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Modern Digital Technologies for Monitoring Tuberculosis Adherence

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ABSTRACT

Tuberculosis (TB) is a persistent contagious disease caused by Mycobacterium tuberculosis which is highly prevalent globally. The bacterial disease can manifest as either pulmonary or extrapulmonary. The timely identification of the disease and initiation of anti-tubercular therapy significantly influences the management and treatment outcome of TB. TB is typically treated with a 6 to 9-month medication regimen requiring strict adherence to the therapy. Medication nonadherence leads to increased hospitalization, disabilities, deaths, reoccurrence of the disease, and antimicrobial resistance. Medication non-adherence is a significant global health concern, especially in TB, several approaches including education, behavior, and the use of digital tools can improve that. This review highlights the features, use, benefits, and limitations of various digital tools such as Video Observed Therapy (VOT), 99-DOTs, Drone Observed therapy system (Dr-OTS), Medication Event Reminder Monitor System (MERM), Bio-ingestible sensors and smart pill bottles used in improving the medication adherence of TB. Digital adherence technology could prove to be an acceptable alternative approach to monitoring and improving TB medication adherence....

Keywords: *Tuberculosis, medication adherence, Digital Technology, VOT, 99-DOTS.*

1. INTRODUCTION

Tuberculosis (TB) remains a global health challenge, affecting millions of individuals worldwide [1,2]. According to the Global TB Report of 2023, TB ranks among the top 10 causes of mortality worldwide. In 2022, approximately 10.6 million individuals were infected with TB globally [3]. India carried the highest TB burden globally in terms of incident cases (27%), accounting for one-fourth of the global TB load, with nearly 2.8 million cases and 342,000 deaths. TB is one of the top infectious causes of mortality worldwide.

The disease is primarily caused by the bacteria Mycobacterium tuberculosis. It mainly affects the lungs (pulmonary TB), but can also affect other parts of the body (extrapulmonary TB). It is treated with a 6 to 9-month medication regimen that may lead to adverse effects and non-adherence to the treatment [4,5]. The first line of standard treatment for TB consists of a regimen of Isoniazid, Rifampicin, Ethambutol, and Pyrazinamide. One of the frequent side effects of isoniazid and pyrazinamide is liver damage, affecting 2.4% of TB patients [6]. More number of medications are nowadays being used to treat drug-resistant TB, including novel medications like Bedaquiline, Pretomanid, and Delamanid, as well as repurposed medications including Moxifloxacin, Levofloxacin, Linezolid, Clofazimine, and Beta-lactams [6]. Adherence to TB treatment refers to the extent to which patients follow the prescribed medication regimen. Poor medication adherence is widely recognized as a contributing factor to increased risks of morbidity, and mortality. Non-adherence to treatment poses a significant risk for multidrug-resistant tuberculosis (MDR-TB). Moreover, MDR-TB patients tend to experience poorer treatment outcomes compared to those with drug-susceptible TB [7,8].

The World Health Organisation (WHO) claims that adherence to anti-TB medication is complicated and multifaceted,

requiring specialized attention through the provision of person-centred care [9]. According to the WHO, improving adherence may have a much bigger effect on the general population's health than any fresh improvement in particular medical treatments. Both the clinical outcomes for patients and the treatment's overall cost are negatively impacted by non-adherence to TB treatment [7,10]. Many factors can lead to non-adherence, such as moving or traveling, feeling better than before, being unemployed, relationships with healthcare workers, having comorbid conditions like diabetes, and favorable time at DOT centers [11]. Having other health conditions alongside TB can make treatment more challenging and increase the risk of negative outcomes. Common comorbidities include COPD, diabetes mellitus, cancer, and HIV. Patients with TB and comorbidities often need multiple medications, which can lead to difficulty adhering to treatment and potentially contribute to MDR-TB [12]. Factors such as complex drug regimens, drug interactions, and overlapping symptoms further complicate adherence [9]. Additionally, challenges like poor relationships with healthcare providers, long wait times, and dissatisfaction with healthcare services can deter patients from sticking to their TB medication [12]. Positive experiences at DOT centers can improve adherence, but inconveniences, such as long travel distances, can hinder it. Furthermore, frequent travel, feeling better before completing treatment, and unemployment can all negatively impact TB treatment adherence [12,13]

Adherence can be measured by two methods

Medication adherence is the practice of following the healthcare provider's advice on the timing, dosage, and duration of taking medication [14,15].

1. **Direct method:** Includes biochemical analysis to identify the presence of the drug or its metabolite in a patient's blood sample or urine sample collected by mixing the medicine with a nontoxic biological marker. Although this procedure is reliable, it cannot be used frequently. Monitoring drug concentrations using blood and urine testing is one direct way to evaluate medication adherence. Only a few medicines can be tracked using this technique, which is costly and inconvenient for patients [5].

2. **Indirect method:** Patient reviews, self-reports, pill counts, response assessments, electronic reviews, physical examinations, and the patient's Index are all examples of an indirect strategy for measuring adherence [16]. Prescription refilling is also an indirect method to track medication adherence which is reasonably effective and affordable.

Although TB is a long-term source of morbidity and mortality worldwide, it has been neglected for many years in both industrialized and developing countries. In recent years, it has been accepted that using technology to deliver high-quality healthcare services in low- and middle-income nations is both economical and simple [17]. Over the past several years, the use of digital health tools for the management of TB has increased, focusing on treatment for patients and focused surveillance. The utilization of digital adherence techniques (DATs), including mobile phone-based methods, digital pillboxes, and consumable sensors, to track and enhance adherence to TB drugs has gained popularity and shows the positive impact of digital technologies on medication adherence [3].

Modern Technologies Used in Adherence of TB

There are several digital tools used for the measurement of adherence as listed in Fig 1:

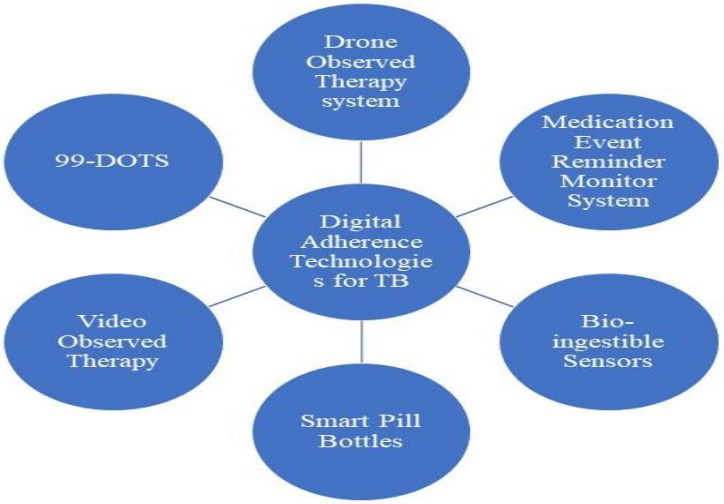

Fig 1: Various modern Technologies in adherence to TB.

1. **Video-Observed Therapy:** VOT is the practice of remotely monitoring TB patients using a videophone as they take their medications [18]. The approach holds promise in ensuring that TB patients complete their therapy. [17,19]. VOT automatically includes the date and time of the dosage taken by the patient [20]. VOT is a patient-centered, economical technique that may be successful for certain categories of patients with TB such as patients who cannot visit DOT centers due to their jobs, study, or financially weaker patients, or for patients who reside away from DOT centers. VOT gives patients more flexibility and saves time & travel costs. A greater focus on VOT in TB patient care may lead to increased commitment and decrease the stigma associated with TB patients [21]. A recent study indicates that the use of video-assisted therapy has improved drug adherence by 10% (VOT adherence was 94.5%) compared to 84% in DOTs [22]. Past studies also suggest that VOT is widely acceptable by both TB patients as well medical professionals [23,24].

Video Observed therapy may be categorized as:

a) **Synchronous VOT:** In synchronized video observed therapy (S-VOT), patients take medications in front of their computer or cell phone camera while a healthcare provider observes from a distance using video conferencing software. The interaction is then recorded on the patient's medical file [25]. S-VOT has been shown to improve the degree of adherence and treatment completion while lowering transportation and staff expenditures for treatment assistance in these programs [25,26].

b) **Asynchronous VOT:** Asynchronous VOT (A-VOT) allows patients to record their video of the anti-TB drug for healthcare providers, who monitor their treatment adherence through recorded video. These videos must include the date and time of the video recording. [20,21,25]. Fig 2 shows the procedure for A-VOT.

Fig 2: Procedure for asynchronous VOT

Advantages and Disadvantages

Video observed therapy (VOT) in tuberculosis (TB) treatment offers several advantages, including increased patient convenience and allowing patients to take their medication under remote observation via video calls, VOT eliminates the need for in-person visits to healthcare facilities, reducing travel time and costs for patients [25]. Additionally, VOT can improve treatment adherence by providing real-time support and accountability. However, VOT also presents some challenges. Technical limitations, such as poor internet connectivity or lack of access to suitable devices, may hinder its effectiveness, particularly in remote or underserved areas. Furthermore, concerns about patient privacy and data security may arise with the use of video technology for healthcare purposes [17]. Table 1 includes a few studies that summarize the key conclusions of multiple studies.

Table 1 VOT technology enabled studies in Tuberculosis patients.

S.no	Study type	Place of study	Number of patients *	Study duration$	Main Findings	Reference
1.	Prospective pilot study	Maryland, USA	28 patients	17	Results indicated that the Comparison between VOT and DOT adherence was found to be not significantly different (94% vs 98%, P = 0.17), However, during the VOT higher percentage of total	[27]

					treatment doses was observed (72% vs 66%, P = 0.03), including those administered on weekends and holidays. The cost was reduced by $1391 per person in VOT as compared to DOTS.	
2.	Randomised Controlled Trials	England	226 Patients	25	Compared to DOTs, VOT had a significantly greater adaptation rate (91% vs 46%). VOT also had significantly higher adherence compared to DOT (77% vs 63% p=0·017). Adverse events were experienced by 16 (14%) of the 112 patients in the VOT group and nine (8%) of the 114 patients in the DOT group. As a result of this trial, VOT was successfully adopted National Health Service in London.	[28]
3.	Observational study	Northern Norway	17 patients	24	The mean drug adherence rate of DOT, among patients was 86.1%. Vs 75.9% in VOT, where the adherence rate was slightly decreased. Notably, a majority of both patients (14 out of 17) and nurses (14 out of 17) expressed a preference for video conferences over traditional DOTs.	[29]
4.	Randomized	Thailand	100 TB	17	Compared to the mobile-	[30]

	controlled trial		patients		based CARE-Call to the Physician visits group at a 90% adherence level, the non-adherence among patients was significantly lower in the intervention group compared to the control group (7.5% vs 27.5% P = 0.037).	
5.	Randomized controlled trial	Moldova, Europe.	197 TB patients	22	VOT led to a significant reduction in nonadherence, with patients missing 4 days less (P<0.01) during 2 weeks compared to DOT. Patients under DOT missed an average of 5.24 days in 2 weeks, whereas VOT patients missed only 1.29 days.	[31]
6.	Pilot study	Baltimore, USA.	26 patients	2	VOT had significantly higher adherence compared to DOT (68% vs 50%) throughout a 60-day study. The VOT program exhibited its greatest feasibility within the initial four weeks and maintained a consistently high level of overall acceptability.	[32]
7.	Cross-sectional	Wuhan, China	1576 patients	6	Digital intervention in the treatment of TB had significantly higher medication adherence compared to DOT (84.28% vs 80.33% p=0.001). The treatment success rate was also significantly higher in the digital group compared to the TCIS group (92.52%	[33]

					vs 92.07% p=0.001).	

* The number of patients represents the total number of patients in both groups.

$ Study Duration represents the duration of the study in months.

VOT= Video Observed Therapy

Procedure of A-VOT

Patients will record their video every day and send it to the healthcare provider where a DOTs observer will observe the video, video recording should have a proper date and time which would help to find medication adherence of the patient [34].

2. **99-DOTS:** It is a cell phone-based approach for measuring medication adherence [35]. 99-DOTS technology is a Short Course initially launched by the Revised National Tuberculosis Programme under the national program in high-burden antiretroviral therapy (ART) centers in 2015 in India, in which real-time online tracking of daily therapy intake at a cheap cost using mobile phone technology [36]. The anti-TB blister packs were packaged in personalized envelopes that masked phone numbers which would only become visible when doses were administered. After taking the dose, the patient must give a missed call using the registered mobile number to the healthcare provider [37,38]. All miss-calls were toll-free to avoid any additional cost to the patient and make it convenient for them. 99-DOTS can reach the greatest number of patients who use mobile phones. 99-DOTS can be used in patients who have a comorbid condition [39]. 99-DOTS is a low-cost method as compared to other digital adherence technologies and directly observed therapy [40]. An interview was conducted in Kampala, Uganda in April-Aug 2021 with 12 healthcare professionals most of them mentioned that 99-DOTS reduced their workload and improved adherence of the patients. Most TB patients like to take medication at home, saving time and transportation costs for patients required to visit the DOT center. Table 2 includes a few studies that summarize the key conclusions of multiple studies. 99-DOTS are feasible and acceptable to support TB medicine, and improve medication adherence because reminders are given through SMS or phone calls [41]. Fig: 3 shows the steps involved in 99-DOTS for measuring medication adherence.

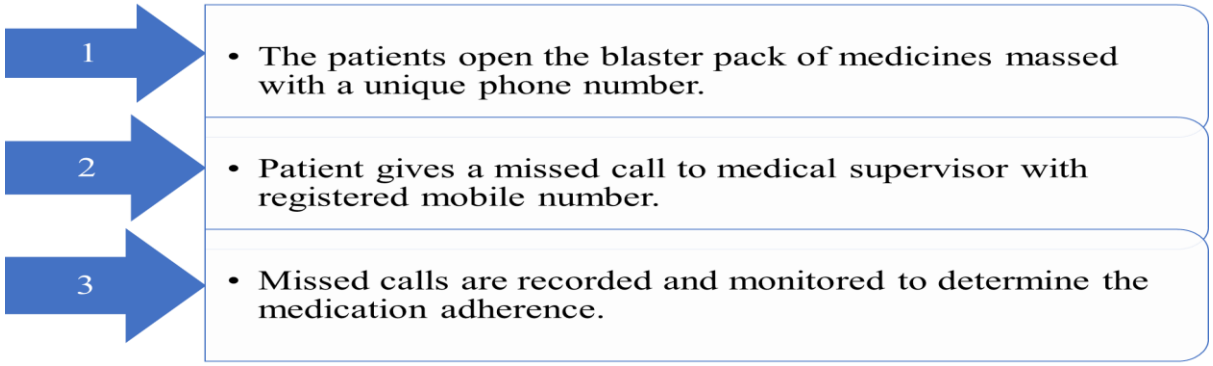

Fig: 3 Steps involved in 99-DOTS for measuring adherence

Table 2 99 DOTs enabled studies in Tuberculosis patients.

S.no	Study type	Place of study	No of patients*	Study Duration$	Main Findings	Reference

1.	Cohort study	Karnataka, India	870 patients	12	Patients who received 99-DOTs had significantly higher unsuccessful outcomes compared to DOT (30.5% vs 23.4 p=0.001). Medication non-adherence was significantly lower in 99-DOTS compared to DOTs (10.9% vs 30.5% p=0.001).	[37]
2.	Cohort study	Philippines	396 patients	24	Treatment success rates for the 99-DOTs patient group were 83.41%, compared to 76.61% of patients in the DOT group. Patients taking 99-DOTs had an average daily adherence rate of 93.41%.	[42]

* The number of patients represents the total number of patients in both groups.

$ Study duration represents the duration of the study in months.

3. **Drone Observed Therapy System (Dr-OTS):** In Dr-OTS, active case finding and modern technology are merged to support community-based TB control [43]. In Dr-OTS, drone use, adherence tracking with digital technology, and cell phone-based educational materials are used to promote TB control. This tool was introduced in Madagascar in 2017 [44]. Dr-OTS aims to improve rural towns' access to healthcare. By transporting patient data, such as blood, urine, sputum, and stool samples needed for diagnosis from primary medical centers to hospitals, and medications needed for treatment from healthcare facilities to patients in nearby rural locations, drones can be used as essential tools to connect primary medical care facilities to hospitals and help in emergency response [5,46]. Dr-OTS reduces transportation money and also helps in connecting remote areas to healthcare facilities and monitoring medication adherence by providing drugs/medicines to patients [47]. A cross-sectional study was conducted by [44] in Madagascar between Nov 2017- Jan 2019, which compares medication adherence between DOT and Dr-OTS groups, where they found medication adherence in Dr-OTS is significantly higher compared to DOT group (80% vs 60%).

4. **Medication Event Reminder Monitor System (MERM):** MERM is a modular electronic monitor that was created to track the treatment of MDR-TB in areas with limited resources for drugs given in the National Tuberculosis Elimination Program (NTEP) [48,49]. These tools were created to make it easy for medical facilities to provide TB treatment throughout the community while carefully observing adherence. It is an indirect approach to measuring treatment adherence, provided by electronic treatment monitors like the MERM gadget [50,51]. By this method, all of the medications required to make the MDR-TB regimens can be organized and stored, when the medications are dispensed in blister packs and kept in separate divided sections within the MERM [52]. Table 3 includes a few studies that summarize the key conclusions of multiple studies.

Table 3 MERM enabled studies in Tuberculosis patients.

S.no	Study type	Place of Study	No of patients*	Study Duration$	Result	Reference
1.	Cross-Sectional	Morocco	347 patients	6	The cure rate in the MERM group was high as compared to the DOT group (62.1% vs 43.3%). Drug adherence was also significantly higher in the MERM group Compared to the DOT group (81.35 ±6.8% vs 80.77 ±9.2%). Loss of follow-up of patients was 0.5% lower in the MERM group than DOT group. The	[53]

					treatment success rate was also significantly higher in the MERM group as compared to the DOT group. (93.2% vs 79.5%).	
2.	Randomized controlled trial	Argentina	42 patients	6	The treatment adherence was 81% for usual care and 95.2% for TB treatment support tools. 93.6% of patients do not report any side effects 6.4% reported 1-2 side effects but 1 patient reported more than 2 side effects in 154 days of their treatment.	[54]
3.	2 arm randomized controlled trials	Ethiopia	114 patients	12	The geometric mean percentage for adherence was high—99.01% in the intervention arm and low 98.97% in the control arm. There was no significant difference between the two groups in terms of adherence to prescribed medication.	[55]
4.	Multicentred randomized controlled trials	Ethiopia	109 patients	12	Patients had significantly higher Effectiveness to treatment in intervention groups compared to the controlled group. (85.78% vs 63.43% p=0.001), Global Satisfaction is also significantly higher in the intervention group compared to Control (90.19% vs 67.11% p=0.001). There were notable associations found between Global Satisfaction and medication adherence (p = 0.017).	[56]
5.	Randomized controlled trial	China	250 patients	3	The mean ratio (MR) for poor adherence was compared between the intervention and control groups, resulting in an MR of 0.72 (95% CI 0.55–0.86). This indicates a substantial difference between the two groups.	[57]
6.	Cross-sectional study	India	126 patients	6	After accepting MERM medication adherence was found to be 89.7% and non-adherence was found to be 10.3% which was statistically significant.	[58]

*The number of patients represents the total number of patients in both groups.

$ Study duration represents the duration of the study in months.

5. **Bio-ingestible sensors**: Ingestible sensors for tuberculosis treatment are microchips embedded in tuberculosis medication. After ingestion, the sensor interacts with the person's gastric fluid and transmits a signal to an adhesive monitor worn by the person [59,60]. These sensors are acceptable, feasible, and useful for monitoring adherence to TB treatments [61].

Bio-ingestible sensors can be of 2 types:

a) **Radiofrequency Identifier**: RFID technology, a wireless network that uses radiofrequency waves to send and receive information that is useful for specifically identifying a product, uses radiofrequency waves to send and receive data. Due to its tiny size, the RFID system, which consists of a label and a reader, can be paired with many other physical forms [62]. RFID works by attaching a physical tag to an item, which transmits information to a remote reader through radio waves, such as the object's location and time. RFID technology has applications in the healthcare system for billing, inventory tracking, assuring drug safety, preventing the supply chain of duplicate medicines, monitoring, and enhancing medication adherence [16,63].

b) **Near Field Communication:** An advancement in RFID technology known as near-field communication (NFC) enables two-way communication between two compatible devices, such as an NFC tag and a smartphone. NFC tags, which can be included on stickers, labels, packaging, etc., are little chips that store data. These data can be read by smartphones at close range [64]. NFC makes monitoring the drug usage schedule by family members, prescribers, and pharmacies possible. For better medication adherence, NFC tags can be added to a drug delivery system such as an automatic injector or an inhaler [16]. A patient's smartphone can link to medication guidelines, useful information, and usage videos by tapping a tagged gadget. [61] conducted a quantitative survey at Amala Institute of Medical Sciences, Thrissur, Kerala, India from April 2021- to May 2022 in which they found that 76% of patients suggested that digital pill systems or bio-ingestible sensors helped improve medication adherence, also a suitable option for DOT.

6. **Smart pill bottles**: Smart pill bottles are smart white plastic bottles that have an automated dosing module program added with a smart battery, on the timing of the dose system is unlocked which avoids dual dosing [65]. These devices can measure adherence using the sensor in the cap, which can recognize when a bottle opens, or sensors in the bottle sensors in bottles themselves, which determine adherence based on the weight of the remaining pills. Although they are simple to use, they are expensive, according to published research, smart pill bottles and pharmacist assistance have increased adherence for individuals with the disease [66]. Table 4 includes a few studies that summarize the key conclusions of multiple studies.

Table 4 Smart Pill Bottles enabled studies in Tuberculosis patients.

S.no	Study type	Country	No of patients*	Study Duration$	Result	Reference
1. 1.	Randomized single-blinded trials	Avella	40 patients	8	After the completion of treatment, medication adherence was statistically improved in the intervention group when compared to the control group (100% vs. 87.4%; P = 0.001).	[67]
2. 2	Randomized pilot study	New York	63 patients	39	Smart pill bottles significantly increased medication adherence compared to the DOTs group, (83% vs 73% p= 0.000).	[68]
3. 3	Randomized control trials	New York	85 patients are included	3	Smart pill bottles significantly increased medication adherence compared to the control group (71.4% vs 61.6% p= 0.001).	[69]

*The number of patients represents the total number of patients in both groups.

$ Study duration represents the duration of the study in months.

Salient Features of various Digital technologies

Table 5 Salient Features of Digital Technologies

S.No	Name of Device	Features	Reference
1. 1	VOT	VOT involves using video technology to remotely monitor patients as they take their medication doses. Patients record and send videos of themselves taking their medication, allowing healthcare providers to verify adherence without the need for in-person observation.	[39,70]
2. 2	99DOTS	This system utilizes mobile phones and blister packaging. Patients receive medication in blister packs with hidden phone numbers. Each time a pill is pushed out, it reveals a phone number to call and confirm medication intake. Healthcare providers can track adherence by monitoring missed calls and generating alerts for non-adherence.	[71]
3. 3	Drone Observed Therapy System	Drones are employed to deliver medication to remote or inaccessible areas, ensuring patients receive their medication even in challenging geographical locations. This approach helps improve access to medication, which can subsequently enhance adherence.	[43,44]
4. 4	Medication Event Reminder Monitor System	MERM systems typically involve electronic dispensers equipped with sensors that record each time a pill is removed. These systems send reminders to patients for scheduled doses and provide data to healthcare providers regarding adherence patterns.	[51,72]
5. 5	Bio-ingestible sensors	These sensors are embedded in medication pills and are designed to be ingested. They transmit signals to an external device or smartphone, providing real-time data on when medication is taken. This technology offers precise tracking of adherence by detecting ingestion of specific medications.	[60]
6. 8	Smart Pill Bottles	These containers are equipped with technology that tracks when they are opened or pills are removed. They often come with built-in reminders and may sync with mobile apps to provide patients with timely dosage instructions. Healthcare providers can access adherence data for monitoring.	[65]

Advantages and disadvantages of different digital technologies

Technology	**Description**	**Advantages**	**Disadvantages**	**Ideal Use Case**
Video Observed Therapy (VOT)	Patients record themselves taking medication via video, reviewed by healthcare providers.	- Flexible scheduling and observation. - Reduces need for frequent in-person visits. - Can be integrated with telehealth platforms.	- Requires reliable internet and familiarity with technology. - Potential privacy and data security concerns. - May not be suitable for all patient demographics.	Ideal for remote monitoring and reducing the need for in-person visits.
99 DOTs	A mobile-based platform where patients use a smartphone to record medication intake and send it to healthcare providers.	- Provides real-time adherence data. - User-friendly with SMS-based reminders. - Enhances patient engagement with digital health. - Scalable and cost-effective for large populations.	- Requires access to a smartphone and stable network. - Potential issues with data privacy. - May not be accessible in areas with low smartphone penetration.	Useful in settings with high mobile phone penetration and digital literacy.

MERM Device	Medication Event Reminder and Monitoring (MERM) devices track medication adherence and remind patients to take their medication.	- Provides structured reminders and tracks adherence. - Reduces human error in medication management. - Can be customized to patient needs.	- High initial cost and ongoing maintenance. - Requires patient compliance with device use. - Limited integration with other health systems.	Suitable for patients who need structured reminders and adherence tracking.
Bio Ingestible Sensors	Pills with embedded sensors that transmit data to an external device when ingested.	- Provides precise and objective adherence data. - Allows for integration with other health monitoring systems. - Can monitor medication efficacy and patient health simultaneously.	- Very high cost; limited availability. - Requires patient understanding and willingness to use. - Potential privacy and data security issues.	Best for patients needing detailed adherence tracking and integrated health monitoring.
Smart Pill Bottles	Pill bottles with built-in sensors that track when the bottle is opened and provide reminders.	- Provides visual and auditory reminders. - Tracks medication usage accurately. - Helps in medication management for chronic conditions. - Can be used alongside other adherence strategies.	- High initial cost. - May have compatibility issues with different pill sizes or bottle types. - Relies on patient adherence to using the bottle correctly.	Useful for patients who need visual and auditory reminders and tracking.

Advantages of Digital adherence technologies

Digital health technologies offer numerous benefits for tuberculosis (TB) management, particularly in enhancing medication adherence. Digital technology reminders and alerts through mobile apps or SMS help patients adhere to their treatment schedules by reminding them to take medication at the right times [73]. Digital platforms provide educational resources about TB and its treatment, improving understanding and motivation for adherence [19]. Telemedicine enables remote monitoring and support from healthcare providers, facilitating communication and addressing adherence concerns [17]. Digital tools track medication intake, offering real-time data for timely intervention if adherence issues arise. These combined efforts can significantly improve medication adherence and overall TB management [28].

Disadvantages of Modern Technologies in Adherence to TB

Digital technology for TB therapy provides advantages as well as disadvantages. It can be challenging for some users to utilize at times because some places don't have fast internet access or the necessary supplies for digital devices [74]. Concerns arise over the security of personal data on these digital sites as well. Some people may deny treatment because they are not comfortable using these technological tools. Furthermore, the devices may not always produce the desired results, which could result in incorrect treatments [75,76]. It can be expensive to purchase and maintain this kind of equipment, particularly in areas with limited financial resources. It is essential that all individuals, physicians included, have skills for using such instruments [77,78].

Present and future trends in Modern technologies

Modern technological developments have played a key role in improving treatment adherence for TB. These days, TB care is being changed by technology including smartphones and tablets, electronic pillboxes, and smartphone applications that monitor medicine intake, send reminders, and provide real-time feedback to patients and healthcare providers [79].

Future developments in adherence technology for TB appear favorable. Future developments include AI-driven unique adherence aids, telemedicine platforms for remote patient monitoring, smart packaging with sensors to measure medication consumption, and even implanted devices for continuous drug delivery. The ultimate goals of these technologies are to improve patient outcomes by decreasing missing doses and increasing adherence to TB therapy [76,80].

2. CONCLUSION

Modern technologies in adherence to TB treatment have shown promise in improving treatment outcomes and medication adherence. Digital adherence technologies (DATs) are increasingly being used in TB management. Studies have shown improved TB treatment outcomes with the use of digital adherence technologies, some studies also show that digital TB technologies are acceptable to patients and healthcare providers, accurate for measuring adherence, effective in improving treatment outcomes, and impactful in improving health system efficiency. When it comes to TB drug monitoring, digital adherence technology might offer a suitable substitute for DOT. Modern technologies in adherence to TB treatment have shown potential in improving treatment outcomes and medication adherence. However, more research is needed to determine the effectiveness and feasibility of these technologies in various settings and populations

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