Journal of Clinical Tuberculosis and Other Mycobacterial Diseases 34 (2024) 100409

Contents lists available at ScienceDirect

Journal of Clinical Tuberculosis and Other Mycobacterial Diseases

journal homepage: www.elsevier.com/locate/jctube

Implementation bottlenecks of real time medication monitoring (evriMED) for improving adherence to anti-TB drugs among people with tuberculosis in Kilimanjaro, Tanzania

Rehema Anenmose Maro [a,b,*], Alan Mtenga [a,b], Benson Mtesha [a], Krisanta Wilhelm [a], Naomi Lekashingo [a], Marion Sumari-de Boer [a,c,d,e], Kennedy Ngowi [a]

[a] Kilimanjaro Clinical Research Institute, Moshi, Tanzania
[b] Nelson Mandela African Institute of Science and Technology, Arusha, Tanzania
[c] Amsterdam Institute for Global Health and Development, Amsterdam, the Netherlands
[d] Kilimanjaro Christian Medical Univesity Collage, Moshi, Tanzania
[e] Knowledge, Innovation & Technology Group at Wageningen & University Research, the Netherlands

ARTICLE INFO

Keywords:
Adherence
evriMED
SMS reminder
Real-time monitoring
Tuberculosis

ABSTRACT

Introduction: Digital Adherence Tools (DATs), which include real-time medication monitoring and Short Message Service (SMS) reminders, have been reported to improve medication adherence among people with Tuberculosis (TB). Recently, in limited resource settings, DATs have been described as a promising tool to monitor patients' medication behaviour. We aimed to determine implementation bottlenecks of real-time medication monitoring using the evriMED device.

Method: We conducted a research study using a mixed-methods approach, involving both people with TB s and directly observed treatment (DOT) providers who participated in the REMIND-TB trial and utilized the evriMED devices. EvriMED is a medication dispenser with internet connectivity that can send real-time SMS reminders. To gather data, we extracted reports from the Wisepill dashboard, specifically the client status report. This report documented the activity status of all devices, including communication and battery status. Additionally, we conducted in-depth interviews with people with TB and TB care providers who were involved in implementing the Remind TB trial in the Kilimanjaro region. These interviews were guided by the MIDI (Measurement Instrument for Determinants of Innovation), which helps identify the factors influencing the implementation of innovations such as evriMED.

Results: Out of the initial 281 participants who were given devices, 245 completed the 6-month follow-up period. The findings indicate that at month 6, most of the devices (49%) reported battery-related challenges. Additionally, forty devices (14%) had reported more than one incidence of losing communication. Through interviews with participants, we observed that evriMED was perceived as user-friendly, and the people with TB reported high satisfaction as the device facilitated improved medication intake. TB care providers also said that evriMED was a relevant tool to be used by the people with TB. However, during the in-depth interview certain implementation bottlenecks were identified, including network issues, limited training, and low technology knowledge among TB care providers, who found the procedure of using the evriMED to be time-consuming.

Conclusion: Implementation of evriMED was perceived as user-friendly and highly satisfactory by people with TB. Certain implementation bottlenecks were identified as potential barriers to the use of devices. These bottlenecks include network issues, limited training, battery-related challenges and low technological knowledge among TB care providers, which may have contributed to communication loss. Further research may be needed to address

Abbreviations: TB, Tuberculosis; CRERC, College Research and Review Committee; DAT, Digital Adherence Tool; DOT, Direct Observed Treatment; EMS, Electronic Monitoring System; GCP, Good Clinical Practice; HCW, Health Care Workers; HIV, IDI In-depth Interviews; KCMC, Kilimanjaro Christian Medical Centre; KCRI, Kilimanjaro Clinical Research Institute; NatHREC, National Health Research Ethics Sub-Committee; NIMR, The National Institute for Medical Research; MDR-TB, Multi-drug resistance TB; MIDI, Measurement Instrument for Determinant of Innovations; RTMM, Real Time Medication Monitoring; SMS, Short Message Service; SSA, Sub-Saharan Africa; PLHIV, People living with HIV.

* Corresponding author at: Kilimanjaro Clinical Research Institute, Moshi, Tanzania.
E-mail address: r.maro@kcri.ac.tz (R. Anenmose Maro).

https://doi.org/10.1016/j.jctube.2023.100409

Available online 3 December 2023

these limitations and develop effective strategies to facilitate the successful implementation of evriMED as a tool for improving medication intake among people with TB.

1. Introduction

Tuberculosis (TB) was the second leading communicable disease after COVID-19 causing mortality worldwide. In 2021, an estimated 10.6 million people fell ill with tuberculosis (TB) worldwide, of whom 1.6 million died [1]. Of the individuals diagnosed with TB, approximately 1.4 million reside in the sub-Saharan region [2]. Tanzania is one of the 30 countries with the highest tuberculosis (TB) burden in the world. According to the World Health Organization (WHO), 142 000 people (253 per 100 000 population) fell ill with TB in 2018, of whom 40 000 (28 %) were people living with HIV [3]. In 2019, the estimated TB incidence rate was 237 cases per 100,000 though in 2021, WHO reported that there is a reduction in the incidence rate [2].

The WHO has recommended directly observed treatment (DOT) as a strategy to improve adherence, prevent Multidrug-resistant TB (MDR-TB) and control TB infections [4]. However, the implementation of DOT and adherence to treatment is still a challenge [5,6]. Non-adherence to TB medications may be caused by various factors related to the patient's situation, such as financial and emotional support, the disease, forgetting and the treatment and healthcare system factors [7–9].

Interventions that tackle these multiple challenges are highly needed. Several innovative digital adherence technology interventions have proven feasible in controlled settings[10–12]; additionally, the WHO recommended using digital adherence tools (DATs) to improve adherence to medications [13]. A systematic review done to evaluate the effect of medication event Electronic Monitoring System (EMS), which is a different term for DATs, on adherence to treatment and clinical outcomes showed that the use of EMS has a positive effect on medication adherence, though it is inconclusive in clinical outcome [14]. Further, there is limited evidence on the feasibility of using the intervention and its effect on adherence among people with TB in real-world settings in Africa [15–19].

One type of DAT is the so-called Real Time Medication Monitoring (RTMM) device. This is an internet-enabled pillbox that monitors medication intake in real time by recording device openings. Using RTMM may tackle factors of non-adherence to medication by sending reminder cues and giving tailored feedback on adherence patterns. Several studies have shown that interventions using RTMM may improve adherence among people with TB [20–25]. Furthermore, in our context, we have done a pilot study on RTMM among people living with HIV and people with TB in Kilimanjaro. The study showed that using RTMM is feasible in our setting but since it was a small sample size as a pilot, there is no data on feasibility in a large number of people, including urban and rural settings [26].

In our context, the acceptability of RTMM was very high among PLHIV [27]. However, less has been explored on the challenges of implementing RTMM in large groups of patients and covering a large area. The main objective of this study was to determine the potential implementation bottlenecks of the evriMED device for improving adherence to Anti-TB drugs among people with TB in Kilimanjaro. The specific objectives are to understand determinants that influence the implementation of evriMED and to explore technical challenges that occurred during the implementation of evriMED.

2. Methods

We first describe the REMIND-TB trial as our study was conducted in the context of this trial.

2.1. REMIND-TB trial

From June 2019 to March 2021, we conducted a two-armed cluster randomized trial. PACTR201811755733759; Registered on 8 November 2018, https://doi.org/10.1186/s13063-019-3483-4. Details of the trial have been explained elsewhere [28]. The REMIND TB trial aimed to investigate the effectiveness of evriMED with reminder cues and tailored feedback on adherence to TB treatment in Kilimanjaro, Tanzania. Clusters were created in each district of the Kilimanjaro Region based on the level of health care facilities. In the intervention arm, evriMED devices were implemented. In the control arm, standard care was followed. People with TB in the intervention clusters took their medication from the evriMED pillbox and received tailored feedback on adherence during consultation. The Kilimanjaro Christian Medical College Research Ethics and Review Committee (CRERC) and the National Health Research Ethics Sub-Committee (NatHREC) of Tanzania approved the study. This study followed Good Clinical Practice (GCP) guidelines in all study procedures.

2.2. Intervention

The intervention comprised two components. One component is the use of real-time medication monitoring consisting of reminder cues through SMS, and the other is the tailored feedback on adherence data. The RTMM-device (evriMED) is a pillbox containing a SIM card produced by Wisepill Technologies in South Africa [29]. In our study, we used the evriMED1000 pillbox, which records and stores medications' time events (with date and time information) every time the pillbox is opened. The information is directly shared with a central server through the mobile network, in near real-time (within 2 min). The first event and all unsent events (Medication events) are sent to the server at that time. In addition, the pillbox delivers a heartbeat event every day that contains device identification, the health of the device and technical information on the battery status and signal strength. If the evriMED1000 is not opened, any unsent (Heartbeat and medication event) data are sent at the time of the next heartbeat.

An intake period was configured on the server, which was the participants' preferred time of intake, in which he/she usually takes medication. Half an hour before the intake period, a reminder SMS was sent to the mobile number of the participant, to remind the participant to take their medication. The reminder SMS content was "Habari ndugu, muda wako wa kumeza dawa umekaribia unakumbushwa kumeza dawa zako kwa wakati kama ulivyoelekezwa na wataalamu wa afya", which in English means "Hello dear, your time to take medications is near, you are reminded to take your medications as instructed by the health care professionals". If the medication was not taken within one hour of the intake time, the participant and his/her treatment supporter received another reminder SMS message.

In addition, when a patient visits the clinic, adherence reports generated by the device are discussed by the TB care providers with the patient. This is the second part of the intervention, which is tailored feedback. We used a modified version of the Stages of Change Model for the feedback given by nurses to the patient [30]. Participants in the intervention arm received feedback on adherence reports in each visit, which was every two weeks for patients in the intensive phase and every four weeks for patients in the continuation phase for six months.

2.3. Trial population and sample

Inclusion criteria were: Diagnosed drug-susceptible people with TB (including smear-negative patients); Attending care at any of the TB

treatment centres in Kilimanjaro Region, Tanzania; Aged between 18 and 65 years; Living in Kilimanjaro Region; Willing to use the evriMED-device; Willing to come to the clinic according to standard care; Able to read and understand SMS; Able to understand and willing to sign the informed consent document. Exclusion criteria were: Participating in other trials or previously participating in studies with electronic monitoring devices and participants who were admitted to the hospital.

2.4. Trial procedures

Details of the trial have been explained elsewhere [28]. In summary, eligible participants were asked to participate in the trial. A thorough informed consent procedure was used. The aim of the study was explained thoroughly by TB care providers of the respective clinic using a patient information sheet. After informed consent, we collected baseline information through case report forms (CRF). TB care providers set up the evriMED devices. After they prepared the device, participants were given information on how to use the device and they placed the medications in the evriMED device.

2.5. Mixed-methods study

The current study involved people with TB who were in the intervention arm of the REMIND TB trial. We conducted a parallel convergent mixed methods study with different data sources. We used quantitative data from the Wisepill dashboard and qualitative data from in-depth interviews with healthcare workers (DOT nurses) and people with TB. After six months of treatment, we purposively selected TB care providers and people with TB for in-depth interviews. We aimed to interview 20 TB care providers and 20 people with TB as we believed that would be adequate to reach saturation [31].

3. Data collection

3.1. Quantitative data

We extracted a report from the Wisepill dashboard, which is called the *client status report*. The client status report recorded all devices' activity status, including communication status and battery status of the device. When devices reported a loss of communication, it means the device could not detect any activity or any opening of the device. When the device reported critical battery status, it means the battery was below 20 %. If the device had reported a loss in communication, it means we were unable to retrieve actual adherence data from participants at that moment when the client was at the hospital for the tailored feedback. Later, we were able to download the report when the device started sending signals.

3.2. In-depth interviews with people with TB and TB care providers

People with TB were purposively selected from the clusters in the intervention arm. They were selected based on their adherence patterns with low adherence (less than 70 %) and high adherence (at least 95 %) based on their report from the Wisepill dashboard. We also considered variability in demographic characteristics such as rural or urban residence and gender to ensure heterogeneity. In-depth interviews were done with people with TB at the end of the six months of treatment to understand the context of adherence to treatment, experience, and barriers to the use of evriMED among people with TB. In addition, we purposively selected two TB care providers in each cluster who provided services in the intervention arm for the in-depth interviews. They were selected based on their professionals. In-depth interviews with TB care providers were done to understand more about the experience of implementation of evriMED devices among people with TB. Interviews were done in Kiswahili, transcribed verbatim and translated to English, and were conducted at an agreed time and space that was convenient for the participants.

3.3. Data collection tools

3.3.1. Topic guides

Interviews were done by trained research assistants. The topic guides were semi-structured. Topic guides for TB care providers were focused on understanding experienced implementation barriers of evriMED devices, facilitators and overall feedback of the intervention. The IDI guide also included a warm-up exercise involving a role-play scenario, where the research assistant assumed the role of a patient. Topic guide for people with TB focused on experience with evriMED devices, facilitators, barriers to using evriMED devices, psychosocial factors (stigma, disclosure, and social support), medication adherence and usage of graphs which are generated from digital adherence tools. The topic guides were adapted during the study in an iterative process. Interviews were transcribed verbatim and translated into English.

3.4. Data analysis

3.4.1. Quantitative data

To analyse the quantitative data, we used descriptive analysis to summarize the number of devices that reported battery challenges from month 1 to month 6. We summarized the percentage of communication loss events, which occurred more than once during the study period as it caused the devices to wrongly send a second reminder.

3.4.2. Qualitative data

To analyse determinants that influence the implementation of the evriMED device, we conducted a thematic content analysis of all qualitative data. Firstly, all transcripts were read several times to gain an understanding of the content. Memos were created by two research team members (RM and AM) and coded data separately before they reached an agreement on the final code book. An analytical scheme was developed, inspired by the MIDI (Measurement Instrument for Determinant of Innovations), an instrument designed to identify which determinants influence the actual use of an innovation to be introduced or that had already been implemented [32]. We selected two categories from the MIDI framework that were most relevant to the study. These categories include determinants associated with the intervention and determinants associated with the healthcare provider. Please refer to Table 1 for more details. Data were interpreted by trained social scientists in the team to ensure the coded data corresponded to the identified frameworks and validity of the data. NVivo.12pro was used for data organization and extracting the quotes.

4. Results

We enrolled a total of 280 participants in the intervention arm across six clusters, with a mean age of 31.3 (SD 6.3) years, ranging from 19 to 45 years. Among these participants, 245(87.5 %) successfully completed the 6-month follow-up period while utilizing the evriMED device. Additionally, we conducted eighteen in-depth interviews with individuals diagnosed with TB and fifteen in-depth interviews with TB care providers. The interviews, lasted for approximately 40 to 90 min each. Among eighteen individuals with TB, we included twelve (66.6 %) male and six (33.3 %) female participants. And for health care providers, three (20 %) were male, and twelve (80 %) were female. Details of the demographic characteristics is shown below in the Tables 2 and 3.

Determinants associated with the intervention

Procedure clarity: According to some of the participants with TB, they had received clear instructions on how to use the device.

> *"….The nurse showed me how to open and close the device and told me not to open it when I am not taking medications. But, only to open it when taking medicine."* ***-Female participant with TB 53 years***

Table 1
Themes: MIDI categories and determinants.

Categories	Determinants	Description
Determinants associated with the intervention	Procedure clarity	The extent to which the intervention is described in clear steps/procedures
	Completeness	The degree to which the activities described in the intervention are complete
	Complexity of intervention	The degree to which the intervention is complex to implement
	Compatibility	The degree to which the intervention is compatible with the values and working method in place
	Observability	Visibility of the outcomes for the user (how the graph appeared)
	Relevance to people with TB	The degree to which the people with TB believes the intervention is relevant for them
Determinants associated with DOT provider	Outcome expectations	Perceived probability and importance of achieving the objectives as intended by the intervention
	People with TB satisfaction	The degree to which the health professional expects people with TB to be satisfied with the intervention
	Professional obligation	The degree to which the intervention fits in with the tasks for which the health professional feels responsible when doing their work
	People with TB cooperation	The degree to which the health professional expects people with TB to cooperate with the intervention
	Descriptive norm	Colleagues' observed behaviour; the degree to which colleagues use the Intervention
	Subjective norm	The influence of important others (RTLC, DTLC, Doctor In charge and colleague) on the use of the intervention
	Self-efficacy	The degree to which the TB care providers and people with TB believe they can implement the activities involved in the intervention
	Awareness of the content of the intervention	The degree to which the health professional has learned about the evriMED

Table 2
Demographic and adherence characteristics of in-depth interview individuals diagnosed with TB.

No	Sex	Age	education	Marital status	Participants adherence as shown by DAT
1	Female	30	Secondary	Married	10 %
2	Male	40	Primary	Married	24 %
3	Male	58	Primary	married	21 %
4	Male	55	Primary	Married	38 %
5	Female	53	Primary	Single	99 %
6	Male	48	Primary	Married	99 %
7	Male	56	Primary	Married	21 %
8	Female	38	Primary	Single	0 %
9	Female	49	Primary	Married	100 %
10	Male	63	Secondary	Married	100 %
11	Female	45	Primary	Separated	68 %
12	Male	52	Primary	Married	90 %
14	Male	59	Primary	Married	99 %
14	Male	41	Primary	Married	99 %
15	Female	45	Primary	Divorced	41 %
16	Male	52	Primary	Married	93 %
17	Male	40	Primary	Married	96 %
18	Male	60	Secondary	Married	98 %

Table 3
Descriptive characteristics of the selected TB care providers.

Variable	Category	Frequency	Percentage (%)
Gender	Male	3	20
	Female	12	80
Inclusion clusters			
	Moshi rural DH	2	13.3
	Moshi rural HC	3	20.00
	Moshi urban DC	1	6.67
	Moshi urban HC	3	20.00
	Same &Mwanga	4	26.67
	Kibong'oto	2	13.3
Profession's			
	Clinician	4	26.67
	Medical attendant	4	26.67
	Pharmacist	1	6.67
	Registered nurse	6	40

"…. There is a nurse here [in the clinic], who instructed me about the device and said that when you open it and see it does not show the power sign, you bring it back here to charge it." ***-Male participant with TB 56 years***.

Some of the TB care providers explained that they received training in a very short period, which made them not fully understand how the intervention works. Moreover, some of the clients with TB explained that they did not receive all information on how the intervention worked because some of the clients with TB did not know they will receive a message to remind them to take medications.

"No, he [DOT nurse] didn't tell me about the message. I only saw the message later. That is, he only said it will ring the alarm for you. If the alarm rings, you will open the device and take the pills. Close it properly." ***-Female participant with TB 45 years***.

"Aah, you know these trainings are good, but sometimes you find that there are many things to learn, but with limited time. Maybe, I think it's because of the budget. The budget is sometimes small, but the things that are being taught are a lot. Something that was to be taught in three days or four days is taught in two days. So, it becomes difficult for someone to understand." ***- TB care provider***.

"This device! The nurse told me that it keeps my records, but I didn't understand much more about how it keeps records. I ended up there." ***-Female participant with TB 45 years***.

Completeness: Sometimes, the activities described in the interventions seem not to be complete. During the study period, 40 devices (14 %) reported multiple instances of communication loss. At month six of the treatment period, 140 devices (57 %) experienced battery challenges. During in-depth interview people with TB till receive a second reminder, saying: 'Hello, you have forgotten to take medication on time…' while they already opened the device and took the medications. That means that the device was not able to communicate with the server due to either a poor mobile network or the device battery being low or other reasons that make the device not communicate. On the other hand, some of the participants interviewed explained that they had no problem in receiving messages, opening, or closing the devices or even charging.

"Eee…. It was a bit difficult for me to understand, because you may find the time is not yet for me to take the medicine or I have already taken the medicine. But, I receive an SMS on my phone saying; 'you have forgotten to take the medicine'. So, it brings a bit of confusion." ***-Female participant with TB 45 years***.

"There are few [patients] who said that the device didn't work well and we told them to bring the devices back. So, as we can try to check." ***-TB care provider***.

The complexity of intervention: The evriMED device was easy for people with TB to use, and they found the process straightforward. They could use the device on their own without any issues. During the IDI warm-up exercise with TB care providers, we noticed that most of them could use the evriMED device independently without any difficulties. This suggests that the intervention was not complicated to implement.

"No, this is not difficult, because when you open a device, there is a place to hold and open. Though if you don't close it properly, the lights don't go off." – ***Male participant with TB 53 years***.

"No, I have not had any difficulty in using the device." ***- Female participant with TB 45 years***.

Compatibility: During IDI with the TB care providers, it was mentioned that the study procedures took a long time. (Approximately 20 min for one patient). The study procedures involved explaining to patients how to use the device. This contrasted with the normal standard of care. In the standard care, they were able to attend to many patients. Standard care usually took a shorter period (usually 10 min). Since it is a new technology to our setting, it needed time and a calm place.

"Sometimes, you may find out that you have so many other patients that you are attending. This gives you no time to attend a client with TB t with all that information about the intervention at the same time." –***TB care provider***.

"It takes time because you used to stay with a patient for ten minutes. If you want them to understand properly, you need to double the time." ***-TB care provider***.

Observability: People with TB did not have doubts about the perceived outcomes of using the device, as it reminds them to take medication and stores the medication in a safe place. Though, the visible outcomes, such as graphs, which were generated by the evriMED device were not always shown to clients with TB.

"It's okay because I've used it myself, and then I've found it very useful to remind me about the time to take medication." – ***Male participant with TB 59 years***.

"This device! I recommend that it should be used because the doctor becomes aware of the patient's progress at home and it stores the medication in a very hygienic environment." ***- Male participant with TB 52 years***.

"Honestly, the graph has never been shown to me." ***-Female participant with TB patient 30 years***.

Relevance to participants with TB: Using the device was perceived to be relevant by people with TB s as they sometimes people forget to take medication, and the evriMED helped them to take medications on time. Moreover, it was relevant for the TB care providers, as they were able to monitor the progress of their patients.

"The device is good because when you forgot to take the medication, our experts (Researchers) let us know that, 'today you forgot to take the medicine.' Because sometimes a person forgets, but through this device, it helps us." ***- Female participant with TB 45 years***.

"For us – health care providers, the devices were helpful, because they not like only remind but also do other things. We get the patient's information for reference from the devices. They help us to know if the patients are in good care and take medications compared to those who are not using the devices because for them, we are not able to know if they are taking medication or not." ***-TB care provider***.

Determinants associated with DOT provider.

Outcome expectations: TB care providers mentioned that the intervention meets the needs, as most of the participants were able to finish medication treatment, so they recommended it to be used as part of standard practice.

"The success is that for those who used the device, a large percentage of patients tried to finish taking their medications properly, even though there are two who died before completing the medication." ***-TB care provider***.

*"I would advise the devices to be used because they can help to stop the increase of TB cases. This is because we will have the real records that can be used to justify whether the patient is really taking medication or not because of the percentage scores [as shown in the adherence reports] …****-TB care providers***.

People with TB satisfaction: The degree to which people with TB were satisfied is another determinant that influences the implementation of the intervention. TB care providers mentioned that clients with TB were willing to use the device and that they were happy to use them.

"When the client with TB came, they were happy that the service has been made better, that devices have been brought for them. It means that they are taken care of because I know these things are expensive and they are brought to us. So, there is no need for us to not use them. Clients with TB even have a bag for it. When they come here [in the clinic], they open their bags and they take devices. On some days, when they come, you ask them 'How do you see this? is it annoying you at home?' and they say 'Aah, (no) it stays far from children so they don't touch it.' This device is good. I don't even know how to explain." ***-TB care provider***.

*"Client with TB said 'it was good.' Firstly, it stores medication in the right place because the medicine card and its pills were all being stored together. This makes it easy to take the medicines and fill the chat for medication (Clients TB card). When he is done, he just closes the device. They also said that it's a nice device for storing their medication…"****-TB care provider***.

People with TB cooperation: The cooperation of the intervention might be hindered by issues such as the poor mobile network. The network issue leads to clients with TB receiving a wrong SMS, stating that they have not taken their medication while they have already taken it.

"I was very upset because I took the medication at the required time and then the reminder came in half an hour after I took medication. Telling me that 'you forgot to take medication.' Now, I wanted to reply to that message and let them know I have already used it, but the message fails."– ***Male participant with TB 63 years***.

Subjective norm: The influence of others on the use of the device was also a determinant of the implementation of the intervention. People with TB were also scared to be seen with the evriMED device as it might be stolen or someone else may get curious and open the device and find medication inside. Some of them could not travel with device because they feared how others may think. So, they had to travel without the evriMED device and use medications outside of it.

"I was afraid to travel with the device because maybe the environment where I was there wouldn't be suitable…." ***- Female participant with TB 45 years***.

"If you don't store the device carefully, people might think that maybe it's a big phone or a radio or something else. They can steal it." ***- Male participant with TB 63 years***.

"…. When they opened the device, because it blinks the light, they can think this device is sold at a very high price. So, they might throw the drugs away, so that they can find a market to sell because they don't know its function. That is why I did not want to show anyone." – ***Male participant with TB 63 years***.

"I am reminded 'why you haven't taken the medicine. You didn't take the medicine.' Other times, I am reminded by the doctors here. But it wasn't like I stopped taking medications; it was because I took medicine out and then travelled with them, unlike taking them from the evriMED device." – *Female participant with TB 46 years*.

Self-efficacy: The degree to which TB care providers believe they

can implement the intervention and the degree to which people with TB think they can use the device is also a determinant that influences the implementation of the device. Our results showed that people with TB believed they could use the intervention accordingly.

> *"I was able to use the device because I liked it, how it's used, you just open it, take your medicine and close it."* ***- Female participant with TB 47 years***.

Awareness of content of intervention: During the informal interviews with TB care providers, it was revealed that most TB care providers who implemented the intervention did not receive the initial training on implementing the evriMED device. Through sensitization, some of them were aware of how to implement though others were not fully aware. So, they could not inform the patients well on how the intervention works.

> *"I do not understand what is going on in these devices. I open it, take the medication, and then I close it because that's what my doctor told me to do and then I just continue with my activities."* ***- Male participant with TB 54 years***.
>
> *"I understood that in this device, if someone delays taking the medication, then he will receive the reminder message, but not before he has taken the medication."* – ***TB care provider***.

5. Discussion

Our study aimed to explore the determinants that influence the implementation of evriMED devices, which are designed to improve treatment adherence among people with TB. We also reported on the technical challenges encountered. At the end of the treatment period (month six), we found that most of our devices (49 %) experienced battery challenges. This means that the devices can remain without recharging for almost 5 to 6 months. However, few devices had critically low battery levels, resulting in the loss of adherence information from those participants. When the devices reported communication loss, it cannot accurately real time records the participants' adherence data. In in-depth interviews among people with TB, they mentioned receiving a second reminder message indicating non-adherence, even though they had taken their medication. Through the Wisepill dashboard, we discovered that several devices (14 %) were not sending signals and, as a result, were incorrectly sending the second reminder message. A similar study conducted among people living with HIV also noted that participants were receiving the second reminder message erroneously, possibly due to network issues [26]. In low- and middle-income countries, network connectivity and power outages have been major challenges [33,34].

We explored the determinants that influence the implementation of evriMED as perceived by people with TB and TB care providers. The implementation process is affected by various determinants, which can be related to providers, the community, the innovation itself, and its support system (training and technical assistance). Using the MIDI framework, we were able to identify and describe a wide range of determinants that could play a role in implementing evriMED to improve adherence to TB medications among people with TB. These MIDI determinants can be interrelated and can influence one another. For example, the degree to which the intervention influences the tasks for which the TB care providers feels responsible (professional obligations), the degree to which the intervention is compatible with the existing values and working methods (compatibility), or the belief in one's ability to perform (self-efficacy).

We found that clear and structured training and sensitization before implementing the intervention are crucial, especially for the implementers. Some TB care providers who understood the intervention well were able to explain it to their people with TB, resulting in successful usage of the evriMED devices. Several studies implementing mHealth approaches have also shown that providing education to healthcare workers about mHealth and involving them in the process has helped improve clinical outcomes [35,36].

Occasionally, the devices themselves did not function as intended (completeness). Various reasons, such as network availability and power issues for charging the devices, led to these performance problems. This issue was also observed in another study, which experienced network availability issues during the research[27]. Furthermore, we found that the intervention itself was not difficult to implement (Complexity of intervention). People with TB were able to open the devices and take medication without any problems. Similar studies utilizing real time medication monitoring devices in low- and middle-income countries have also shown feasibility [37,38].

During interviews, people with TBs expressed that the use of evriMED was highly beneficial to them. The devices helped remind them to take medication on time and improved overall treatment outcomes. TB care providers were pleased to monitor patients' progress and adherence to medication. Previous studies using RTMM devices have reported similar results, indicating that healthcare providers found the intervention to enhance clinical outcomes and be acceptable to patients [21,39,40].

While our study has several strengths, there are also a few limitations to consider. Firstly, the sample size and geographical location of our study may limit the generalizability of our findings to other populations and settings. Further research is needed to validate these findings in different contexts. Secondly, our study methodology, including the use of in-depth interviews, may introduce bias or limitations in the accuracy of the obtained information. Lastly, the follow-up period in our study may have been limited. Longer follow-up periods could provide additional insight into the long-term sustainability and impact of implementing the evriMED devices.

A major strength of our study is the utilization of different data collection methods, allowing us to identify technical challenges associated with the evriMED devices and gain insights that further our understanding of the determinants affecting their implementation. Additionally, the involvement of researchers with diverse backgrounds in implementation research and clinical trial research enhances the reliability of our findings. Moreover, the use of the MIDI theoretical framework enabled us to measure a wide range of determinants that play a role in the implementation of evriMED.

6. Conclusion

Our study investigated the determinants influencing the implementation of evriMED devices aimed at improving treatment adherence among people with TB. We explored technical challenges using MIDI Framework. Certain implementation bottlenecks were identified that might impact the effective use of the device. These bottlenecks include network issues, limited training of healthcare workers, and low technological knowledge among TB care providers. These may have contributed to the incidence of communication loss and battery-related challenges. Overall the use of evriMED was perceived as user-friendly and highly satisfactory by people with TB. Future studies should consider strategies to overcome the identified bottlenecks and develop effective strategies to ensure potential benefits of evriMED are fully realised. Our study serves as a foundation for ongoing efforts to refine and optimize the implementation of evriMED, contributing valuable insights that can inform the development of effective strategies to maximize its impact on medication intake among people with TB.

Ethics approval and consent to participate.

We obtained ethical clearance from the local institutional review board which is Kilimanjaro Christian Medical College Research Ethics and Review Committee (CRERC) No.2403 and the National Medical Research Institute of Tanzania (NatHRERC) with reference number of NIMR/HQ/R.8a/Vol. IX/2992. We followed Good Clinical Practice (GCP) guidelines in all study procedures including informed consent. All study methods were carried out in accordance with guidelines and

regulations of Tanzania ethical review boards. All interventions done in the protocol were approved by both local and national ethical review boards. We obtained informed consent from all participants.

Authors' contributions.

RM: Wrote the main manuscript text and analysis. AM, KW: Involved in qualitative analysis. NE BM: Involved in quantitative analysis, MSB: Is a principal investigator of the study and she was involved in study design and review of the manuscript, KN: He is a co principle investigator of the study and he was involved in review of the manuscript. All authors read and approved the final manuscript.

CRediT authorship contribution statement

Rehema Anenmose Maro: . **Alan Mtenga:** Conceptualization, Writing – original draft, Writing – review & editing. **Benson Mtesha:** Formal analysis, Methodology, Writing – original draft. **Krisanta Wilhelm:** Formal analysis. **Naomi Lekashingo:** Writing – original draft. **Marion Sumari-de Boer:** . **Kennedy Ngowi:** Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Marion Sumari-de Boer reports financial support and administrative support were provided by Kilimanjaro Christian Medical Centre.

Acknowledgements

We thank all participants who participated in this research. We thank the administration of the health facilities, Kilimanjaro Region to allow us to conduct this study in their facilities. We also thank the TB care providers and research assistants in recruiting participants and collecting data. We thank the TB reach wave 6, as this project was supported by them.

Funding

The TB Reach wave 6 (grant number1169, TZA_TOT1_KCMC) supported this study. The funder had no role in design of the study, execution, analysis or interpretation of data.

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