Digital Adherence Technologies and Mobile Money Incentives for Management of Tuberculosis Medication among People Living with Tuberculosis: A Mixed Methods Formative Study

Angella Musiimenta, Wilson Tumuhimbise, Esther Atukunda, Aaron Mugaba, Sebastian Linnemayr, Jessica Elizabeth Haberer

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Angella Musiimenta[1, 2] PhD; Wilson Tumuhimbise[2, 3] PhD; Esther Atukunda[4] PhD; Aaron Mugaba[2, 5] MBA; Sebastian Linnemayr[6] PhD; Jessica Elizabeth Haberer[7, 8] MD

[1]Mbarara Univeristy of Science and Technology Faculty of Computing and Informatics Mbarara UG
[2]Angels Compassion Research and Development Initiative Mbarara UG
[3]Mbarara University of Science and Technology Faculty of Computing and Informatics Mbarara UG
[4]Mbarara University of Science and Technology Faculty of Medicine Mbarara UG
[5]Mbarara University of Science and Technology Mbarara UG
[6]Rand Corporation Santa Monica US
[7]Harvard Medical School Boston US
[8]Massachusetts General Hospital Center for Global Health Boston US

Corresponding Author:
Angella Musiimenta PhD
Mbarara Univeristy of Science and Technology
Faculty of Computing and Informatics
Mbarara
Mbarara
UG

Abstract

Background: Suboptimal tuberculosis (TB) medication adherence can lead to treatment failure, the development of drug-resistant TB, and secondary transmission. Digital adherence technologies (DATs) such as real-time monitors and SMS reminders can improve TB treatment adherence. However, financial constraints can limit their utility. The design of mechanisms to incorporate financial support into DATs for TB treatment remains unclear

Objective: This paper describes the perceived usefulness and design mechanisms for a DAT intervention called My Mobile Wallet which is composed of real-time adherence monitor, SMS reminders, and mobile money incentives to improve TB medication adherence in a low-income setting.

Methods: This study employed mixed methods approaches among persons living with tuberculosis (PLTB) recruited from the TB Clinic in the Mbarara Regional Referral Hospital. We purposively sampled 21 PLWTB aged 18 years and older, who owned cell phones, and were able to use SMS. We also enrolled 9 participants who used DATs in our previous study. We used focus group discussions with the 30 participants to solicit perceptions about the initial version of the My Mobile Wallet intervention, and iteratively refined subsequent versions of the intervention following a user-centered design approach until the beta version of the intervention that suited their needs was developed. We also administered surveys eliciting information about participants' cell phone use and perceptions of the intervention. We used content analysis to inductively analyze data to derive categories describing the perceived usefulness of the intervention and design mechanisms. We used STATA 13 to analyze survey data.

Results: Participants expressed the perceived usefulness of the My Mobile Wallet intervention in terms of being cared for as a result of being monitored, sent an SMS reminder, or receiving a financial incentive, which could subsequently motivate and support medication taking. To address possibilities of unintended TB status disclosure and using the money meant for transport to the clinic for other competing demands, participants suggested using SMS language that is confidential and not easily related to TB and sending transport refund a day before the appointment to limit the time lag between receiving the money and visiting the clinic.

Conclusions: Digital adherence technologies complemented with mobile money financial incentives could potentially provide acceptable approaches to remind, motivate and support patients to adhere to taking their TB medication Clinical Trial: ClinicalTrials.gov NCT05656287

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Digital Adherence Technologies and Mobile Money Incentives for Management of Tuberculosis Medication among People Living with Tuberculosis: A Mixed Methods Formative Study.

Abstract

Introduction: Suboptimal tuberculosis (TB) medication adherence can lead to treatment failure, development of drug-resistant TB, and secondary transmission. Although there is an increasing use of digital adherence technologies (DATs), such as real-time monitors and SMS reminders in TB medication adherence, suboptimal patient engagement with various DATs has been reported. The World Health Organization calls for assessment and mapping of potential users of DATs to support adoption and user engagement. Additionally, financial constraints can limit DAT's utility. The perceived usefulness and the design mechanisms of DATs linked to mobile money financial incentives for TB medication management remain unclear.
Objective: To describe the perceived usefulness and design mechanisms for a DAT intervention called *My Mobile Wallet* which is composed of real-time adherence monitor, SMS reminders, and mobile money incentives to support TB medication adherence in a low-income setting.
Methods: This study employed mixed methods approaches among PLTB recruited from the TB Clinic in the Mbarara Regional Referral Hospital. We purposively sampled 21 PLTB aged 18 years and older, who owned cell phones, and were able to use SMS. We also enrolled 9 participants who used DATs in our previous study. We used focus group discussions with the 30 participants to solicit perceptions about the initial version of *the My Mobile Wallet* intervention, and then iteratively refined subsequent versions of the intervention following a user-centered design approach until the beta version of the intervention that suited their needs was developed. We also administered surveys eliciting information about participants' cell phone use and perceptions of the intervention. We used content analysis to inductively analyze qualitative data to derive categories describing the perceived usefulness of the intervention, concerns and design mechanisms. We used STATA 13 to analyze survey data.
Results: Participants expressed the perceived usefulness of the *My Mobile Wallet* intervention in terms of being reminded to take medication, supported with transport to the clinic and money to meet other TB medication-related costs, all of which were perceived to imply care which could create a sense of connectedness to healthcare workers. This could consequently cause participants to develop a self-perceived need to prove their commitment to adherence to healthcare workers who care for them, thereby motivating medication adherence. For fear of unintended TB status disclosure, 67% of participants suggested using SMS language that is confidential—not easily related to TB. To reduce the possibilities of using the money for other competing demands, 83% participants preferred sending the money 1-2 days before the appointment to limit the time lag between receiving the money and visiting the clinic.
Conclusions: Digital adherence technologies complemented with mobile money financial incentives could potentially provide acceptable approaches to remind, support, and motivate patients to adhere to taking their TB medication.
Trial Registration: ClinicalTrials.gov NCT05656287

Keywords: digital adherence technologies; real-time monitoring; SMS reminders; mobile money; financial incentives; tuberculosis; medication adherence; user-centered approach

Introduction

Tuberculosis (TB) is a major public health concern that kills more people annually than HIV and malaria combined [1]. Suboptimal TB medication adherence can lead to treatment failure, development of drug-resistant TB, and secondary transmission [2-4]. Importantly, treatment for multi-drug resistant (MDR) TB is difficult to tolerate, prolonged, and expensive. Although there is an increasing use of digital adherence technologies (DATs), such as real-time monitors and SMS reminders, in TB medication adherence, research to date reports mixed results [5]. Differences in findings may relate to the extent of patient involvement in technology development, context, culture, and technology exposure. The World Health Organization (WHO) calls for assessment and mapping of potential users of DATs to support adoption and user engagement [6]. Additionally, despite their potential, data supporting the impact of DATs on treatment success and mortality is limited [7, 8], and suboptimal patient engagement with various DATs for TB has been reported [9, 10].

Our recently completed pilot randomized controlled trial demonstrated that real-time adherence monitors and SMS reminders are feasible and acceptable among persons with TB (PLTB) in southwestern Uganda; in particular, participants found the technologies helpful in reminding and motivating medication adherence as well as being an important source of social support [11]. We also found potential for real-time monitoring linked to SMS reminders to improve TB treatment adherence; however, financial constraints were a notable limitation [12], suggesting a potential role for financial incentives.

The WHO End TB strategy recommends using reimbursements and social protection schemes to lower the social and economic burden of TB [13] and address social determinants of health. Although research in this area is limited, a monthly financial incentive package improved TB treatment success (presumably completion of 6 months of treatment) and reduced loss to follow-up among low income people in Nigeria [14]. A recent systematic and meta-analysis literature review composed of only 8 studies indicates that cash transfer interventions for patients initiating tuberculosis treatment may improve clinical outcomes [15]; for instance, in Brazil, cash transfers improved rates of TB cure by 82.1% [16]. The review called for more research specifically in low income countries where financial incentives may have the strongest effect. Importantly, the impact of these studies may be limited by providing incentives face-to-face; they are thus restricted by geographical boundaries, are time consuming, and involve transport costs.

Currently, there are over 5.48 billion unique mobile phone users globally, and nearly 5.04 billion mobile internet users [17]. In Uganda specifically, mobile phone reception is available across the vast majority of the country, including many rural areas and among economically disadvantaged populations [18]. The rapid evolution of mobile phones has enabled a mobile payment platform (often known as mobile money) which enables micro-banking financial transactions (e.g. sending, saving, paying, and receiving money) possible using simple mobile phones that are independent of smartphone capabilities or internet access. Indeed, use of “mobile money” (money accessed through mobile phones) services is nearly ubiquitous in Uganda and much of the developing world [19]. Many people in Uganda are increasingly relying on mobile money as they lack access to formal banking services—more than 23.5 million people have mobile money subscriptions [19]. Among the underserved populations, mobile money has enabled routine payment of health insurance and improved access to family planning [20], as well as enabling saving and making payment for pregnancy-related care [21].

Mobile services could also be used to provide financial support for TB treatment adherence; however, research in this area is lacking.

Optimal design of mechanisms to incorporate financial support into DATs for TB treatment would include input from people with TB. User-centered design (sometimes known as human-centered design) involves systematically eliciting input from prospective users to guide the design of interventions [22] rather than assuming that designers know what users need. Incorporating insights from prospective users may result in context specific and culturally acceptable interventions that can most effectively meet the needs of the end users [23]. This paper describes the perceived usefulness, concerns and designed opportunities regarding a DAT intervention called *My Mobile Wallet* that is composed of real-time adherence monitor, SMS reminders, and mobile money incentives to improve TB medication adherence in a low-income setting.

Methods

Study design and setting

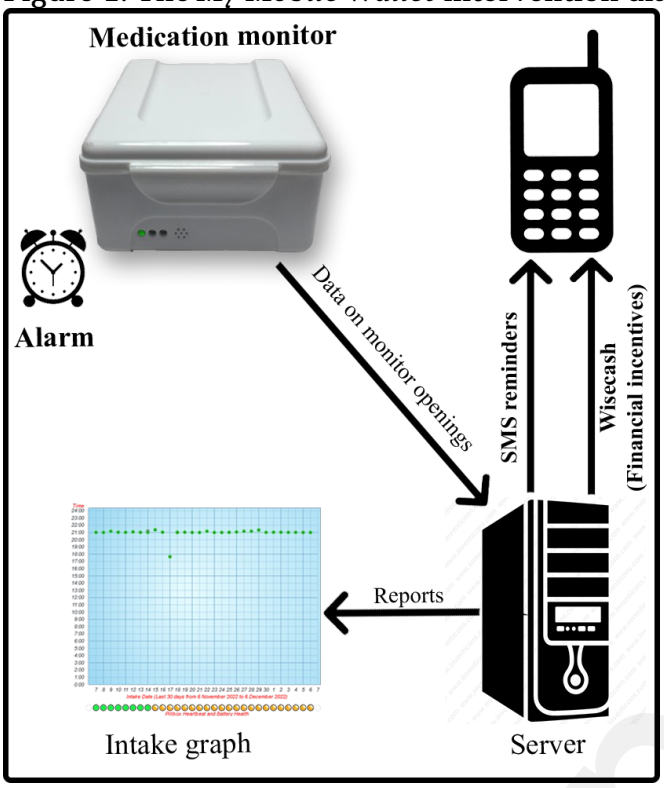
This study employed convergent mixed methods study design because we concurrently collected qualitative and quantitative study, analyzed qualitatively and quantitative data independently and interpreted the results together [37]. Our study participants were persons living with drug-sensitive tuberculosis (PLTB) recruited from the TB Clinic in the Mbarara Regional Referral Hospital (MRRH) in southwestern Uganda, which provides care to an estimated 600 PLTB annually. At the TB Clinic, the newly diagnosed PLTB receive free TB medication and are counseled about the benefits of TB medication. Directly observed therapy is not employed for monitoring medication adherence at MRRH due to the costs involved for both PLTB and the healthcare workers. Instead, PLTB are given the 2RHZE/4HR TB treatment regimen (2HRZE: isoniazid, rifampin, pyrazinamide and ethambutol for 2 months; 4HR: isoniazid plus rifampin for 4 months) every two weeks for the first two months, at which time they return to the TB Clinic for a sputum conversion check. Those who become smear negative continue with isoniazid and rifampin only for a period of four additional months in the continuation phase. Those with positive test result receive GeneXpert to exclude rifampicin resistance; subsequent treatment is then individualized. Treatment is also extended up to a full year to cater for missed medication pick-ups or doses.

Selection of study participants

Between May 2022 and June 2022, we purposively recruited 21 participants (PLTB) according to the following inclusion criteria: a) being aged 18 years and older, b) being infected with TB and undergoing a first-line six month course of standard anti-TB therapy (per above) and counseling per clinic records, c) owning a cellphone for personal use, and d) being able to use SMS. We excluded participants who were unwilling or unable to give consent, didn't have a cell phone, and unable to use SMS text messages. We purposively sampled a sub-set of participants for focus group discussions to achieve relatively balanced gender representation. We also purposively enrolled nine participants who used DATs in our previous, above-noted study [11] who had completed a first-line six-month course of anti-TB therapy. The selection of the 9 participants was purposive based on: i) our perceptions about their openness in discussing qualitative issues based on our previous experience with them in the DATs study; ii) the functionality of their phones at a time of calling them to request their study participation; iii) their proximity to MRRH where we recruited participants for the current study; iv) as well as their willingness to participate in the current study. The main aim of including the 9 participants

in the current study was to learn from their practical experiences unlike the other newly recruited 21 participants who had no practical experience in using DATs.

Figure 1: The *My Mobile Wallet* intervention diagram



Intervention technology

As indicated in Figure 1, the *My Mobile Wallet* intervention is composed of 1) a real-time medication monitor (Wisepill Technologies, Cape Town, South Africa) to monitor medication adherence, 2) SMS reminders to support PLTB in taking their medication as prescribed, and 3) a *WiseCash* component for sending mobile money incentives for transport to the clinic and motivating medication adherence.

Figure 2: The evriMED dispenser container to easily hold a month's supply of TB medication

Figure 3: The evriMED electronic module slots into the container so that the indicator LEDs are visible through the front of the container

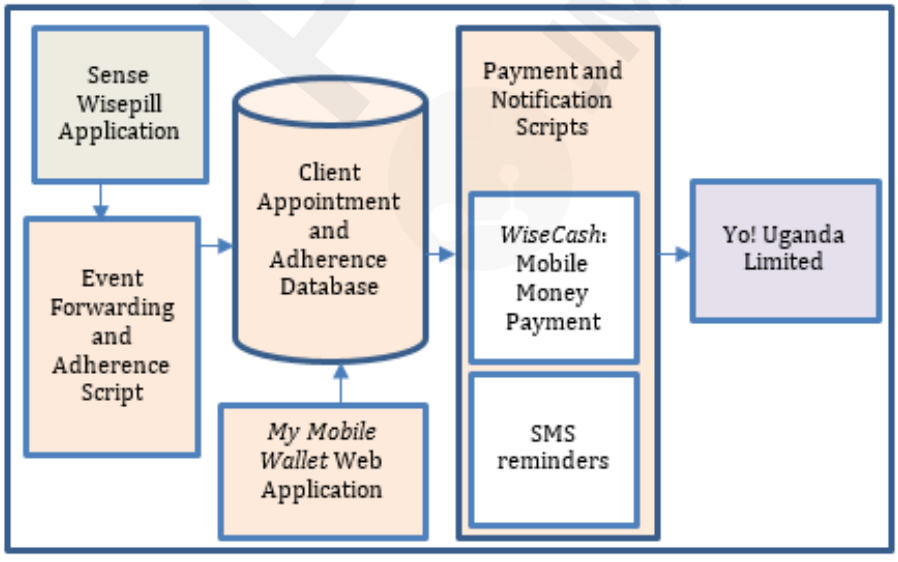
The real-time adherence monitor (evriMED1000 internet enabled pillbox) is a device that sends signals when opened (records a date-and-time stamp) as a proxy for taking medication. The evriMED1000 is a tabletop dispenser, designed to easily hold a month's supply of TB medication. It is an affordable scalable tool, which allows real-time adherence management by automatically synchronizing with the Wisepill cloud service. The evriMED1000 dispenser consists of two hardware components, namely the medication container (Figure 2), and the electronic module (Figure 3). This modular design allows the electronic module to be reused and the container to be replaced if needed. The electronic module slots into the container so that the indicator LEDs are visible through the front of the container. An internal modem and SIM card enable the device to send a real-time mobile signal to a secure web-sever (hosted in South Africa). GPRS maintains the data

in transit until the web server acknowledges receipt, which minimizes possible data loss because of power failure or/and lack of internet connectivity. In the event of inadequate mobile network coverage, the monitor stores openings in flash memory and sends them when the network becomes available. The monitor also transmits a daily 'heart beat' that indicates current battery life, remaining airtime balance, and signal strength as indication of its functionality. The monitor can be charged using electricity or a solar device. Its battery life is six months.

As indicated in Figure 4, *WiseCash* consists of five main elements: i) "Sense Wisepill" which is a web-based software application that allows the configuration and management of the real-time adherence monitor, including linking participants to their respective real-time monitors; ii) an event forwarding and adherence software program that enables the receipt of the real-time monitor openings as adherence events from the Wisepill server; iii) a clinic appointment and adherence database to store and track participant data and adherence; iv) *My Mobile Wallet* web application to allow the management of participant clinic appointments and payments; and v) payment and notification applications to implement the actual payments and to send notifications to participants in the local language (Runyankole).

WiseCash includes a script that daily checks participant appointments; evaluates user adherence; and queues and make payments and payment notifications to participants when due. Yo! Uganda Limited (Kampala, Uganda) is a technology solutions' company that offers a single application program interface (API) to provide payments to SIM cards for two telecom providers (i.e., MTN and Airtel). *WiseCash* is hosted by Xneelo limited, a web hosting company in South Africa. Additionally, Yo! Uganda Limited also provides a second API for the SMS reminders. A number of security elements are included in *WiseCash* including Yo! Payment platform passwords for the research team members to manage the *My Mobile Wallet* intervention; API keys with Wisepill data stored on a secure server; and a digital authorization by the research staff to triggered payments by the API Wisepill Technologies implemented an audit trail to record all activities on the *My Mobile Wallet* intervention.

Figure 4: My *Mobile Wallet* functional diagram



Study procedures

We first oriented each participant about the *My Mobile Wallet* intervention components by presenting to them an initial version of the intervention as described above.
We explained and demonstrated how the real-time adherence monitor (Wisepill) works, including how it monitors medication and sends a signal to researchers every time it is opened, how the monitor makes an alarm to remind medication taking, and how to open and close it to put in or retrieve medication. Participants who had never used the monitor were asked to practically demonstrate how it works. We then demonstrated how the intervention could send daily SMS reminders to remind PLTB take medication. We also explained how the intervention will send monthly mobile money ($8) to phones belonging to PLTB for transporting them to the clinic at recruitment until the end of their six months treatment, and monthly medication adherence incentives ($1.5) to those who meet a ≥90% medication adherence as ascertained from a real-time adherence monitor. The ≥90% medication adherence was considered because adherence less than 90% has been reported as a risk factor for unfavorable treatment outcomes [24].

Data collection and user-centered technology development

We used focus group discussions (FGDs) to solicit participants' (PLTB and former TB patients) perceptions about the initial version of *My Mobile Wallet* intervention. The development of questions for the FGDs (Appendix 1) was informed by the Unified Theory of Acceptance and Use of Technology (UTAUT) model with specific focus on participants' perceived usefulness of the intervention, as well the anticipated challenges in using the intervention[25]. Subsequent versions of the intervention were developed using a user-centered design (UCD) approach, which is an iterative technology design process in which users' needs are continuously solicited and included in the design and development process in order to generate products that can easily work in specific contexts [26, 27].
With UCD, technologies are designed and tailored towards users' needs (rather than the users having to adjust their behaviors to accommodate the technology) to enhance usefulness, usability and use of technology. An iterative refined version of the intervention was developed based on feedback from participants until the beta version of the intervention suited their needs. Specifically, we conducted series of five FGDs over a period of 6 months to develop the intervention. FGDs were focused on assessing how participants would feel about using the intervention, including: a) anticipated benefits and barriers, b) usage of mobile phones, mobile money and SMS, c) preferred content of mobile phone messages, and d) appropriateness of the intervention for all PLTB in the region versus those with demonstrated poverty (e.g., means testing). FGDs lasted between 90-120 minutes and were conducted in Runyankole digitally recorded, transcribed, and translated to English. Participants tested the initial version of intervention (e.g., to withdraw money from it, receive SMS texts, open the real time monitor) and provided feedback. We also administered surveys (Appendix 2) composed of both closed and open-ended questions eliciting information about participants' cell phone use, preferred frequent and content of SMS, timing for sending transport incentives, anticipated barriers in using the intervention, and people who would benefit most from the intervention.

Data Analysis

We used inductive content analysis [28] to derive categories describing and summarizing how participants perceived the intervention. Initially, authors AM and WT reviewed and discussed 20% of transcripts for content relevant to participants' perceptions about the intervention,

anticipated benefits, and challenges.
AM and WT then assembled a codebook from the identified concepts, using an iterative process, which included developing codes to represent content, writing operational definitions, and selecting illustrative quotes. JEH and SL reviewed and discussed the codebook. Following completion of the codebook, AM and WT applied codes using NVIVO 11 (QSR International, USA). Differences in coding were harmonized through discussion. We followed the Consolidated Criteria for Reporting Qualitative Research (COREQ-2) [29] in reporting qualitative results. ATM and AM used STATA 13 to describe study participants, cell phone use, preferences regarding the intervention.

Ethical review

The institutional review committees of Mbarara University of Science and Technology (MUST-2021-102), and the Uganda National Council for Science and Technology (HS1688ES), approved this study. All participants provided signed informed consent before study participation.

Results

Of 35 screened participants; 3 (9%) were excluded for not having a cell phone and 2 (6%) were excluded for being unable to use SMS text messages. Between May 2022 and June 2022, a total of 30 participants were enrolled in the study, and participated in five FGDs (each FGD composed of 6 participants, totaling to 30) of whom 21 (70%) were still on TB treatment with a median months on medication of 1 (interquartile range [IQR] 1.0-3.5), while 9 (30%) were former PLTB from our previous study with a median months after completing treatment of 30 (IQR 28.0-34.5) (Table 1).
The majority of participants were living with HIV co-infection (n=26; 87%) and female (n=20; 67%). Most were in their early forties (median age 44.5; IQR 32.3 – 52.5) and had not studied beyond primary level (n=19, 63%).

Table 1: Demographic characteristics of participants at enrolment

Characteristics	(N=30) N (%) or Median (IQR)
Median age years (IQR)	44.5 (32.3 – 52.5)
Female	20 (67%)
Male	10 (33%)
Education	
-None	3 (10%)
-Primary (P1 to P7) *	19 (63%)
-Ordinary level (Senior 1 to 4)	8 (27%)
Median (IQR) months on medication (N=21)	1 (1.0 – 3.50)
Median (IQR) months after TB treatment (N=9)	30 (28.00 – 34.50)
Positive HIV status	26 (87%)
No regular income (fixed wages/salary)	27 (90%)

* In the Ugandan education system, primary (P1-P7) is often attended by 6 to 12-year-olds. Ordinary level is often attended by 13 to 16-year-olds.

Survey results

As indicated in Table 2, the majority of participants reported not sharing their phones (n=24; 80%), checking their phones for SMS more than once a week (n=24; 83%), preferring to receive daily SMS reminders to weekly SMS (n=23; 77%), and preferring to receive SMS reminders that

are not easily related to TB (n=20; 67%). The majority of participants (n=15; 50%) preferred being sent mobile money transport incentives a day before clinic visitation. Barriers anticipated in receiving money included automatic reduction of money by mobile phone service providers for participants who borrow money from the service providers (n=4; 13%), the possibility of using the money for other competing demands such as buying food (n=12; 40%), misusing the money by other people in case of phone sharing (n=4; 13%), and inability to read mobile money messages (n=8; 27%).

Table 2: Phone usage

Characteristics	N (30)
Phone use	
Who else uses your phone?	
Spouse	3 (10%)
Family member	2 (7%)
Friends	1 (3%)
No one	24 (80%)
Check for SMS at least once week	
Never	3 (10%)
Less than often	2 (7%)
More than often	25 (83%)
Delayed from checking SMS last week	
Phone not charged	6 (20%)
Phone used by somebody else	1 (3%)
No adequate signal	1 (3%)
Used by someone else	1 (3%)
Never delayed	21 (70%)
Preferred frequency of receiving SMS reminders	
Daily	23 (77%)
Weekly	7 (23%)
Preferred content for SMS	
Not easily related to TB (e.g. hello today)	20 (67%)
Easily related to TB (e.g. take your TB drugs)	10 (33%)
When to send the incentive for transport	
A day before clinic visitation	15 (50%)
Two days before clinic visitation	10 (33%)
More two days before clinic visitation	5 (17%)
Barriers anticipated in receiving mobile money*	
Automatic reduction of money due to phone loan	4 (13%)
Using the money for other things due to competing interests	12 (40%)
Money ending in wrong hands due to phone sharing	4 (13%)
Inability to read mobile money messages	8 (27%)
People to benefit most from the intervention	
All persons with TB	4 (13)
Persons with TB with demonstrated poverty (e.g. lack of regular income)	26 (87%)

*Participants could provide multiple responses

Qualitative results

Perceived usefulness of the components of the My Mobile Wallet intervention

As indicated in Table 2, some participants (particularly those who had used the real-time device in the prior study) reported that looking at the device and knowing that their medication taking is being monitored motivated them take medication on time.
Participants perceived the real-time monitor as a friendly *companion* that can offer welcoming medication monitoring compared to human beings whose mood may be dictated by circumstances. Additionally, some participants perceived SMS reminders as useful for reminding patients to take medication especially for those who are initiating treatment because they not yet accustomed to the behavior, those who lack social support in their homes, and busy patients who can easily forget. Participants reported that incentives for transport to the clinic could address the challenges that constrain medication adherence such as missing pill refills due to lack money for transport, which often require walking long distances to the clinic and/or borrowing money to get transport. Participants indicated that adherence incentives could instill inward motivation to take medication well in order not to miss the money to buy basic necessities of life (such as food) and consequently improve medication adherence.

Table 3: Technology description and participants' perceived usefulness of the technology

Technology description	Perceived usefulness
Real-time adherence monitor (Wisepill device) is a "smart" pill box that records a date-and-time stamp for each opening as a proxy for medication ingestion. The data is sent to a central server by GPRS (general packet radio service, as is standard for most data transmission) with SMS back up in the case of poor cellular network availability. The device monitors medication adherence, and also has an alarm that sounds at the exact time of taking medication to remind medication taking.	*This device helped me a lot when I was still taking my TB medication. From the time you gave it to me, I started taking my medication well because every time I would look at it, I would be automatically reminded about my obligation to take medication on time. And because you told me it reports the way I take medication, I made sure I was taking my medication on time to maintain a good report.* *Sometimes being monitored by the device may save the persons with TB from interfacing with healthcare workers or treatment supporters who are rude in talking and handling patients. Some people are naturally rude, while others become rude due to personal problems. Imagine if you have to swallow your medication before such a rude person? For instance in a case where a patient missed some dose for unavoidable reasons, the patient may fear to be confronted by a rude person and instead decide not to turn up medication taking. But when you have this device, you are not worried of such.*
SMS reminders Daily reminders sent to persons with TB 30 minutes before their time for taking medication to enable them prepare to take medication.	*The SMS reminders I was receiving from the study played a big role of reminding me to take medication. When I had misunderstandings with my wife, she could no longer remind me take my medication or even provide food and drinks on time to enable me take my medication. Much as no one cared for me at home or gave me counseling,*

	because of receiving SMS reminders, I was confident that that someone out there was with me in the struggle and cared for me, so, I kept taking my medication on time, and I did not feel a lot of stress.
WiseCash inform of transport incentives. Monthly mobile money for transport ($8) to the clinic is sent to the patient's phone a day before the clinic appointment	*Assisting persons with TB with transport is important because for example, personally, I always struggle to get transport for my clinic appointment because I have no source of income. I am serious with taking medications but I am challenged with lack money for transport to come to the clinic for refill. Sometimes I fail to honor my appointments because I have no one to help me and it is difficult to walk for long distances with this sickness because of chest pain. This makes me spend some days without taking medication.*
WiseCash inform of adherence incentives. A monthly medication adherence incentive of $1.5 sent with the transport funds to persons with TB that meet a ≥90% medication adherence as ascertained from a real-time electronic adherence monitor.	***It is good as it doesn't only help persons with TB but it also motivates those who have not tested to have themselves tested when they know about the incentives. I know some people who are sick out there but because they are poor, they have not come out for treatment because they think it is costly to come for testing, undergo treatment, and take the required foods and drinks. This money can be used to buy food for taking medication because this medication makes you weak and dizzy if you take it on an empty stomach. Actually, I would dodge it whenever I had no food because it made me eat a lot which means I was spending more on food.*** ***Giving incentives to good adherers is useful because it will make persons with TB compete and focus on taking medication in order to be incentivized and in the process, they will adhere to their medication and eventually have their health improved. I remember when we were studying, we used to work hard in order to get presents for performing well in class, so the same thing applies to this approach. Even persons with TB who have been poor adherers are likely to start taking well because they do not want to miss that money.***

Concerns about My Mobile Wallet intervention and design considerations

Concerns and design opportunities reported by participants are described in Tables 4 and 5 below. They include the possibility of unintended status disclosure triggered by seeing the SMS reminders, real-time monitor or hearing the alarm from the monitor; utilizing the money meant for transport to the clinic for other competing demands, technology fatigue mainly emanating from daily SMS and monitor alarms. Design considerations adopted in response to

the concerns include using language in the SMS that is confidential and not easily related to TB, allowing participants decide if they want to have the alarm on the monitor activated, sending transport refund a day before the appointment to limit the time lag between receiving the money and visiting the clinic, sending the money to patient's personal phone to avoid possibilities money being misused by other people.

Table 4: Participants' concerns and design opportunities

Concerns	*Illustrations*	*Design considerations*
Possibility of unintended status disclosure	*Someone might read the SMS reminder sent to your phone to remind you to take TB medication, or might open the device and realize that it contains TB medication. They may in the process get to know your TB status and start spreading the rumor in the whole village, treating you badly, and avoiding you.*	Using SMS reminders and mobile money messages which are not easily linked with TB preferred to reminders which can easily be linked to TB
	The alarm on the Wisepill device might attract people's attention and result into unintended status disclosure.	Participants decide whether they want the alarm on the Wisepill device on or off.
Utilizing money meant for transport to the clinic, for other competing interest	*My worry is that this money will be used for different purposes for example a patient has received this money when he/she has some financial problems at home, they will just focus on addressing that problem using the money that is meant for transport to the clinic and when the time for hospital visitation comes they find themselves helpless.*	Sending the money a day before rather than several days before the appointment could reduce the possibility of using it for other purposes. Giving transport refund when persons with TB come to hospital than sending then money before (this option was not considered).
Money ending in wrong hands due to phone sharing	*If that money is sent during unfortunate times when the person I share the phone with is having some financial challenges or emergencies, he will just use the money for himself and ignore me.* *Some husbands especially those who are alcoholics may not give the money to their wives if it is sent on their phones.*	Considering personal ownership at recruitment so that money is sent to the phones owned by persons with TB

Technology fatigue from SMS reminders and device alarms	***Since both SMS reminders and device alarms are both meant to remind persons with TB take their medication, it might be too much for them to have both.***	Participants are given an opportunity to choose whether or not they want to receive medication taking alarms from the device on top of receiving SMS reminders.

Other modifications added during the iterative phase of technology development are outlined in Table 5 below.

Table 5: Other intervention design issues considered

Initial design	*Refinement/addition*
Mobile Money messages in English language	A Language option was added so that participants can be notified in the local language (Runyankole) to cater for participants who cannot read English
No default payment date	To cater for instances where no appointment has been set, a default payment date was added as 25 day of the month.
No arrangement for pending payments	The ability to cancel a payment was added. Cancelling a payment is effective if a payment is still pending (after two hours of failed attempts e.g. in case of invalid phone numbers) or if there is a problem with the transaction at the service provider.
No notifications for payment delivery status	To keep track of the mobile money transactions and notifications, an email notification to the *My Mobile Wallet* administrator for successful or unsuccessful payment was added.
Absence of a log file on the administrator's side	**A link to a log file was added to the payment screen in order to provide history of transactions, analyze the performance of the payment and notification functionality.**

Discussion

Principal Results

The *My Mobile Wallet* intervention composed of real-time adherence monitor, SMS reminders, and mobile money incentives was perceived as useful in supporting TB medication adherence in a low-resource setting. Participants expressed the perceived usefulness of the *My Mobile Wallet* intervention in terms of being reminded to take medication, supported with transport to the clinic and money to meet other TB medication-related costs, all of which were perceived to imply care which could create a sense of connectedness to healthcare workers. This could

consequently cause participants to develop a self-perceived need to prove their commitment to adherence to healthcare workers who care for them, thereby motivating medication adherence.

Through a user-centered design process, we learned that the main concerns were i) unintended status disclosure triggered by seeing the real-time monitor or hearing the alarm from the monitor or seeing the SMS reminders, and ii) utilizing the money meant for transport to the clinic for other competing demands. The main design considerations that arose in the process were i) using language in the SMS that is confidential and not easily related to TB, ii) and sending transport refund a day before the appointment to limit the time lag between receiving the money and visiting the clinic.

Limitations

The main limitation of this study is that we asked participants about perceptions before they could use the intervention in real life, although 9 participants (30%) had used the real-time monitor and SMS in our prior study. Although we practically demonstrated the use of the intervention to all participants, 21 participants (70%) were not able to describe actual experiences using the device or medication-related SMS reminders or financial incentives as part of their daily routine.

Comparison with Prior Work

Participants who had used the real-time monitor felt being *cared for* and as a result of being monitored or/and sent an SMS reminder. This created a sense of connectedness to healthcare workers and consequently caused participants to develop a self-perceived need to prove their commitment to adherence to healthcare workers who cared for them. Participants referred to the real-time monitor as a *friendly companion* that can potentially offer welcoming medication monitoring compared to human beings whose mood may be dictated by circumstances.

Given the prevailing stigma and discrimination that is associated with living with TB in Uganda [30], such positive perceptions could empower participants to cope with social isolation and other challenges of having TB, especially among those who do not have adequate social support, those initiating treatment who are not yet accustomed to taking medication, and those living with HIV co-infection who are more likely to experience double stigma from both TB and HIV. Experiences of unintended HIV status disclosure were reported by the people living with HIV/AIDS who used the real-time device and SMS reminders in the same setting [31]. Noteworthy however, these technologies can also facilitate intended HIV status disclosure in order to get social support [32]. To reduce the potential effects of the TB status disclosure that can potentially emanate from using the intervention, strategies to ensure privacy and confidentiality (e.g. using SMS that is not easily related to TB) and reduce stigma and discrimination were incorporated into the intervention.

Participants felt that providing financial incentives in form of mobile money could relieve PLTB of the transport burdens associated with clinic visitations for pill refill, thereby eliminating the need to walk long distances to the clinic and/or borrow money to get transport or miss pill refill appointments. Lack of transport to the clinic is one of the major challenges constraining TB medication adherence in Uganda [33]; two in every 10 people (21% of the population) live on $1.25 a day or less [34], making saving for health difficult amidst other immediate competing interests. To reduce the possibility of using the money meant for transport to the clinic for other competing demands, participants proposed sending transport refund a day

before the appointment. Participants also reported that financial incentives could promote medication taking in order to not to miss the money involved, which could be used to meet other costs related to TB-treatment such as nutritional supplements and food. This is important given that in Uganda, a TB/HIV high burdened country, over 53% of TB affected households experience TB costs which are above 20% of their annual household expenditures, and the main cost drives are non-medical expenses such as transport to the clinic and food [35]. Because TB disproportionately affects the poorest in the population, its poverty-aggravating effects are felt more by those who are already vulnerable. Moreover, having TB is associated with other negative socioeconomic consequences, such as divorce, school interruptions for children, and social exclusion, in addition to the hardship of deteriorating health. Incentive-based interventions can potentially overcome the poverty-based structural barriers to TB treatment, although research in this area is limited. Incentive-based interventions can also potentially be integrated in routine healthcare especially given the evidence that an incentive as small as one United States Dollar (1USD) can improve TB cure and reduce loss-to-follow-up among PLTB in rural Uganda [36]. This can potentially prevent drug resistance, thereby relieving the country of the financial burden associated with MDR-TB treatment—Uganda has over 16,000 MDR-TB patients (MoH 2019). The country currently spends US$105 (on transport refund and food incentives) per month on each MDR-TB patient from the time they are discharged (after the initial six months of hospitalization) until treatment completion (one year). This translates to a cost of $1,260 per patient for the 12 months of treatment. Importantly, treatment for MDR-TB leads to productivity loss for patients and their caregivers, which negatively affects the economic development of the country.

Conclusions
Using a mixed-methods approach to collect both closed- and open-ended data, this study identifies important insights (about perceived usefulness, concerns, and design considerations) from TB patients that can inform the development of monitoring technologies linked to mobile money-based financial incentives. In sum, real-time adherence technologies complemented with mobile money-delivered financial incentives could potentially provide acceptable approaches to remind, motivate and support patients to adhere to taking their medication especially in settings where Directly Observed Therapy Short course (DOTS) is difficult to implement as well as low resource settings where poverty-based structural barriers to TB treatment are prevalent.

As digital adherence technologies proliferate, using user-centered approaches to understanding how they are perceived by users is critical to developing tailored interventions that are useful, usable and acceptable in supporting TB medication adherence. Findings from this formative study enabled the design of the *My Mobile Wallet* to support TB care and treatment adherence which is currently being implemented for initial feasibility and acceptability assessment. After this initial assessment, further refinements will be done before the technology can be further tested for large large scale feasibility, acceptability and impact, in a planned randomized control trial (NCT05656287).

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Conflicts of Interest

None declared

Data availability

The data sets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Abbreviations

TB: Tuberculosis
MDR: Multi-drug resistant
DATs: Digital adherence technologies
WHO: World Health Organization
PLTB: Persons with TB

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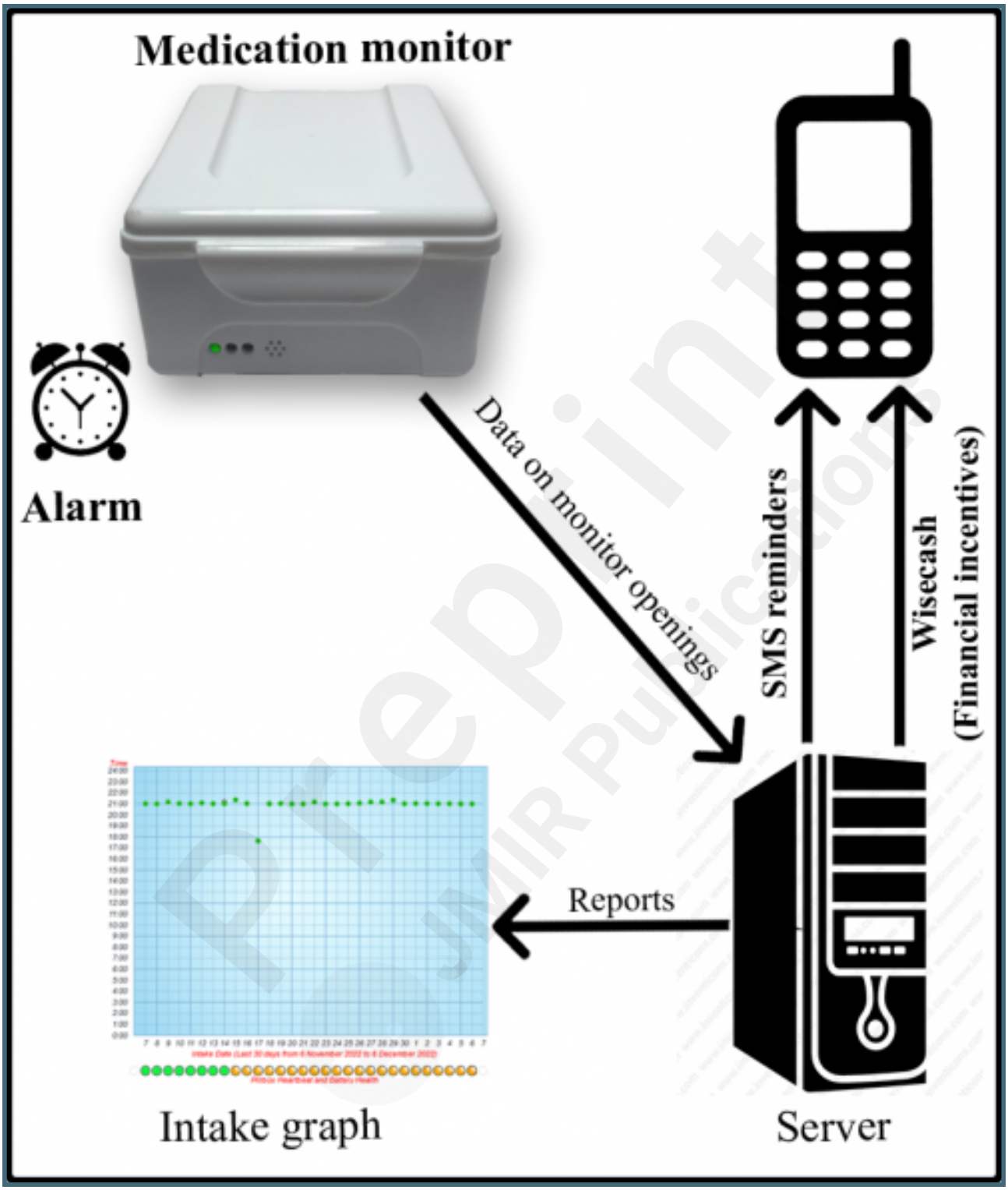
Supplementary Files

Figures

My mobile wallet intervention.



The evriMED dispenser container to easily hold a month’s supply of TB medication.

The evriMED electronic module slots into the container so that the indicator LEDs are visible through the front of the container.

My Mobile Wallet functional diagram.