



SmartTB: An Integrated Digital Patient-Centric Tool for Promoting Adherence to Treatment among People Living with TB in Tanzania

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Abstract

Tuberculosis (TB) is one of the most common killer diseases in Tanzania. The WHO report shows that a person infected with TB bacteria can be treated and prevented. During treatment, TB patients are required to visit a health facility to take medication. A 6-month course of drug treatment has been shown to successfully treat approximately 85% of infected individuals and reduce transmission of the disease. Despite this, there is a high rate of TB patients who discontinue treatment, consequently forgetting to visit the clinics at the required appointments to take medication. In this context, TB patients remain ill for a long time, which leads to drug-resistant TB. In addition, DOT nurses have difficulty identifying TB patients who miss a dose and are therefore unable to follow up by phone or home visits. This results in poor reporting that delays decision-making for TB management. The application of digital technologies such as artificial intelligence in healthcare has shown potential in healthcare services, including TB treatment and monitoring. In an effort to improve and maintain the quality of TB care, we have developed an integrated digital patient-centric tool called SmartTB that promotes treatment adherence among people living with TB in Tanzania and supports real-time reporting and monitoring. Using the agile methodology, requirements analysis was acquired from three hospitals in Tanzania, and user acceptance testing was implemented to validate the performance of the system before launch. The validation results show that SmartTB can improve TB treatment, monitoring, and reporting. Therefore, policymakers must consider the use and integration of SmartTB with other healthcare systems in Tanzania for efficient TB management after release.

Keywords: *Digital healthcare, Digital patient-centric tool, Electronic health records, Tuberculosis, Treatment, Monitoring*

Received: 03/04/23

Accepted: 31/08/23

Published: 14/09/23

Cite as: Mnyambo and Barakabitze, (2023) SmartTB: An Integrated Digital Patient-Centric Tool for Promoting Adherence to Treatment among People Living with TB in Tanzania. *East African Journal of Science, Technology and Innovation 4(special issue 2)*.

Introduction

Tuberculosis (TB) is one of the leading airborne diseases that causes a high rate of morbidity and mortality in Tanzania (TB Prevalence in Tanzania report, 2022.). Consequently, in 2019, an estimated 32,000 people died from TB (Bukundi

et al., 2021). The World Health Organization (WHO) report shows that a person who is infected with TB bacteria can be cured and prevented, thus reducing the transmission of the disease and the rate of new TB cases in Tanzania (WHO, 2017). The Tanzania Tuberculosis

Roadmap Overview, Fiscal Year 2022 report shows that there was a decrease in TB new cases by 15% and deaths by 43% from 2015 to 2019. In this conception, Tanzania is one of the TB burden countries that has succeeded in reducing the TB incidence and contributing to achieving the End TB Strategy by 2030 (WHO, 2017). The decrease in new cases and the transmission of TB may be due to the availability and adherence to TB treatment. The WHO established TB treatment standard guidelines, such as a treatment regimen that every TB patient has to adhere to their medication (Nahid *et al.*, 2019).

However, some TB patients find it difficult to finish their doses and fail to follow the treatment recommendations (Garfein & Doshi, 2019). The consequences of the non-adherence of the TB patients to the treatment include drug resistance, treatment failure, and relapse (Ruru *et al.*, 2018). As a result, there is a high rate of TB patients who drop out dropout from the treatment due to various reasons, including forgetting to take medications and feeling well (Maartens & Wilkinson, 2007). DOT (directly observed treatment) nurses must make sure TB patients adhere to the specified course of treatment procedures. Despite this, the DOT nurse faces difficulties in identifying TB patients who have missed doses and making follow-up calls or home visits. This results in reporting challenges and delays in decision-making for TB hospital care management. Due to the long treatment of TB, the WHO End TB Strategy emphasizes the development of TB digital systems that support patient-centric care (WHO, 2017). These systems can ensure and enhance effective collaboration between patients and DOT nurses for the reduction of disease transmission. As a result, there is an increase in interest in the application of digital adherence technologies (DATs) to solve TB patients many problems. (Lupton, 2014).

It has been demonstrated that patient-centered approaches have boosted adherence to treatment of TB and decreased ill health since the TB medication is prolonged (Horter *et al.*, 2021). The tuberculosis patient-centered approach involves communication between patients and healthcare service providers (Harrison *et al.*, 2022). The government of Tanzania, through the Ministry of Health, ensures the provision and access of free

and quality health services to its citizen's through the use of digital technologies (Nahid *et al.*, 2019; Neumark 2023). Tanzania uses digital adherence technologies (DATs) to monitor TB treatment adherence. The DATs used in Tanzania include a District Health Information Software 2 Tracker (DHIS2 Tracker), a web-based application that helps data collection and analysis of transactional data. The DATs are a patient-centric approach and have shown great importance in TB health care delivery services (Iribarren *et al.*, 2022).

Nevertheless, there is a need to implement a web-based system aiming to track patients dropping out of treatment for further follow-up using automatic messaging (Tanzania Tuberculosis Roadmap Overview, Fiscal Year, 2021). Therefore, the aim of this paper is to develop a digital patient-centric tool called SmartTB for promoting adherence to treatment among people living with TB in Tanzania. The system may help the health workers with treatment, coordination, monitoring of the TB patients, and reporting (Verma *et al.*, 2019).

Materials and Methods

SmartTB system development

A methodology based on agile development was used to develop the SmartTB system. This approach allowed for flexibility and continuous improvement throughout the development process. The agile methodology also facilitated collaboration between the development team and healthcare stakeholders. System requirements were gathered from health professionals at Mazimbu, Morogoro regional referral, and Sekou Toure hospitals to develop a SmartTB system. Due to the iterative nature of the methodology, the system is expected to meet the needs of end users by reducing the burden of manual record-keeping and increasing the accuracy of data management.

Agile techniques and tools

The system was developed using the free and open-source PHP web development framework to allow easy customization and community support. These frameworks are Laravel Version 8 for the backend and Livewire Version 2 for the front end, which enhance a powerful and extensible solution. Additionally, the system was

developed using the UNIX platform to ensure high performance, stability, and integration with other applications and systems. Meanwhile, database management was driven by MySQL to ensure the reliability and scalability of the database by handling large amounts of data and multiple users. On the other hand, a bulk SMS Application Platform Interface (API) was used for the SMS reminder module. The SMS API ensures seamless integration with the existing system and makes it easy to send automated SMS reminders to patients and DOT nurses in Swahili. It also provides real-time delivery reports and ensures that messages are delivered promptly.

The SmartTB system developed in this study has two subsystems: treatment and monitoring, as shown in Figure 1. The treatment subsystem involves a TB patient and a DOT nurse

who assigns medication to the patient. This subsystem is responsible for providing a standard schedule for patients to adhere to during treatment. Furthermore, it is responsible for ensuring successful referrals to patients. The monitoring subsystem is accountable for tracking treatment progress by reminding patients and providing feedback to healthcare providers. This subsystem comprises the SMS reminder module for reminding patients to visit the health facility to take drugs on the scheduled date. Tuberculosis patients can receive normal real-time SMS one day before a clinic day. Moreover, the monitoring subsystem helps DOT nurses monitor TB patients in treatment adherence by receiving a normal real-time SMS one day after a patient misses clinics.

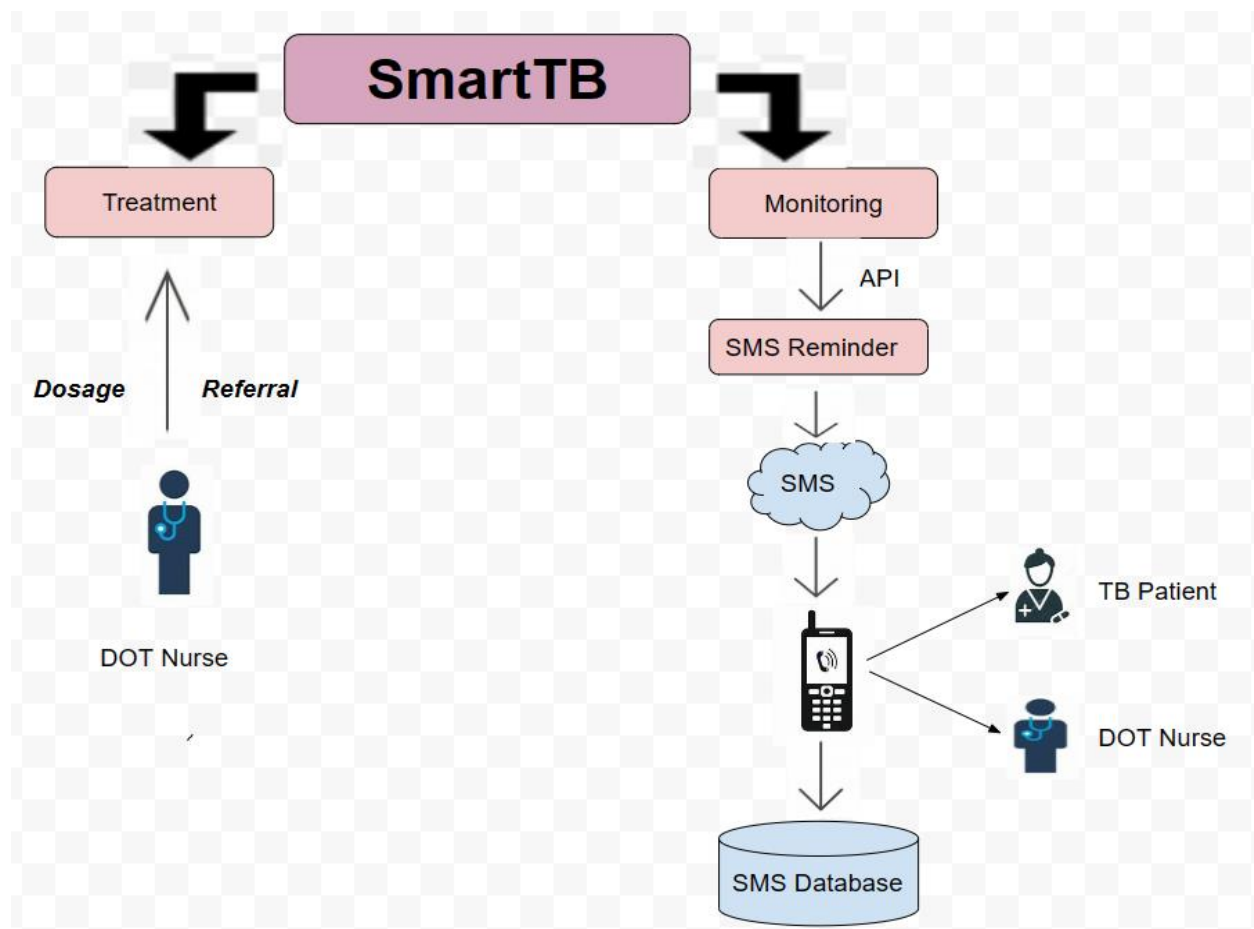


Figure 1: The figure shows the architecture of the SmartTB system

SmartTB system testing phases

The SmartTB involved three test phases: a unit test, a system test, and a user acceptance test.

Unit test

System developers conducted unit tests to verify that each code line performed according to the given specifications. During testing, the system developers verified that lines of code such as controls, data validation, input, and output were working correctly.

System test

The test team affirmed that the system as a whole performs according to the specification and that the required user requirements have been met. Moreover, this test checks the completion of end-to-end processing as intended and ensures that the system meets the needed requirements.

User acceptance tests

The user acceptance test was the final stage of testing the SmartTB system. The main purpose of acceptance testing was to validate that the system corresponds with the needs of users and is ready to be released for operational use. The healthcare professionals from Mazimbu, Morogoro regional referral, and Sekou Toure hospitals validated the SmartTB system to ensure that it meets the user's expectations. Generally, this testing was done by preparing test definition workshops in each hospital. These workshops were used as tools to help healthcare professionals test the system's functionalities and find out what tasks were performed well.

After the unit and system tests, the project team prepared test definition workshops for each hospital at different times. The workshops aimed to find out the features of the system that were working well and those that needed to be improved. The project team closely collaborated with the healthcare stakeholders, who are the users of the system in each hospital, to ensure that the intention of the workshop was achieved successfully. Users were given the chance to practice practical tasks, interactive discussions, and group activities during the workshops in order to better understand how to use the system.

The process of involving actual users of the system in the workshop was important in identifying areas that need enhancement. As a result, a more efficient and effective system was developed. Therefore, test definition workshops have been an invaluable tool that supports user satisfaction and reduces human errors in hospital operations areas. Significantly, the workshop strategy proved to be a more user-centered and collaborative process, which may enhance the improvement of treatment outcomes for patients and healthcare professionals.

Results

Architecture of the SmartTB system

Figure 1 illustrates the architecture of SmartTB, consisting of two sub-systems: treatment and monitoring. The treatment subsystem helps the DOT nurse administer medication adherence to TB patients until the end of the TB treatment. The DOT nurse can assign doses to the patient and process and receive patients' referrals. Moreover, the monitoring subsystem supports the DOT nurse in monitoring TB patients in adhering to treatment by receiving a normal real-time SMS one day after a patient misses clinics, and a patient receives a normal real-time SMS one day before a clinic day using the SMS reminder module. The sent SMS are stored in the SMS database. This database can be accessed by various applications on the device, allowing the administrator of the system to view, delete, or manage SMS.

User acceptance test results

The acceptance test was the final step in the testing process and aimed to determine whether the software met the requirements of the users. This test ensured that healthcare stakeholders were involved in the acceptance testing process to avoid any misunderstandings of requirements. The user acceptance test results in Table 1 report that the system will help to monitor adherence of the treatment of TB patients and is ready for release.

Table 1

User acceptance test results from healthcare professionals at three hospitals

SN	Acceptance Requirement	Critical		Test Result		Comments
		Yes	No	Accept	Reject	
1	The system must allow a DOT nurse to assign doses to TB patients		✓	✓		Recommended for usage
2	The last date of treatment must be correct based on the day when dosage was initiated		✓	✓		Good
3	The system has to enable the DOT nurse to request a patient's referral		✓	✓		Accepted for use
4	A DOT nurse can track the progress of the referred patient's treatment		✓	✓		Good
5	The system should ensure that patients receive a normal real-time SMS one day before a clinic day		✓	✓		The system can reduce TB patient dropouts
6	A DOT nurse receives a normal real-time SMS one day after a clinic		✓	✓		This can monitor non-adherence patients

Implementation of the treatment sub-system for TB patients

The treatment sub-system allows a DOT nurse to assign doses and process referrals for the TB patient.

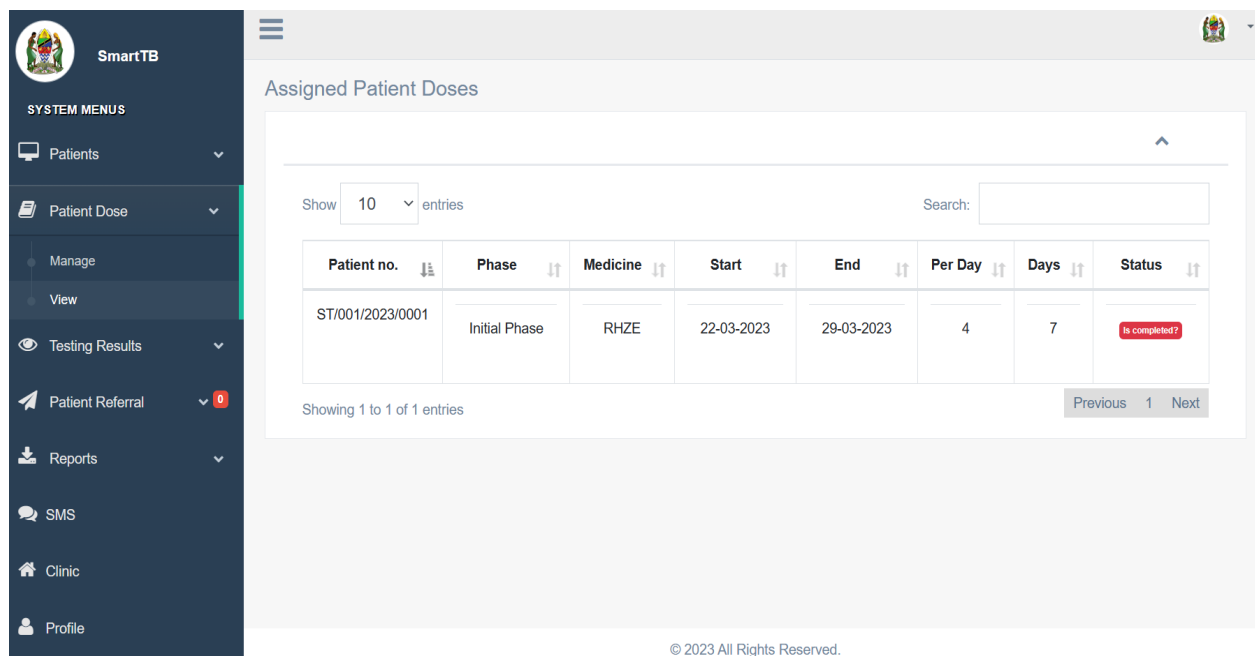


Figure 2: The figure shows the assigned dose patient and the patient's status

Figure 2 shows the assigned dose patient and patient's status, the subsystem allows the DOT nurse to assign doses to the patient and view the status of the assigned dose. The DOT nurse can view the patient's 'status and assign the patient a

dose. The system generates alert notification to remind the nurse of the missed assigned dose in the pharmacy store. This may ensure prompt and accurate medication administration.

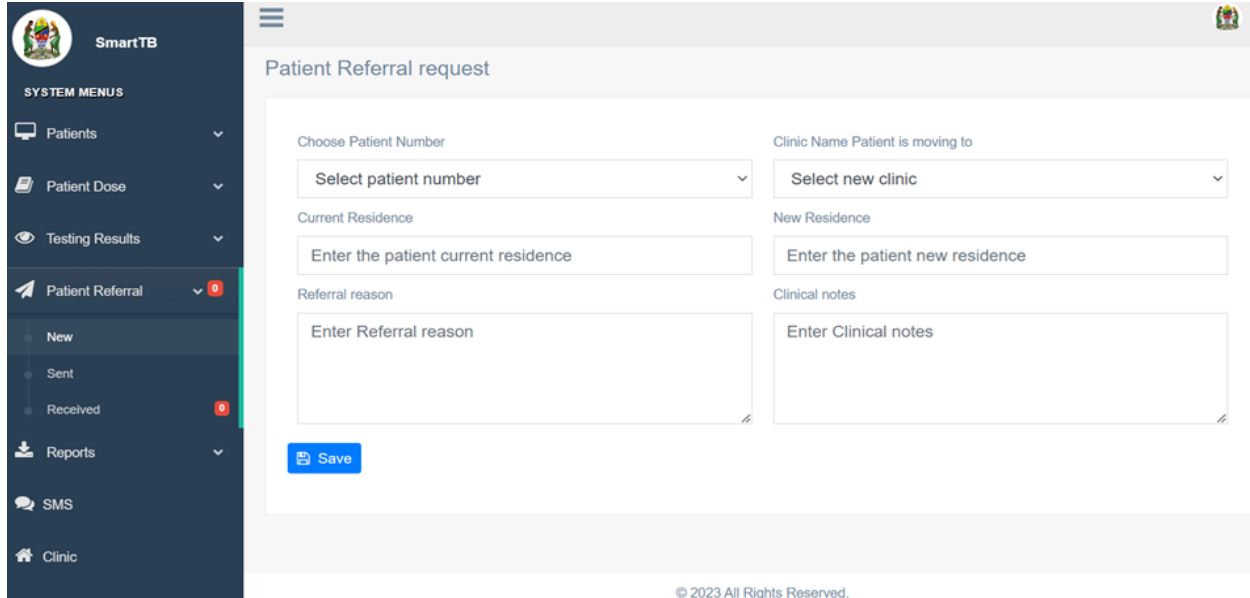


Figure 3: The figure indicates a patients' referral request

Figure 3 reports that a DOT nurse can request a referral for a patient. This feature ensures that tuberculosis patients receive real-time treatment. Moreover, it promotes continuity of care between different healthcare facilities. Furthermore, the

DOT nurse can track the progress of the referred patient's treatment and provide necessary follow-up care.

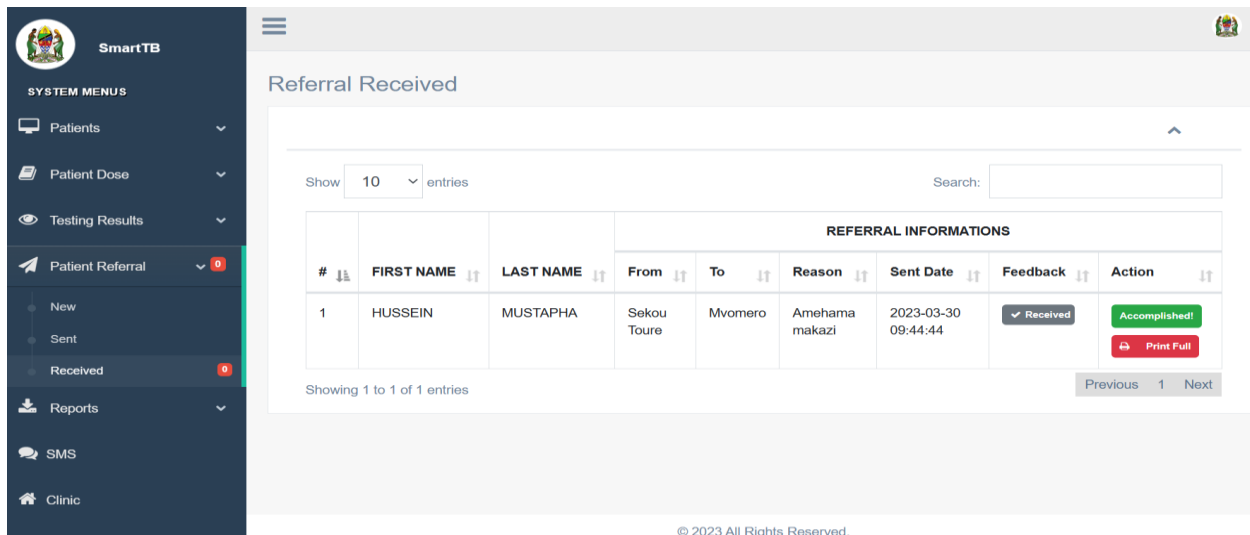


Figure 4: The figure shows status of a received patients' referral request

Implementation of Monitoring Sub-system for TB patients

The monitoring sub-system for TB patients enables healthcare providers to track the progress of patients using real-time SMS. This system ensures that both patients and DOT nurses are adhering to their treatment plans.

SMS database for TB patients

This database is designed to store the SMS sent to both patients and DOT nurses. It helps healthcare workers monitor and manage TB patients through text message reminders and updates. It can also be used to track treatment progress and provide support to patients who may have difficulty adhering to their medication regimen. The storage of SMS messages sent to patients and DOT nurses is a crucial aspect of managing the treatment of TB patients through text message reminders and updates. As a result, the DOT nurse will be able to monitor and manage patients' treatment progress in an effective way. With the ability to track the progress of treatment, DOT nurses can ensure that patients are adhering to their medication guidelines. Furthermore, the SMS-based approach is important because it has promised results in supporting effective communication between patients and DOT nurses. Therefore, the application of SMS reminder technology in monitoring TB treatment has paved the way for the provision of quality patient-centric care (Sumari-de Boer *et al.*, 2019).

#	Phone No.	Message	Date sent
1	0626818326	Ndugu HUSSEIN NUHA MUSTAPHA unakumbushwa kuhudhuria MVOMERO Kliniki tarehe 2023-03-31 ili kupata dawa za matibabu na taarifa ya maendeleo ya afya yako	3 days 10 hours ago
2	0626818326	Habari, Mgonjwa, HUSSEIN NUHA MUSTAPHA alitakiwa kuhudhuria MVOMERO Kliniki tarehe 2023-03-29 ili kupata taarifa ya maendeleo ya afya yake	3 days 9 hours ago

Figure 5: The figure shows SMS sent to patient and DOT nurse

TB patients' SMS

A patient receives a normal real-time SMS one day before a clinic day, as indicated in number 1 in Figure 5. The SMS reminds the patient of their upcoming appointment to ensure that the patient is well-prepared and arrives on time for their appointment.

DOT nurses' SMS

A DOT nurse receives a normal real-time SMS one day after a clinic day, as indicated in number 2 in Figure 5. The SMS informs the DOT nurse

about the patient who missed clinic. The DOT nurse can then follow up with the patient to determine the reason for missing the clinic and provide support to ensure they continue their treatment. This real-time notification system helps improve patient adherence and ultimately leads to better health outcomes.

Discussion

It seems possible to use the SmartTB system in Tanzania to encourage adherence to TB treatment based on the user acceptance testing results. The

results reveal that the system had the support of the stakeholders; they believed it improved the monitoring of TB treatment. This study has shown that SmartTB, as an innovative digital tool, may improve adherence to TB treatment because a patient may receive a text message on the scheduled day to visit the healthcare facility. Automatic messages can be sent to TB patients, reminding them to visit the clinic. This approach has been shown to be effective in improving treatment adherence and reducing the risk of drug resistance (Awad et al., 2021). The use of digital tools in healthcare has shown promising results in minimizing the rate of non-adherence to TB treatment. Stagg et al. (2020) and WHO (2017) have identified the benefits of using digital tools in monitoring patients treatments, such as communication between healthcare providers and patients, increased patient engagement, and better medication adherence.

Furthermore, healthcare professionals have a crucial role to play in ensuring that tuberculosis patients receive the necessary treatment and care. Fortunately, it would be easy to use the SmartTB system to facilitate this process by sending real-time messages to DOT nurses about patients who missed clinics. In addition, DOT nurses can use these messages to make follow-up calls through either SMS messaging or phone calls, ultimately monitoring patient progress and adjusting treatment plans (Seethamraju et al., 2018). As a result, the DOT nurse may have more time to devote to other tasks. This is comparable to the study that showed how automatic appointment reminders improved clinics' capacity to treat more patients (Boone et al., 2022).

SMS reminders can help with tuberculosis treatment monitoring and reduce the transmission spread of the disease (Seethamraju et al., 2018). Studies have shown that patients who receive SMS reminders are more likely to adhere to their TB treatment plan and complete the full course of medication. This can lead to better health outcomes for the patient and also help prevent the development of drug-resistant strains of TB (Liu et al., 2015). A DOT nurse can track patient progress and spot potential problems early on with the aid of SMS reminders. This technology can also help reduce missed appointments and improve medication adherence, ultimately

leading to better health outcomes for patients. Additionally, SMS reminders are a cost-effective and efficient way to communicate with patients, especially those who may not have access to email or smartphones (Rodriguez et al., 2022). However, some stakeholders expressed privacy concerns and were concerned that receiving the SMS might make others aware of their TB condition and influence discrimination. The other concern was about the cost-effectiveness of the SmartTB system, and finding more affordable alternatives was recommended. The suggested alternatives include the provision of education and awareness-raising activities to reduce stigma and promote acceptance of TB patients.

Limitations of the study

Despite the fact that the SmartTB is not yet launched, most healthcare professionals from Mazimbu, Morogoro regional referral, and Sekou Toure hospitals validated it to confirm if it meets user needs during the user acceptance testing phase. As a result, they were satisfied with the system and recommended that the SmartTB be released for operational use. In this sense, the study has not used any real data from TB patients. However, future plan is to pilot the SmartTB system in DOT centers in Tanzania, ultimately scaling-up the SmartTB technology. Therefore, future studies could incorporate real data captured by SmartTB from DOT centers to measure the effectiveness of monitoring the treatment of TB patients in Tanzania.

Conclusion

Tuberculosis is one of the major killer diseases and needs immediate solutions to reduce the significant problems associated with it, such as drug resistance. This study has revealed that sending SMS to remind patients to take their medication and notify the DOT nurse is technically possible and acceptable to TB patients and DOT nurses. As a result, TB patients can remember to visit healthcare facilities and make follow-up appointments. This technology-based approach has the potential to improve the efficiency of TB control programs and decrease the need for in-person visits by healthcare workers. Overall, incorporating SMS reminders into TB control programs could be a cost-effective

solution for enhancing patient outcomes and reducing the burden on healthcare systems in resource-limited settings.

Recommendations

SmartTB will need to be successfully adopted into the current healthcare infrastructure, and this will require cooperation from a number of stakeholders, such as healthcare professionals, policymakers, and technology experts. In this conception, the potential challenges of the system will be easy to identify and prompt solutions. In addition, training for capacity building among healthcare workers is important to ensure that the SmartTB is used efficiently for monitoring the

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treatment of tuberculosis with the support of experts. Therefore, stakeholders should ensure that SmartTB is successfully integrated into the healthcare system to improve the outcomes of treatment for people living with TB in Tanzania.

Acknowledgments

This study was funded by the Sokoine University of Agriculture on behalf of the government of Tanzania. Furthermore, requirements gathering and user acceptance testing were implemented by healthcare professionals from Mazimbu, Morogoro regional referral, and Sekou Toure hospitals.

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