ingestible sensor taken together with the medication, a wearable patch, and a mobile phone that recorded the timing of medication ingestion. The system achieved a detection accuracy of approximately 99.3%. In the randomized controlled trial component involving 61 participants, 93% of doses were confirmed in the WOT group, compared with 63% in the DOT group. Browne et al. (2019) also reported high patient acceptability; however, the study was conducted only during the continuation phase of treatment and did not evaluate treatment success across the entire therapeutic regimen [20].

Huang et al. (2017) proposed a body-worn sensor-based directly observed therapy (BSDOT) approach consisting of a medication-storage wristband, a smartphone application, reminder functions, and communication between patients and healthcare providers in rural China. However, because the publication was limited to a study protocol, no empirical data were available to determine whether the intervention improved treatment adherence, treatment success, or quality of life. Therefore, this article is better classified as evidence of conceptual and technological innovation rather than clinical effectiveness [12].

Effectiveness of Mobile Health Applications

Qin et al. (2025) evaluated a WeChat-based application among 741 newly diagnosed patients with rifampicin-susceptible tuberculosis (TB) in Shanghai. The composite outcome of death, treatment failure, loss to follow-up, or recurrence occurred in 22% of patients in the application group and 28% of those in the control group. The adjusted risk difference of -7.04 percentage points indicated a significant reduction in unfavorable outcomes. Poor adherence was also less frequent in the intervention group, with an adjusted risk difference of -16.39 percentage points [21].

A key strength of the intervention evaluated by Qin et al. (2025) was that its functionality extended beyond simple medication reminders. The application facilitated communication between patients and healthcare providers, delivered educational materials, recorded medication intake, and supported follow-up care. Nevertheless, requiring patients to own a smartphone and maintain a WeChat account may exclude individuals with limited financial resources or low digital literacy. Therefore, the findings may be more readily generalizable to urban settings with well-developed communication infrastructure than to areas with limited internet access.

Effectiveness of Digital Interventions Combined with Economic Support

Ismail et al. (2025) assessed an intervention package consisting of pre- and post-TB-testing counseling combined with conditional digital cash transfers. Among 381 participants with confirmed rifampicin-susceptible pulmonary TB, 82.0% of the intervention group achieved treatment success compared with 66.9% of the control group. After weighting, the prevalence of unsuccessful treatment outcomes was 15.9% in the intervention group and 28.6% in the control group, corresponding to a relative risk of 0.52. Pre-treatment loss to follow-up was also lower in the intervention group [22].

The intervention evaluated by Ismail et al. cannot be classified as a purely digital adherence

technology because its main components were counseling and reducing financial barriers. Digital payment primarily functioned as a mechanism for delivering economic support. Nevertheless, the study remains relevant to the TB care cascade because it demonstrates that treatment success does not depend solely on monitoring medication intake. Financial support linked to timely attendance may reduce patient attrition from diagnosis through treatment completion [22].

Overall Synthesis of Findings

Among the 10 studies that provided empirical data, most demonstrated improvements in process-related outcomes, including triage accuracy, the number of observed doses, reporting regularity, and medication adherence. However, effects on clinical outcomes were less consistent. Wei et al. (2024), Ismail et al. (2025), and Qin et al. (2025) reported improvements in treatment outcomes, whereas Liu et al. (2023), Cattamanchi et al. (2021), and Jerene et al. (2025) found no significant effects in their primary analyses. Browne et al. (2019) and Sekandi et al. (2025) showed improvements in verifying medication ingestion but did not provide strong evidence on cure or long-term recurrence.

The findings of this review indicate that digital health technologies can strengthen the TB care cascade, although their effectiveness varies across stages of care. In case detection, CAD4TBv7 demonstrated good technical performance as a triage tool, whereas TB Check faced limitations in user reach and engagement. This comparison suggests that the effectiveness of digital case-detection strategies depends on two distinct components: technological accuracy and the program's ability to reach target populations and successfully link users to confirmatory testing. Even highly accurate technology may fail to increase case detection if the intended population does not access and use it effectively.

During the treatment phase, digital technologies showed more consistent benefits for adherence monitoring than for clinical outcomes.

Video-observed therapy (VDOT) and ingestible sensors provide more direct evidence of medication ingestion than electronic medication-box openings or patient reporting through 99DOTS. However, more observed doses do not necessarily translate into treatment success. TB treatment outcomes are also influenced by drug resistance, adverse effects, comorbidities, socioeconomic conditions, regimen quality, and delays in addressing clinical problems. Therefore, digitally recorded doses should be distinguished from actual medication adherence and ultimate treatment success.

The contrasting findings of Liu et al. (2023) and Wei et al. (2024) are particularly noteworthy. Both studies used electronic medication monitors, yet Wei et al. observed substantial improvements in treatment success only in the intervention package they evaluated. In Liu et al., the technology reduced missed doses but did not improve clinical outcomes. In contrast, Wei et al. combined real-time monitoring with communication, treatment support, connectivity assistance, and proactive follow-up. These findings suggest that digital adherence data generate meaningful clinical benefits only when they are translated into timely and patient-centered healthcare actions [15,9]

This pattern can be conceptualized as a closed-loop digital care model, in which adherence data are collected, analyzed, and subsequently used to trigger an appropriate response from healthcare providers. Technologies that merely generate reminders or store adherence data may provide limited benefits. In contrast, the intervention described by Qin et al. (2025) enabled continuous patient-provider communication, whereas Ismail et al. (2025) simultaneously addressed economic and behavioral barriers. Taken together, these findings suggest that digital technologies should be positioned as tools to strengthen human-centered healthcare delivery rather than replace direct healthcare support.

The absence of significant benefits in Jerene et al. (2025) also has important implications. As a large-scale pragmatic study, its findings may more

closely reflect the challenges encountered during implementation in routine healthcare settings. Healthcare workers' adherence to intervention procedures, delays in responding to digital data, variability in access to mobile phones, and relatively high performance of standard care may all reduce differences between intervention and control groups. Therefore, a null effect does not necessarily mean the technology itself lacks utility; rather, it highlights how much digital health effectiveness depends on the readiness and responsiveness of the healthcare system in which the technology is implemented [19].

Equity and privacy considerations also warrant attention. Application- and video-based interventions generally require access to suitable devices, electricity, internet connectivity, and adequate digital literacy. These requirements may disproportionately exclude patients from lower socioeconomic groups, who may already be at greater risk of loss to follow-up. In addition, notifications, video recordings, electronic medication devices, or distinctive labels may inadvertently disclose a patient's TB status to others. Implementation strategies should therefore include non-digital alternatives, privacy-sensitive notification settings, robust data protection measures, and informed patient consent to ensure that digital technologies do not widen existing inequalities or contribute to TB-related stigma.

Strengths and Limitations

A strength of this review is its outcome-based organization across several stages of TB care and its explicit separation of technical or process measures from clinical outcomes. The revised evidence table also reconciles intervention labels, comparators, study designs, and principal effect estimates with the primary publications. Several limitations should temper interpretation. First, the documented electronic search used only PubMed, supplemented by citation searching; relevant studies indexed only in other databases could have been missed. Second, the retained search record did not preserve the exact final expanded search string, search date, or record-level reasons for all exclusions.

Third, only two empirical studies addressed detection or triage, whereas most evidence concerned treatment. Fourth, study designs, interventions, comparators, and outcomes were too heterogeneous for meaningful pooling. Fifth, one included record was a protocol and contributed no effectiveness data. Finally, several trials were open-label or had incomplete intervention uptake, and small adherence-verification studies were not designed to establish cure or recurrence. These limitations mean that the review supports cautious, stage-specific conclusions rather than a single overall estimate of digital-health effectiveness.

Conclusion

Digital health technologies can strengthen multiple points in the TB care cascade, but their effects differ by function and implementation. CAD can support triage, while VDOT and ingestible sensors can improve objective measurement of medication intake. Electronic medication monitors, 99DOTS, and smart pillbox/label systems do not consistently improve treatment outcomes when adherence data are not translated into timely care or when program uptake is incomplete. More favorable clinical results were observed when digital tools were embedded within broader packages involving communication, active follow-up, patient support, or economic assistance. Digital technologies should therefore complement, not replace, patient-centered TB services. Future evaluations should report both process and clinical outcomes, assess routine-service implementation, and determine which closed-loop combinations of digital monitoring and human response deliver equitable and sustainable benefit.

Materials and Methods

Study Design and Reporting

This systematic review was revised and reported in accordance with PRISMA 2020 [11]. Because the included studies differed substantially in intervention type, care-cascade stage, study design, population, and outcome definition, a narrative

synthesis was planned rather than a pooled meta-analysis.

Eligibility Criteria and Review Question

Eligibility was defined around the review question using population, intervention, comparator, outcome, and study-design concepts. Populations included adults or patients undergoing TB screening, diagnostic evaluation, or treatment. Eligible interventions used a digital technology as a material component of TB detection, adherence monitoring/support, continuity of care, or treatment support. Comparators included standard care, directly observed therapy, non-digital alternatives, or an alternative triage approach. Outcomes included diagnostic/triage accuracy, screening uptake, objectively observed or recorded doses, medication adherence, treatment completion/success, treatment failure, loss to follow-up, death, or recurrence. Empirical randomized, cluster-randomized, pragmatic, or diagnostic-accuracy studies published in English were eligible. Conference abstracts without full text, duplicate reports, non-empirical papers, and protocols without effectiveness or diagnostic-performance data were excluded from the effectiveness synthesis. The Huang et al. protocol, which the submitted manuscript treated as an included study, was therefore reclassified as contextual evidence only [12].

Protocol and Registration

The review was not prospectively registered in PROSPERO. This limits auditability of deviations from the original review plan and is acknowledged as a potential source of reporting bias.

Information Sources and Search Strategy

PubMed was the primary electronic database. Reference lists of eligible publications were examined, and backward/forward citation searching was used to identify additional relevant reports. The source manuscript documented the primary PubMed strategy as: ("digital health") AND ("primary health care") AND ("tuberculosis"). Controlled vocabulary (MeSH) and related free-text terms were also

considered in the source search. The review covered publications from 1 January 2017 through 2026. The submitted manuscript did not record the exact final search date and must confirm it from the authors' search log before resubmission; this date was not fabricated in this revision.

Study Selection

Records were screened by title and abstract, followed by full-text eligibility assessment. The submitted manuscript states that eligible studies were independently assessed using a dual-review approach. The available files did not document the exact procedure used to resolve reviewer disagreements, and the authors should confirm it before final resubmission. The study protocol by Huang et al. was excluded from effectiveness conclusions because it did not provide empirical outcome data [12].

Data Extraction

For each eligible empirical study, the revised extraction framework captured author/year, country and setting, study design, population and sample size, intervention, comparator, stage of the TB care cascade, principal outcomes, effect estimates, and implementation characteristics that could plausibly explain heterogeneity. Numerical values were rechecked against the cited primary reports during this revision.

Risk-of-Bias and Quality Appraisal

Randomized and cluster-randomized trials were appraised using the design-appropriate version of the revised Cochrane Risk of Bias tool (RoB 2) [13]. The prospective diagnostic-accuracy study was considered using domains consistent with QUADAS-3 [14]. Appraisal focused on randomization, deviations from intended intervention, missing outcome data, outcome measurement, selective reporting, patient selection, index-test conduct, reference standard, and flow/timing as applicable. Quality judgments informed interpretation but were not used as an automatic exclusion criterion.

Data Synthesis

Findings were organized by intervention type, outcome type, and implementation context. Process outcomes (for example, screening uptake, observed doses, and adherence signals) were distinguished from clinical outcomes (for example, treatment success, failure, death, recurrence, and loss to follow-up). Causal language was restricted to what could be supported by each study design.

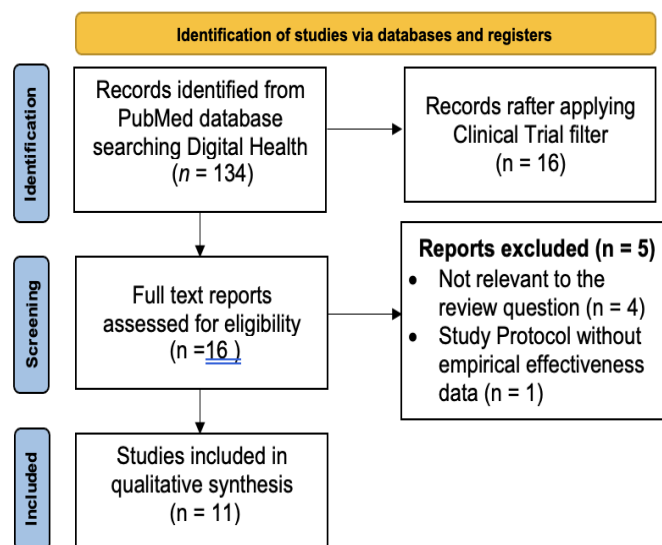


Figure 1. PRISMA Flow Diagram of the Article

The study selection process was conducted following the PRISMA guideline. A total of 134 records were identified from the PubMed database using the Digital Health search strategy. After applying the Clinical Trial filter, 16 records remained for full-text assessment. During the eligibility assessment, five articles were excluded due to irrelevance to the review question ($n = 4$) and lack of empirical effectiveness data because they were study protocols ($n = 1$). Finally, 11 studies met the inclusion criteria and were included in the qualitative synthesis.

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