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Digital monitoring technologies could enhance tuberculosis medication adherence in Uganda: Mixed methods study

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ABSTRACT

Background: Effective administration of tuberculosis therapy remains challenging. The recommended strategy of direct observed therapy is challenging and its implementation has been limited in many settings. Digital adherence technologies could be promising patient-centered strategies for monitoring adherence. However, few quality studies have assessed patients' experiences with these technologies.

Objective: To explore TB patients' perceptions of a digital adherence intervention composed of a digital adherence monitor and SMS texts.

Methods: We purposively sampled TB patients who owned phones, had been taking TB medication for at least a month, and were receiving their treatment from Mbarara Regional Referral Hospital. We interviewed 35 TB patients to elicit information on perceptions of the proposed intervention which electronically monitors how they take their medication, and sends SMS reminders to patients to help them take their medications, as well as send SMS notifications to patients' social supporters to provide the patient with assistance if possible. We inductively analyzed data using content analysis to derive categories describing how participants perceived the intervention.

Results: Participants anticipated that the intervention would enhance medication adherence by reminding them to take medication, and helping in the management of complicated regimen. Participants felt that monitoring adherence could enable them to demonstrate their commitment to adherence. Participants expressed concerns about not seeing the SMS on time and unintended TB status disclosure.

Conclusion: Digital adherence technologies may provide acceptable alternative approaches to monitoring TB medication, especially in settings where DOT is difficult to implement.

1. Background

Poor TB (tuberculosis) medication adherence contributes to treatment failure, development of drug-resistant TB, and secondary transmission [1–3]. Enabling effective administration of TB therapy remains challenging [4]. The directly observed therapy (DOT) strategy recommended by the World Health Organization requires that patients take their medication under the supervision of a health worker or a trained treatment supporter to ensure that patients adhere to treatment. However, DOT does not perform better than self-administered therapy for diseases relapse and acquired drug resistance [5]. Moreover, this approach demands a significant time commitment from health workers and treatment supporters, generates substantial financial burdens, and inhibits patient autonomy [6,7]. For these reasons, its implementation has been limited in many settings. For instance, a Chinese study by Lei and colleagues found that only 14% of patients were on DOT, of which 28% were lost to follow-up [8]. Alternative, innovative approaches for effective administration of TB therapy are needed.

The WHO End TB Strategy 2017 suggests a suite of new interventions to improve adherence, including mobile phone-based short message service (SMS) text messages, digital medication monitors that record when a pill container is opened, and "supportive treatment supervision by treatment partners" [9]. In addition to supporting treatment supervision, the monitors can motivate adherence and be used to deliver interventions such as alarms or SMS [10]. Given

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widespread telephone ownership and mobile network coverage in sub-Saharan Africa [11], SMS can provide affordable means of communicating with TB patients about their medication adherence. A recent study from Uganda indicates that most TB patients (75%) own mobile phones and are willing to received TB-related communication via SMS texts [12]. The same study indicates that even patients without mobile phones were willing to receive SMS on a family phone.

Real-time versions of the digital medication monitors transmit records of device openings via a cellular network. Such devices provide real-time adherence information, enabling timely interventions to poor medication adherers before consequences of non-adherence can develop. Real-time adherence monitoring technologies with SMS reminders have been shown to improve adherence to HIV antiretroviral therapy [13,14]. However, high quality studies about the application of these technologies for TB medication adherence are limited, especially in resource-limited settings.

Given the novelty of real-time adherence monitoring and SMS technologies for TB medication, an in-depth assessment of their potential benefits and challenges is needed to inform the development of interventions that can effectively meet the needs of prospective users. In this study, we explored how TB patients perceive a real-time adherence monitoring intervention consisting of (1) use of a real-time adherence monitoring device, and (2) SMS text messages providing adherence reminders to patients and notifications to their social supporters (i.e., friends or family who have helped them with medication or other needs previously).

2. Methods

2.1. Study design and setting

This study combines semi-structured interviews and surveys in a parallel mixed methods study design. TB patients were recruited from the TB clinic within Mbarara Regional Referral Hospital (MRRH) in rural, southwestern Uganda. Uganda ranks among the 22 countries with the highest number of TB cases in the world, with the 16th position in 2016 [15]. The treatment completion rate stands at 75% in Uganda. The MRRH TB unit provides care to approximately 600 TB patients annually. Newly diagnosed patients receive free TB medication and counseling on the benefits of TB medication. All patients with presumed drug-sensitive TB self-administer their medications based on fixed dose combinations. The clinic does not employ the DOT strategy due to the significant burdens it places on patients and healthcare providers. Rather, TB patients are given pills every 2 weeks for the first 2 months. After 2 months, the patients return to the clinic to check for sputum conversion. Patients then collect pills every month for an additional 4 months, with another conversion check at 4 months and a final checkup at 6 months of treatment, which can be extended up to 8 months to account for missed visits.

2.2. Selection of study participants

Between June 2017 and June 2018, authors AMT and WT purposively sampled patients receiving TB treatment from Mbarara Regional Referral Hospital. We aimed to achieve relatively balanced representation by gender and HIV status to elicit diverse perspectives. Inclusion criteria were as follows: (a) had chart documentation of drug-sensitive TB, (b) had access to a mobile phone, (c) had been undergoing a first-line 6-month course of anti-TB therapy as described above for at least 1 month, (d) were 18 years and older, (e) lived in Mbarara District, (f) were willing and able to give consent, and (g) were willing and able to name one social supporter. Adherence was not a consideration in participant selection.

2.3. The intervention technology: real-time adherence monitor (Wisepill device)

The proposed intervention is composed of electronic device that monitors how patients take their medication, and sends SMS reminders to patients to help them take their medications, as well as sending SMS notifications to patients' social supporters to provide the patient with assistance if possible. The SMS application is then linked to the real-time adherence monitoring system. The contents of SMS reminders and notifications are determined by each participant. The proposed default message is "This is your reminder." The SMS reminders are meant to remind TB patients take their medication on time. For the first 3 months, the intervention sends daily SMS notifications to social supporters irrespective of whether the patients take their medication. For the next 3 months, we send notifications only if the patient misses or delays taking medication. As described in [24], the real-time adherence monitor (Fig. 1) (Wisepill Technologies, Cape Town, South Africa), is a medication container that can hold up to 28 tablets of a 4-drug combination of rifampicin, isoniazid, pyrazinamide, and ethambutol). When an individual opens it to take pills, the device records a date-and-time stamp. 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) by General Packet Radio Service (GPRS). Receipt of this signal is taken as a proxy for taking medication. GPRS maintains the data in transit until acknowledgement of receipt by the web-server, which minimizes possible data loss because of power failure or/and lack of internet connectivity. Data transmission is backed up by the SMS to mitigate possible temporal GPRS network disconnections. 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 6 months.



Fig. 1. The Wisepill device.

2.4. Study procedures

Before the interview, we first oriented each participant about the potential interventions to support adherence to TB medication. First, we explained and demonstrated how the real-time adherence monitor (Wisepill device) works, including how it monitors medication and sends signals to researchers or health workers every time it is opened, how to open it to insert/retrieve tablets, and how to close it after taking tablets. Participants were then given the monitor and asked to explain what it does and to practically demonstrate how it works to the researcher. We then explained to participants how the intervention could send scheduled (e.g., daily reminders) or triggered (i.e., a reminder triggered by a delayed/missed dose) SMS reminders to TB patients to help them take their medications, as well as send SMS notifications to patients' social supporters to provide the patient with assistance if possible.

2.5. Data collection

Authors WT and AMT carried out separate semi-structured, in-depth interviews with TB patients; both authors are bilingual in English and the local language (Runyankole) and trained in qualitative research and research ethics. Interviews were conducted in a private space at a research office near the MRRH. Each interview lasted between 30 and 60 min. All

questions in the interview guide were translated into the local language (Runyankole) and back-translated to English by a different translator, after which the two versions were compared for accuracy. Interviews were conducted in the local language, digitally recorded, transcribed, and translated to English. We elicited participants' perceptions and opinions about the different components of the integrated intervention, including the real-time monitoring device, SMS reminders for patients, and SMS notifications for social supporters. We solicited information about how participants would feel about being monitored or sent an SMS text about their TB medication, anticipated benefits of the intervention, and anticipated challenges related to it. Following each interview, author AM, with support from JEH and JLD, reviewed transcripts for quality, clarity, and detail. WT and AMT also administered surveys eliciting information about participants' preferences of the proposed intervention. We also administered surveys to patients and social supporters to collect information on socio-demographics, socio economic status, food security, HIV status, cellular phone ownership and utilization, TB medication use, and SMS text preferences.

2.6. Analysis

We used inductive content analysis [16] to derive categories describing and summarizing how participants perceived the intervention. Initially, AM, WT, and ATM 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, JLD, and DB also reviewed and discussed the codebook. Following completion of the codebook, AM and WT applied codes using NVIVO 11. Differences in coding were harmonized through discussion. ATM and TW used STATA 13 to describe study participants and their preferences regarding frequency and type of SMS texts.

2.7. Ethical reviews

All participants provided signed informed consent before study participation. The Institutional Review Committee of Mbarara University of Science and Technology, the Uganda National Council for Science and Technology, and the Partners Human Research Committee at Massachusetts General Hospital approved this study.

3. Results

3.1. Participant characteristics

Of 53 screened TB patients, 18 (34%) were excluded. Patients were excluded for (individuals could have >1 criterion): having no cellphone (n = 6; 11.3%), inability to use SMS text messages (n = 5; 9.4%), unwillingness or inability to name at least one social supporter (n = 3; 5.7%), being <18 years old (n = 2; 3.8%), receiving a diagnosis of drug-resistant TB (n = 1; 1.9%), and/or inability to provide informed consent (n = 1; 1.9%). A total of 35 TB patients, of whom 15 (42.8%) were persons living with HIV/AIDS, enrolled in the study between February 2017 and April 2018 (Appendix 1, Table A1). The majority of TB patients were males (n = 20; 57.5%) in their early 30 s while the majority of social supporters were females (n = 9; 60.0%) in their early 40 s. Only one patient reported not being able to read Runyankole (local language), while the majority of patients were able to read English (n = 27; 77.1%).

3.2. Survey results

The majority of patients (n = 27; 77.1%) reported that they sometimes delayed taking their medication, while 9 (25.7%) missed taking medication sometimes (Appendix 2, Table A2). The main reason participants cited for delaying medication was forgetfulness (n = 24; 68.6%). The majority of TB patients who were living with HIV (n = 12; 80%) reported forgetting to medication on time. Being mainly qualitative study, we did not see any obvious differences based on how long patients had spent on medication. Most patients reported ever using their phones for health-related purposes (n = 32; 91.4%); the most frequently reported purpose being arranging transport to the clinic (n = 23; 65.7%). Participants chose "phone not charged" (n = 26; 74.3%) and "someone else had my phone" (n = 25; 71.4%) as the most common reasons they did not receive SMS immediately. Most participants (n = 24; 68.6%) preferred daily SMS reminders to weekly reminders. Participants preferred reminders to take medication (n = 30; 85.7%) to reminders to pick up medication at the clinic (n = 5; 14.3%).

3.3. Interview results

Participants said they thought the intervention would motivate medication adherence by reminding them to take pills, which could help them form new habits of adherence. Respondents who were living with HIV noted that the reminders might also help them manage their complicated regimen.

Participants felt that the technology could enable them to demonstrate their commitment to following treatment instructions in order not to disappoint researchers. Finally, participants felt the functionality of the intervention may be limited if they did not see the SMS on time, or if there were concerns about unintended TB status disclosure.

3.4. Reminding medication adherence

TB patients felt that SMS could serve as medication reminders to overcome forgetfulness. SMS reminders, especially those that are sent daily, were seen as an opportunity to familiarize oneself with medication adherence, especially among those who did not have experience taking medication regularly.

> "SMS reminders will help me get used to taking my medication. In case I forget taking medication and I receive a SMS reminder I will automatically remember."
>
> *~Male, 50 years, TB patient*

Patients noted that taking medication after being reminded by the SMS could develop a habit of taking the pills daily as prescribed. This function was particularly important for patients with busy schedules who can easily forget taking medication:

> "Like sometimes I can forget especially when I am fixed with other things. But when you send me an SMS, I can remember and immediately take my medicine."
>
> *~ Male, 36 years, TB patient*

Some TB patients had already developed their own informal version of the intervention. They reported that they had previously received reminders to take TB medication through mobile phone calls and SMS texts from their social supporters to remind them take medication:

> R: Sometimes my good friend calls me or sends me a text message on my phone to remind me take my medicine. I work with him, but when I am off duty, I think he gets worried that I might forget, so he calls me or sends me a text to remind me take my medicine.
>
> *~ Male, 27 years, TB patient*

In particular, patients living with HIV reported that it was easy to forget to take medication on time due to the number of drugs involved. These patients noted that the complexity of their medication coupled with the incurable nature of HIV could make adherence challenging.

> Because I am taking very many drugs of HIV and TB drugs, so it is good to be reminded to take my medication. Otherwise I can easily forget, yet, I have so many thoughts especially about HIV which I am

sure has no cure.

~ *Female, 47 years, TB/HIV patient*

For these patients, reminders could cut through the complexity of their drug regimen and emotional state to ensure adherence.

3.5. Demonstrating commitment to adherence

TB patients said that monitoring could provide an opportunity to demonstrate their commitment to adherence by providing evidence of their seriousness in following instructions. Patients perceived not taking medication on time as a disappointment to people who gave them devices, whom they believed cared about their health. To demonstrate commitment to the health providers who will have invested in patients by dispensing the devices, patients said they felt obliged to return that care by "*not letting that person down*."

"When I have the device, I know that I must take my medicine so that people that gave it to me will not think that I am not serious in following the instructions".

~ *Male 37 years, TB patient*

Some patients suggested that a sense of being especially cared for might motivate them to work harder to adhere.

"If someone cares for you and gives you the device to help you take your medication well and have good health, you should not let that person down by not doing what he wants."

~ *Male, 30 years, TB patient*

TB patients described how the real-time monitor would "*put them on pressure*" to take medication by monitoring and reporting their adherence to perceived authority figures, thus motivating them to adhere. This motivation stemmed from a desire not to disappoint their healthcare providers and be in '*their bad books*'.

The device will put me on pressure not to forget taking my medication so that that doctors can know that I take my medication on time. Since you said that they will be seeing how I take my medication through the device, I will be serious because I know that doctors want me to be well, and I don't want to be in their bad books.

~ *Male, 27 years, TB Patient*

Patients perceived this "*pressure*" positively because they associated it with the healthcare workers' desire for patients to be cured.

As further illustrated below, patients reported two concerns associated with the use of digital adherence technologies.

3.6. Concerns: not seeing the SMS on time

TB patients anticipated technical limitations that could result in not seeing the SMS reminders on time. Participants shared concerns about phone sharing, depleted batteries, phone dysfunction, or inadequate network coverage preventing them from seeing an SMS reminder immediately. Some worried they would miss notifications while sleeping or busy with work. Participants were concerned about the possibility of not seeing the messages in time, which could limit the feasibility of the intervention.

"If you send an SMS reminder when she has taken my phone, I will definitely miss the reminder, which is a bad thing."

~ *Female, 37 years, TB/HIV patient*

3.7. Concerns: unintended TB status disclosure

Some patients were concerned about the possibility of unintentional disclosure of their disease status. They worried that if SMS messages specifically mentioned TB, if phones were shared, if unauthorized phone access occurred, or if others recognized the Wisepill device, their TB status would be known. TB patients living with HIV appeared more concerned about disclosure compared to those without HIV. These patients feared that unwanted disclosure could result in double stigma and discrimination.

Sometimes my phone is with my child or any other person so if the SMS directly tells me to take my TB medication, the person may end up knowing that I have TB. People see TB disease as a disease of the unfortunate ones, and automatically associate TB with AIDS. So there is that double stigma that follows you wherever you go, and of course that makes me feel bad.

~ *Female, 38 years HIV/TB patient*

4. Discussion

In this study, TB patients reported that a real-time adherence monitor (Wisepill device), and SMS reminders could support medication adherence by reminding patients to take their medicine, which could result into forming a habit of medication adherence. The reminders could also help TB patients living with HIV to manage the complexities of having to adhere to multiple medications (known as polypharmacy) since being reminded to take TB medication can also indirectly remind a patient to take antiretroviral drugs. Monitoring adherence could motivate patients to take their drugs in order not to disappoint those that care for them. However, patients also worried about the possibility of unintended TB status disclosure if others saw the SMS message or monitor. They also expressed concerns about missing reminders due to technical problems.

Real-time adherence monitoring interventions may remind patients take their TB medication on time. In our study, patients described forgetfulness as a major barrier to adherence, especially for those with busy schedules, complex drug regimens, or inexperience with regular medication. Daily SMS reminders were preferred to weekly reminders in addressing forgetfulness due the possibility of facilitating a habit of medication adherence since they are aligned to the daily routine of taking medication. Preference of daily SMS reminders has previously been reported in an antiretroviral adherence study in the same setting [21]. However, it remains unknown whether TB patients would maintain the preference of daily SMS reminders for the entire duration of their treatment since there could be a possibility of patients being overwhelmed by the messages; this issue is being explored in our current ongoing study.

Although the application of SMS reminders in supporting TB medication adherence is still rare, there is some evidence that they could improve TB medication adherence. For example, in a randomized trial in China, audio reminders from a medication monitor improved TB medication adherence with or without scheduled SMS reminders, while scheduled SMS text alone did not [17]. Additionally, a recent study in Pakistan showed no significant difference between the daily SMS arm and control arm (no SMS) for treatment outcomes among patients with drug-sensitive tuberculosis [18]. The potential of SMS texts to improve TB medication adherence through a reminding function was also reported in Peru [19], and in Uganda among TB patients living with HIV [20]. Reminders have previously been linked to improved medication adherence in other infectious and stigmatized diseases such as HIV/AIDS in the same setting [13].

Participants associated real-time monitoring of pill-taking behaviors and receiving SMS texts with feelings of being cared for and connected to their healthcare providers. This connection could address the challenge of social isolation that frequently accompanies stigmatized diseases. Feeling cared for and connected to the clinic can create a sense of obligation to adhere. TB patients thought that electronic medication monitoring would motivate them to take medication on time in order to demonstrate their commitment to adherence to an audience of clinic workers and/or social supporters. Real-time monitoring has previously been associated with demonstrating commitment with regard to antiretroviral treatment among people living with HIV/AIDS in Uganda

[21]. Adherence behaviors developed while using the electronic monitor could potentially be maintained even after withdrawing the technology [22]. The motivation to adhere also comes from self-perceived need for patients to prove to social supporters that they are not undermining supports' efforts to help them regain their health. Social supporters expect patients to adhere to their medications, and patients comply to this expectation to maintain the inflow of support [23].

In our study, participants expressed concerns about missing SMS reminders. Ensuring personal phone ownership, providing solar-powered phone chargers, and sending reminders at the participants' pre-identified time of preference could address some of the identified potential limitations to receiving reminders. Although participants only reported potential concerns associated with SMS reminders, in one of our previous studies that employed a similar intervention among HIV patients, technical limitations that could potentially limit the functionality of the real-time time monitor were identified [24]. These include difficulties in charging the battery, absence of battery levels, inability of the monitor to function without being charged, and opening the monitor without taking medication or using the monitor for other medications. Teaching patients to charge the device and informing them about the need to only use the monitor for the intended medication, and to open it only when taking medication could address some of these challenges.

The reported uunintended disclosure can interfere with patients' privacy. This can result in stigma/discrimination and negative attitudes that may limit access to support, limit coping strategies [25], and distress the patients. Emphasizing personal phone ownership, using messages that cannot easily be associated with TB/HIV, and/or using password protected phones could mitigate this concern.

The main strength of this study is that it used a mixed-methods approach to collect both closed- and open-ended data. In addition, because the study was conducted in a rural sub-Saharan African area and population, it has implications for similar settings. This study also identifies important insights from TB patients that can inform the development of monitoring technologies. This study is limited by the fact that we asked participants about perceptions before they could use the intervention in real life. Although we practically demonstrated the use of the intervention to all participants, participants were not able to describe actual experiences using the device or medication-related SMS messages as part of their daily routine. Lastly, findings could be vulnerable to social desirability bias because participants self-reported their preferences and anticipated uses of the monitoring intervention.

In sum, real-time adherence interventions could potentially provide acceptable and feasible approaches to remind and motivate patients to take medication regularly. They provide a promising alternative or complementary approach to administering TB medication in settings where DOT is difficult to implement. As real-time monitoring technology proliferates, understanding how these technologies are perceived by prospective users is critical to developing interventions that are acceptable, feasible and effective in improving TB medication adherence. Findings from this formative study will inform the design of an intervention to be implemented in an upcoming randomized, controlled trial where a real-time monitoring intervention will be assessed for acceptability, feasibility, and impact on TB medication adherence in Uganda. Further research is needed to understand how participants in diverse settings perceive this intervention.

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Consent

All participants provided signed informed consent before study participation.

CRediT authorship contribution statement

Angella Musiimenta: Writing - review & editing. **Wilson Tumuhimbise:** Writing - original draft. **Aaron T. Mugaba:** Writing - original draft. **Conrad Muzoora:** Writing - review & editing. **Mari Armstrong-Hough:** Writing - review & editing. **David Bangsberg:** Writing - review & editing. **J. Lucian Davis:** Writing - review & editing. **Jessica E. Haberer:** Writing - review & editing.

Declaration of Competing Interest

None.

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Appendix 1

Table A1.

Table A1
Socio-demographic and basic health status characteristics of study participants.

	TB patients (n = 35)	Social supporters (n = 15)
Female	15 (42.9%)	9 (60.0%)
Median age (years)	32.0 IQR = 11	37.0 IQR = 16
Able to read English	27 (77.1%)	10 (66.7%)
Able to read Runyankole	34 (97.1%)	14 (93.3%)
Had regular income	18 (51.4%)	8 (53.3%)
Worried about food security	20 (57.1%)	8 (53.3%)
Living with HIV	15 (42.9%)	1 (6.7%)
Mean (SD) months of treatment completed at time of interview	3.3 (1.49)	–

SD = standard deviation.

Appendix 2

Table A2.

Table A2
Survey results for TB medication use, cellular phone ownership and utilization, and intervention preferences.

	TB patients (n = 35)
TB medication use *	
Often take pills at exact prescribed time	23 (65.7%)
Sometimes have delays	27 (77.1%)
Sometimes miss taking pills	9 (25.7%)
Reasons for delaying/missing medication*	
Forgets	24 (68.6%)
Delayed somewhere	8 (22.9%)
Lacked food/drinks to take before taking medication	3 (8.6%)
Lacked transport to pick medication	1 (2.9%)
Cell phone utilization*	
Ever used phone for health-related reason	32 (91.4%)
Check SMS 1–3 times a week	4 (11.4%)
Check SMS 4–6 times a week	4 (11.4%)
Check SMS >6 times a week	27 (77.3%)
Health-related reason for using a cell phone*	
Arranging transport to clinic to pick medication	23 (65.7%)
Inquiring about TB medication	20 (57.1%)
Calling for money for basic needs	6 (17.1%)
Informing others about TB status	1 (2.9%)
Reasons for being delayed from usual schedule of receiving SMS[a]	
Phone not charged	26 (74.3%)
Someone else had my phone	25 (71.4%)
Phone not functioning	15 (42.9)
Inadequate cellular network	16 (45.7%)
Preferred frequency of SMS reminders	
Daily	24 (68.6%)
Weekly	11 (31.4%)
Preferred type of SMS reminder	
Reminders for taking medication	30 (85.7%)
Reminders for picking pills from the clinic	5 (14.3%)

[a] Responses are not mutually exclusive.

References

[1] Horsburgh CRJ, Barry III CE, Lange C. Treatment of tuberculosis. N Engl J Med 2015;373(22):2149–60.
[2] Adane AA, Alene KA, Koye DN, Zeleke BM. Non-adherence to anti-tuberculosis treatment and determinant factors among patients with tuberculosis in Northwest Ethiopia. PLoS One 2013;8(11):e78791.
[3] World Health Organization. Global tuberculosis control: WHO report 2000, in *Global tuberculosis control*: WHO report 2000.
[4] Alipanah N, Jarlsberg L, Miller C, Linh NN, Falzon D, Jaramillo E, et al. Adherence interventions and outcomes of tuberculosis treatment: a systematic review and meta-analysis of trials and observational studies. PLoS Med 2018;15(7):e1002595.
[5] Pasipanodya JG, Gumbo T. A meta-analysis of self-administered vs directly observed therapy effect on microbiologic failure, relapse, and acquired drug resistance in tuberculosis patients. Clin Infecti Dis 2013;57(1):21–31.
[6] O'Donnell MR, Daftary A, Frick M, Hirsch-Moverman Y, Amico KR, Senthilingam M, et al. Re-inventing adherence: toward a patient-centered model of care for drug-resistant tuberculosis and HIV. Int J Tuberc Lung Dis 2016;20(4):430–4.
[7] Tanimura T, Jaramillo E, Weil D, Raviglione M, Lonnroth K. Financial burden for tuberculosis patients in low-and middle-income countries: a systematic review. Eur Respir J 2014;43(6):1763–75.
[8] Lei X, Huang K, Liu Q, Jie Y, Tang S. Are tuberculosis patients adherent to prescribed treatments in China? Results of a prospective cohort study. Infect Dis Poverty 2016;5(1):38.
[9] World Health Organization. Guidelines for the treatment of drug-susceptible tuberculosis and patient care. 2017.
[10] Subbaraman R, de Mondesert L, Musiimenta A, Pai M, Mayer KH, Thomas BE, et al. Digital adherence technologies for the management of tuberculosis therapy: mapping the landscape and research priorities. BMJ Global health 2018;3(5):e001018.
[11] International Telecommunication Union. Key global telecom indicators for the world telecommunication service sector. 2016 [cited 2017 17th Oct]. Available from:. http://www.itu.int/en/ITU-D/Statistics/Documents/statistics/2016/ITU_Key_2005-2016_ICT_data.xls.
[12] Ggita J, Ojok C, Meyer AJ, Farr K, Shete PB, Ochom E, et al. Patterns of usage and preferences of users for tuberculosis-related text messages and voice calls in Uganda. Int J Tuberc Lung Dis 2018;22(5):530–6.
[13] Haberer JE, Musiimenta A, Atukunda EC, Musinguzi N, Wyatt MA, Ware NC, et al. Short message service (SMS) reminders and real-time adherence monitoring improve antiretroviral therapy adherence in rural Uganda. AIDS 2016;30(8):1295.
[14] Sabin LL, DeSilva MB, Gill C, Li Z, Vian T, Wubin X, et al. Improving adherence to antiretroviral therapy with triggered real time text message reminders: the China through technology study (CATS). J Acquir Immune Defic Syndr 2015;69(5):551.
[15] World Health Organization. Global tuberculosis report 2016. 2016.
[16] Hsieh H, Shannon SE. Three approaches to qualitative content analysis. Qual Health Res 2005;15(9):1277–88.
[17] Liu X, Lewis JJ, Zhang H, Lu W, Zhang S, Zheng G, et al. Effectiveness of electronic reminders to improve medication adherence in tuberculosis patients: a cluster-randomised trial. PLoS Med 2015;12(9):e1001876.
[18] Mohammed S, Glennerster R, Khan AJ. Impact of a daily SMS medication reminder system on tuberculosis treatment outcomes: a randomized controlled trial. PLoS ONE 2016;11(11):e0162944.
[19] Albino S, Tabb KM, Requena D, Egoavil M, Pineros-Leano MF, Zunt JR, et al. Perceptions and acceptability of short message services technology to improve treatment adherence amongst tuberculosis patients in Peru: a Focus Group Study. PLoS ONE 2014;9(5):e95770.
[20] Hermans SM, Elbireer S, Tibakabikoba H, Hoefman BJ, Manabe YC, et al. Text messaging to decrease tuberculosis treatment attrition in TB-HIV coinfection in Uganda. Patient Prefer Adherence 2017;11:1479.
[21] Ware NC, Pisarski EE, Tam M, Wyatt MA, Atukunda E, Musiimenta A, et al. The meanings in the messages: how SMS reminders and real-time adherence monitoring improve antiretroviral therapy adherence in rural Uganda. AIDS 2016;30(8):1287.
[22] Musiimenta A, Atukunda EC, Tumuhimbise W, Haberer JE. Resilience after withdrawing a technology-based medication adherence support intervention from people living with HIV in rural Uganda. AIDS Care 2018:1–8.
[23] Ware NC, Idoko J, Kaaya S, Biraro IA, Wyatt MA, Agbaji O, et al. Explaining adherence success in sub-Saharan Africa: an ethnographic study. PLoS Med 2009;6(1):e1000011.
[24] Musiimenta A, Atukunda EC, Tumuhimbise W, Pisarski EE, Tam M, Wyatt MA, et al. Acceptability and feasibility of real-time antiretroviral therapy adherence interventions in rural Uganda: mixed-method pilot randomized controlled trial. JMIR Mhealth Uhealth 2018;6(5).
[25] Katz IT, Ryu AE, Onuegbu AG, Psaros C, Weiser SD, Bangsberg DR, et al. Impact of HIV-related stigma on treatment adherence: systematic review and meta-synthesis. J Int AIDS Soc 2013;16:18640.