Published in final edited form as:

J Health Commun. 2016 October ; 21(10): 1115–1121. doi:10.1080/10810730.2016.1222035.

Evaluation of a Mobile Health Approach to Tuberculosis Contact Tracing in Botswana

YOONHEE P. HA^{1,2,3}, MARTHA A. TESFALUL^{4,5}, RYAN LITTMAN-QUINN⁵, CYNTHIA ANTWI⁵, REBECCA S. GREEN¹, TUMELO O. MAPILA^{6,7}, SCARLETT L. BELLAMY^{1,2,3,8}, RONALD T. NCUBE⁹, KENNETH MUGISHA⁹, ARI R. HO-FOSTER^{1,5}, ANTHONY A. LUBERTI^{1,5,10}, JOHN H. HOLMES^{1,2,3,8}, ANDREW P. STEENHOFF^{1,5,11}, and CARRIE L. KOVARIK^{1,5,12}

¹Perelman School of Medicine, University of Pennsylvania, Philadelphia, Pennsylvania, USA

²Center for Public Health Initiatives, University of Pennsylvania, Philadelphia, Pennsylvania, USA

³Center for Clinical Epidemiology and Biostatistics, Perelman School of Medicine, University of Pennsylvania, Philadelphia, Pennsylvania, USA

⁴Doris Duke Clinical Research Fellowship Program, Perelman School of Medicine, University of Pennsylvania, Philadelphia, Pennsylvania, USA

⁵Botswana-UPenn Partnership, Gaborone, Botswana

⁶Nextel Enterprises (Pty) Ltd., Gaborone, Botswana

⁷Graduate School of Technology Management, University of Pretoria, Pretoria, South Africa

⁸Department of Biostatistics and Epidemiology, Perelman School of Medicine, University of Pennsylvania, Philadelphia, Pennsylvania, USA

⁹Botswana National Tuberculosis Programme, Republic of Botswana Ministry of Health, Gaborone, Botswana

¹⁰Center for Biomedical Informatics, The Children's Hospital of Philadelphia, Philadelphia, Pennsylvania, USA

¹¹Department of Pediatrics, Division of Infectious Diseases, The Children's Hospital of Philadelphia, Philadelphia, Pennsylvania, USA

¹²Department of Dermatology, University of Pennsylvania, Philadelphia, Pennsylvania, USA

Abstract

Tuberculosis (TB) contact tracing is typically conducted in resource-limited settings with paper forms, but this approach may be limited by inefficiencies in data collection, storage, and retrieval and poor data quality. In Botswana, we developed, piloted, and evaluated a mobile health

Address correspondence to Carrie L. Kovarik, Department of Dermatology, University of Pennsylvania, 2 Maloney Building, 3600 Spruce Street, Philadelphia, PA 19104, USA. carrie.kovarik@uphs.upenn.edu.

Supplemental Material

A supplemental online appendix (National Tuberculosis Contact Tracing Paper Form) is available on the publisher's website at <http://dx.doi.org/10.1080/10810730.2016.1222035>.

(mHealth) approach to TB contact tracing that replaced the paper form–based approach for a period of six months. For both approaches, we compared the time required to complete TB contact tracing and the quality of data collected. For the mHealth approach, we also administered the Computer System Usability Questionnaire to 2 health care workers who used the new approach, and we identified and addressed operational considerations for implementation. Compared to the paper form–based approach, the mHealth approach reduced the median time required to complete TB contact tracing and improved data quality. The mHealth approach also had favorable overall rating, system usefulness, information quality, and interface quality scores on the Computer System Usability Questionnaire. Overall, the mHealth approach to TB contact tracing improved on the paper form–based approach used in Botswana. This new approach may similarly benefit TB contact tracing efforts in other resource-limited settings.

Tuberculosis (TB) remains a leading cause of morbidity and mortality worldwide. In 2013, there were approximately 9.0 million new cases of TB and 1.5 million deaths from the disease, and more than 95% of these deaths occurred in low- and middle-income countries (World Health Organization, 2014, 2015).

TB contact tracing can play an essential role in disrupting the spread of disease in high-, middle-, and low-income countries (Becerra et al., 2005; Fox, Barry, Britton, & Marks, 2013; World Health Organization, 2012). As part of this public health practice, health care workers identify and screen contacts of recently diagnosed cases and refer symptomatic individuals to health care providers for treatment. In addition to facilitating the early detection and treatment of infected or exposed individuals, TB contact tracing can be used to assess the burden of disease and the effectiveness of disease control efforts within an area.

In Botswana, a middle-income country in sub-Saharan Africa that ranks 10th in the world in TB incidence (408/100,000 people; World Bank, 2014a) and second in HIV prevalence (23.0% of people ages 15–49 years; World Bank, 2014b), health care workers conduct TB contact tracing by visiting cases' homes and using a national TB contact tracing paper form to screen household contacts (see the supplemental online appendix; Puryear et al., 2013). Health care workers record contacts' responses directly onto the paper form and later enter these data into a Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) database by hand. These data are also used to generate summary reports.

There may be considerable limitations to conducting TB contact tracing with a paper form–based approach in Botswana and other resource-limited settings. For example, the use of paper forms may result in inefficiencies in data collection, storage, and retrieval and errors (e.g., missing, incorrect, or illogical values). In addition, summary reports must be generated by hand, and the precise location of cases' homes may be difficult to record in areas with limited infrastructure and poor signage. Each of these limitations may be problematic for a public health practice that aims to disrupt the spread of disease and provide TB control programs with high-quality data in a timely manner.

Health care workers in Botswana and other resource-limited settings with sufficient mobile network connectivity are increasingly using mobile technologies (e.g., phones, tablets, and applications [apps]) to complete tasks such as data collection, submission, and analysis

while out in the field (Denkinger et al., 2013; Labrique, Vasudevan, Kochi, Fabricant, & Mehl, 2013). In addition to being portable and easy to use, these technologies can eliminate or reduce the need for paper forms and address many of the limitations of the paper form–based approach to TB contact tracing (Labrique et al., 2013; Timimi, Falzon, Glaziou, Sismanidis, & Floyd, 2012). Few mobile health (mHealth) approaches to TB contact tracing have been developed and evaluated, however (Brinkel, Krämer, Krumkamp, May, & Fobil, 2014; Creswell et al., 2014; Interactive Research & Development, 2012; Kayiwa, Irani, Ahmed, Klungsøyr, & Khan, 2013; Khan et al., 2012; Vella, 2012).

In view of the high burden of TB and critical need for improved approaches to conducting TB contact tracing in resource-limited settings, we sought to develop and evaluate an mHealth approach that addresses many of the limitations of the paper form–based approach used in Botswana.

Methods

Development of an mHealth Approach to TB Contact Tracing

In an effort to improve on the paper form–based approach to TB contact tracing, we partnered closely with Nextel Enterprises (Pty) Ltd. (Gaborone, Botswana), a mobile information communication technology and services firm, to develop an mHealth approach to TB contact tracing composed of a mobile phone/tablet app and online database. This new approach was designed to eliminate the need for paper forms and writing, manual entry of data into a database, and manual generation of summary reports. The mHealth approach was also designed to enable users to capture the geographic coordinates of cases' homes. Throughout the development process, Nextel Enterprises (Pty) Ltd. adopted agile project management principles such as testing, iterations, and feature-driven development in order to maximize flexibility, minimize waste, incorporate user feedback, and ensure rapid product turnaround (Karlesky & Vander Voord, 2008).

Features of the Mobile Phone/Tablet App

The app was developed with Open Data Kit (University of Washington, Seattle, WA, USA) and designed to be used on a mobile phone/tablet running an Android (Google, Inc., Mountain View, CA, USA) operating system. For the purposes of this study, the program was used on an HTC Flyer™ (HTC Corporation, New Taipei City, Taiwan) tablet.

The app included the same fields as the national TB contact tracing paper form used to screen contacts of adult and pediatric TB cases (see the supplemental online appendix). The program was also designed to automatically record start and stop dates and times each time a user began and ended the screening process for a contact. Users could progress through each of the screening questions and, depending on the type of question asked, record a contact's response by selecting an appropriate answer from a prepopulated list of choices or using the mobile device's keyboard to enter an answer into a field. If a field was left blank or completed with an illogical response (e.g., a letter value entered into a numerical field), the app displayed an error message (e.g., "Sorry, this response is required!"); see Figure 1). In order to prevent the occurrence of missing data, users were prevented from accessing

subsequent questions until preceding questions were answered in the proper format. After completing the last question, users could capture the geographic coordinates (latitude and longitude) of a case's home by pressing an onscreen button labeled "Record Location" and activating the mobile device's global positioning system (GPS) functionality.

Both the mobile phone/tablet app and HTC Flyer™ tablet were password protected and encrypted with Transport Layer Security. The latter was also secured with Mobile Security (Lookout, Inc., San Francisco, CA, USA).

Features of the Online Database

Following the completion of each TB contact tracing session, users could submit the collected data to an online PostgreSQL (PostgreSQL Global Development Group) database that was hosted on a server at the Nextel Enterprises (Pty) Ltd offices. If a mobile network or wireless Internet connection could not be established on the mobile phone/tablet or the server was down, users could store the data within the app until a later point in time.

JasperReports Server (TIBCO JasperSoft, San Francisco, CA, USA) was used to automate summarization of data submitted to the online database (e.g., number of cases followed, number of contacts screened), generation of weekly and cumulative reports, and submission of reports to designated recipients at a set day and time each week.

The online database was also password protected and encrypted. Data submitted to the online database were secured with Secure Socket Layer certificates. Once submitted, data were automatically deleted from the mobile device's digital memory card, which was formatted on a regular basis using SD Formatter 3.1 (SD Association, San Ramon, CA, USA). At the end of the data collection period, the online database was exported using the built-in PostgreSQL database backup feature and encrypted using the Advanced Encryption Standard with a 128-bit key (Daemen & Rijmen, 2002).

TB Contact Tracing in Botswana

The paper form-based approach to TB contact tracing was implemented in Botswana in January 2009 and replaced with the mHealth approach during a 6-month pilot period that lasted from September 18, 2012, to March 17, 2013.

For both approaches, the same TB contact tracing team composed of two male health care workers operated as a unit and made home visits to all adult TB cases diagnosed at one of six health care facilities in Gaborone and Kweneng District and all pediatric TB cases diagnosed at one health care facility in Gaborone. Both health care workers were natives of Botswana who spoke English and Setswana fluently and had several years' experience conducting TB contact tracing in the study area.

During home visits, the TB contact tracing team obtained verbal informed consent for participation in the study from adult TB cases, caretakers of pediatric TB cases, and household contacts or their caretakers. Verbal informed consent was also obtained to capture the geographic coordinates of each case's home. The TB contact tracing team then screened the household contacts or their caretakers.

Depending on the approach used, the health care workers recorded contacts' responses to screening questions either on a national TB contact tracing paper form or within the app. For the paper form–based approach, start and stop dates and times were read from a mobile phone clock at the respective time points and recorded directly onto the forms by hand.

In the event a case or contact was not available at the time of a home visit, the TB contact tracing team made up to three follow-up visits shortly thereafter.

Evaluation of Time Required to Complete TB Contact Tracing per Contact and Quality of Data Collected

Start and stop dates and times for the paper form–based approach were collected retrospectively from a Microsoft Excel database for the 6-month period that lasted from March 18, 2012, to September 17, 2012. Start and stop dates and times for the mHealth approach were collected prospectively in the online database during the 6-month pilot period that lasted from September 18, 2012, to March 17, 2013.

For each approach, the differences between the start and stop dates and times were used to calculate the time required to complete TB contact tracing for each contact. These times were compared using a two-sided Wilcoxon rank-sum test. Contacts with missing start and stop dates or times were excluded from the analyses.

In order to assess the quality of data collected with each approach, we determined the proportion of contacts with 1 missing or illogical values for the start and stop dates (e.g., switching the month and day).

Because of differences in the nature of adult and pediatric TB cases, all statistical analyses were conducted separately for the contacts of these groups.

All statistical analyses were performed using Stata Version 11.2 (StataCorp, College Station, TX, USA).

Evaluation of User Satisfaction With System Usability

The Computer System Usability Questionnaire (CSUQ) is a 19-item questionnaire designed to measure user satisfaction with system usability (Lewis, 1993). Respondents answer each question by selecting a score ranging from 1.0 (*strongly agree*) to 7.0 (*strongly disagree*) and elaborating on their selections with written comments. Scores are averaged to generate an overall rating and subscores for system usefulness, information quality, and interface quality. Lower scores indicate more favorable ratings, and higher scores indicate less favorable ratings.

In April 2013, the CSUQ was administered to the two TB contact tracing team members. Each health care worker provided written informed consent for participation in the study prior to completing the questionnaire. Scores for both TB contact tracing team members were averaged.

Identification and Addressing of Operational Considerations for Implementing the mHealth Approach

Operational considerations for implementing the mHealth approach to TB contact tracing were identified and addressed throughout the 6-month pilot period.

Ethical Approval

This study received ethical approval from the institutional review boards at the University of Pennsylvania and Health Research and Development Committee of the Republic of Botswana Ministry of Health.

Results

TB Contact Tracing in Botswana

During the initial 6 months of the study, which lasted from March 18, 2012, to September 17, 2012, 113 contacts of 36 adult TB cases and 57 contacts of 17 pediatric TB cases were screened using the paper form–based approach. Ten contacts of adult TB cases (8.8%) and two contacts of pediatric TB cases (3.5%) were excluded from the comparisons of time required to conduct TB contact tracing because of missing start and stop dates or times.

From September 18, 2012, to March 17, 2013, 265 contacts of 89 adult TB cases and 42 contacts of 13 pediatric TB cases were screened with the mHealth approach to TB contact tracing. No contacts of adult TB cases or pediatric TB cases were excluded from the comparisons of time required to conduct TB contact tracing.

Time Required to Complete TB Contact Tracing per Contact and Quality of Data Collected

For contacts of adult TB cases, the median time required to complete TB contact tracing was significantly greater for the paper form–based approach than for the mHealth approach: 5.0 min per contact (interquartile range [IQR]: 4.0–8.0) versus 2.8 min per contact (IQR: 1.7–4.4), respectively ($p < .001$). Similarly, the median time required to complete TB contact tracing for contacts of pediatric TB cases was significantly greater for the paper form–based approach than for the mHealth approach: 5.0 min per contact (IQR: 4.0–6.0) versus 3.2 min per contact (IQR: 2.3–5.2), respectively ($p < .001$).

With the paper form–based approach, 12/113 (10.6%) contacts of adult TB cases and 45/57 (78.9%) contacts of pediatric TB cases had 1 missing or illogical values for start and stop dates. In contrast, no contacts of adult or pediatric TB cases had missing or illogical values with the mHealth approach.

User Satisfaction With Usability for the mHealth Approach

The mHealth approach had favorable overall rating (2.1/7.0), system usefulness (1.6/7.0), information quality (2.6/7.0), and interface quality (2.3/7.0) scores on the CSUQ (lower scores indicate more favorable ratings, and higher scores indicate less favorable ratings).

Written comments provided by the two TB contact tracing team members on the questionnaire indicated that the mHealth approach was easy to use and simplified their work:

- “It did not take me more than 10 minutes to understand the system.”
- “The system has proved to be time saving and efficient. The system made my work simple.”

Advantages of the mHealth approach included the following:

- “One of the advantages is that the system does not require the user to write a lot of information and that makes it less time consuming.”
- “The system made it simple to enter and receive information. Quickly generates the report. No reason to create a parallel database. No need to carry papers which are often lost.”

Limitations of the mHealth approach included the following:

“The only challenge is when there no mobile network or when the internet is low.”
[sic]

“The server problems which is often up and down was the main barrier to effectively carrying out my duties.” [sic]

Operational Considerations for Implementing the mHealth Approach

Table 1 lists the operational considerations for implementing the mHealth approach to TB contact tracing that were identified and addressed throughout the 6-month pilot period.

Discussion

In this study, we developed and evaluated an mHealth approach to TB contact tracing that addressed many of the limitations of the paper form-based approach that is commonly used in resource-limited settings. Although a small number of mHealth approaches to TB contact tracing have been reported in the literature, this was the first study to evaluate an mHealth approach by directly comparing the time required to complete TB contact tracing and the quality of data collected with this method to those of the paper form-based approach (Brinkel et al., 2014; Creswell et al., 2014; Interactive Research & Development, 2012; Kayiwa et al., 2013; Khan et al., 2012; Vella, 2012).

The mHealth approach eliminated the need for paper forms, writing, manual entry of data into a database, and manual generation of summary reports. In addition, it reduced the time required to complete TB contact tracing per contact for contacts of both adult and pediatric TB cases and generated and e-mailed summary reports to designated recipients.

This new approach also improved the quality of data collected. The app eliminated problems arising from illegibility and prevented users from leaving fields blank or entering illogical values. Although it is possible that the TB contact tracing team members may have entered

incorrect values into fields in some instances, we sought to prevent this from occurring by providing prepopulated lists of answer choices for several questions.

Similar to other mHealth approaches that have taken advantage of the GPS functionalities of mobile devices, our new approach improved the quality of location data collected (Khan et al., 2012; Vella, 2012). With the app, users could activate the mobile device's GPS functionality and capture the geographic coordinates of each case's home. These precise coordinates represent a major improvement over the informal descriptions that are typically used to describe the locations of homes in areas with limited infrastructure and poor signage.

Given that the aims of TB contact tracing are to disrupt the spread of disease and inform disease control efforts in a timely manner, the ability to rapidly collect and access high-quality data is a particularly notable benefit of the mHealth approach described here. Although we did not formally assess the time needed to enter data into the Microsoft Excel database or generate summary reports with the paper form-based approach, the time and labor saved with the mHealth approach are likely to be substantial. In settings with a high burden of disease and a shortage of health care workers, these time and labor savings could be used to expand TB contact tracing and other disease control efforts. Furthermore, TB control programs can use timely, high-quality data to more effectively understand, prepare for, and respond to the disease burden and spread within an area (Chapman, Darton, & Foster, 2013).

The mHealth approach was well received by the TB contact tracing team members and had favorable overall rating, system usefulness, information quality, and interface quality scores on the CSUQ. The TB contact tracing team members reported that the new approach simplified their work and was easy to use. It is important to note, however, that the health care workers in this study had several years' experience conducting TB contact tracing in the study area. In addition, both health care workers were already highly proficient in using mobile technologies. As a result, they required minimal training prior to the implementation of the mHealth approach. In other teams with less experience, sufficient time and resources will need to be devoted to training health care workers and allowing them to practice the new approach and demonstrate their mastery.

Limitations

This study has several limitations. First, this was a pilot-level study in which TB contact tracing was conducted for contacts of TB cases identified at seven health care facilities located in urban or semiurban areas of Botswana. As a result, we were unable to evaluate this approach in more rural areas of the country.

Second, it is possible that the improved times and data quality observed with the mHealth approach were due to the TB contact tracing team members' preferences for the new approach and/or awareness that their performances would be evaluated (i.e., the Hawthorne effect). In order to account for these factors, we collected data for each approach over two separate 6-month periods. Furthermore, no incentives were offered to the TB contact tracing team members, and employment was not contingent on performance with either approach.

Third, we analyzed data entered into the Microsoft Excel database in order to determine the time required to complete TB contact tracing per contact and the quality of data collected with the paper form–based approach. It is possible that errors may have resulted when data collected with paper forms were entered into the database by hand. However, it has been standard practice to use this database to generate summary reports and inform disease control efforts in Botswana.

Fourth, we were only able to administer the CSUQ to the TB contact tracing team members. Although this allowed us to assess the experiences of two health care workers who used the mHealth approach on a day-to-day basis for 6 months, gathering feedback from a larger and more diverse group of users may help us to form a richer understanding of the user experience and this new approach’s strengths and limitations.

Fifth, although the mHealth approach saved time and labor at multiple points of the TB contact tracing process, it relied on the availability of a mobile network or wireless Internet connection and local server. Although the app was designed to enable users to store collected data, it is foreseeable that there may be settings where outages are more frequent or last for extended periods of time. In such areas, it may be necessary to submit collected data whenever a connection is available. In addition, a copy of the online database should be downloaded to a secure location on a regular basis so that the most recent version is available offline. In settings where the appropriate infrastructure is in place, automated failovers and backup power sources can also play an important role in minimizing disruptions to workflow.

Finally, making significant modifications to the app or online database (e.g., adding questions, removing questions) may be challenging and result in delays and additional costs. TB control programs should engage in careful and thorough planning prior to and during the development stages, particularly if they are working with outside developers. In our experience, adopting agile project management principles ensured that these types of changes would be made early on in the development process. Other programs may also wish to consider using open source tools whenever possible, modifying existing mobile technologies, and training personnel so that necessary changes can be made in house.

Future Work

As might be expected in any resource-limited setting, we encountered several challenges to piloting a new approach to conducting TB contact tracing in Botswana. However, the mHealth approach evaluated in this study represents a significant improvement over the standard paper form–based approach to screening contacts of TB cases, collecting data, and informing disease control efforts.

Future work may include a comparative cost analysis of the paper form–based and mHealth approaches to TB contact tracing, and the mHealth approach may be expanded to more rural areas of Botswana. In addition, the mHealth approach may be modified to enable health care workers to track other aspects of TB patient care, such as treatment adherence and management, and data collected with the app may be linked to other data collected by local

health care facilities. Finally, geographic coordinates collected with the mHealth approach may be used to generate offline maps and identify disease hotspots.

Conclusion

In this study, we developed and evaluated an mHealth approach to TB contact tracing. This new approach improved on the paper form–based approach used in Botswana by eliminating the need for paper forms, writing, manual entry of data into a database, and manual generation of summary reports. Compared to the paper form–based approach, the mHealth approach reduced the time required to complete TB contact tracing per contact and generate and access summary data. In addition, the mHealth approach improved the quality of data collected and enabled users to capture the geographic coordinates of each case's home. An mHealth approach may similarly benefit TB control efforts in other resource-limited settings.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

We thank Gorewang Seropola and Steve Kekwaletswe for their technical assistance. We are also grateful to the health care providers, patients, caretakers, and families in Botswana and the many partners that made this study possible, including the Republic of Botswana Ministry of Health; Orange Botswana; Nextel Botswana; Centers for Disease Control and Prevention; U.S. President's Emergency Plan for AIDS Relief; Botswana–UPenn Partnership; and Global Health Programs Office, Perelman School of Medicine, University of Pennsylvania. This project was presented as a poster at the 140th Annual Meeting and Exposition of the American Public Health Association in San Francisco, California, USA, in October 2012; the 14th World Congress on Medical and Health Informatics (Medinfo) in Copenhagen, Denmark, in August 2013 (Ha et al., 2013); and the 6th Annual The Children's Hospital of Philadelphia Pediatric Global Health Conference in Philadelphia, Pennsylvania, USA, in November 2013.

Funding

This publication was made possible through core services and support from the Penn Center for AIDS Research, a National Institutes of Health–funded program (P30 AI 045008). Yoonhee P. Ha was funded by the Medical Scientist Training Program at the Perelman School of Medicine, University of Pennsylvania; a Paul and Daisy Soros Fellowship for New Americans; a P.E.O. Scholar Award; and a Katie Memorial Foundation Leadership Grant. Martha A. Tesfalul was funded by a Doris Duke Clinical Research Fellowship from the Doris Duke Charitable Foundation. These funders had no role in the study design; in the collection, analysis, and interpretation of data; in the writing of the manuscript; or in the decision to submit the manuscript for publication.

References

- Becerra MC, Pachao-Torreblanca IF, Bayona J, Celi R, Shin SS, Kim JY,... Murray M. (2005). Expanding tuberculosis case detection by screening household contacts. *Public Health Reports*, 120(3), 271–277. [PubMed: 16134567]
- Brinkel J, Krämer A, Krumkamp R, May J, & Fobil J (2014). Mobile phone-based mHealth approaches for public health surveillance in sub-Saharan Africa: A systematic review. *International Journal of Environmental Research and Public Health*, 11(11), 11559–11582. doi:10.3390/ijerph111111559 [PubMed: 25396767]
- Chapman AL, Darton TC, & Foster RA (2013). Managing and monitoring tuberculosis using Web-based tools in combination with traditional approaches. *Clinical Epidemiology*, 5, 465–473. doi: 10.2147/CLEP.S37072 [PubMed: 24294008]

- Creswell J, Khowaja S, Codlin A, Hashmi R, Rasheed E, Khan M, ... Khan AJ. (2014). An evaluation of systematic tuberculosis screening at private facilities in Karachi, Pakistan. *PLoS ONE*, 9(4), e93858. doi:10.1371/journal.pone.0093858 [PubMed: 24705600]
- Daemen J, & Rijmen V (2002). The design of Rijndael: AES—The advanced encryption standard (information security and cryptography). Berlin, Germany: Springer.
- Denkinger CM, Grenier J, Stratis AK, Akkihal A, Pant-Pai N, & Pai M (2013). Mobile health to improve tuberculosis care and control: A call worth making. *International Journal of Tuberculosis and Lung Disease*, 17(6), 719–727. doi:10.5588/ijtld.12.0638 [PubMed: 23541232]
- Fox GJ, Barry SE, Britton WJ, & Marks GB (2013). Contact investigation for tuberculosis: A systematic review and meta-analysis. *European Respiratory Journal*, 41(1), 140–156. doi: 10.1183/09031936.00070812 [PubMed: 22936710]
- Ha YP, Littman-Quinn R, Antwi C, Seropola G, Green RS, Tesfalul MA, ... Kovarik CL (2013). A mobile health approach to tuberculosis contact tracing in resource-limited settings. *Studies in Health Technology and Information*, 192, 1188.
- Interactive Research & Development. (2012, May 27). mHealth to improve TB care. Retrieved from the Stop TB Partnership website: <http://www.stoptb.org/assets/documents/resources/publications/acsm/mHealth%20to%20Improve%20TB%20Care.pdf>
- Karlesky M, & Vander Voord M (2008, October 26–30). Agile project management (or, burning your Gantt charts). In *Embedded Systems Conference 2008 (ESC BOSTON 2008)* Retrieved from <https://atomicobject.com/uploadedImages/archive/files/EmbeddedAgilePMPaper.pdf>
- Kayiwa D, Irani J, Ahmed OU, Klungsøyr J, & Khan A (2013). OpenMRS mobile integration into OpenMRS Multi-drug Resistant Tuberculosis (MDR-TB) module for improved management and monitoring of community based MDR-TB treatment program in a low-resource setting In Lehmann CUA, Ammenwerth E, & Nøhr C (Eds.), *MEDINFO 2013: Proceedings of the 14th World Congress on Medical and Health Informatics*. Clifton, VA: IOS Press.
- Khan AJ, Khowaja S, Khan FS, Qazi F, Lotia I, Habib A, ... Keshavjee S. (2012). Engaging the private sector to increase tuberculosis case detection: An impact evaluation study. *The Lancet Infectious Diseases*, 12(8), 608–616. doi:10.1016/S1473-3099(12)70116-0 [PubMed: 22704778]
- Labrique AB, Vasudevan L, Kochi E, Fabricant R, & Mehl G (2013). mHealth innovations as health system strengthening tools: 12 common applications and a visual framework. *Global Health: Science and Practice*, 1(2), 160–171. doi:10.9745/ghsp-d-13-00031
- Lewis JR (1993). IBM computer usability satisfaction questionnaires: Psychometric evaluation and instructions for use. *International Journal of Human-Computer Interaction*, 7(1), 57–78.
- Puryear S, Seropola G, Ho-Foster A, Arscott-Mills T, Mazhani L, Firth J, ...Steenhoff AP(2013). Yield of contact tracing from pediatric tuberculosis index cases in Gaborone, Botswana. *International Journal of Tuberculosis and Lung Disease*, 17(8), 1049–1055. doi:10.5588/ijtld.12.0933 [PubMed: 23827029]
- Timimi H, Falzon D, Glaziou P, Sismanidis C, & Floyd K (2012). WHO guidance on electronic systems to manage data for tuberculosis care and control. *Journal of the American Medical Informatics Association*, 19(6), 939–941. doi:10.1136/amiajnl-2011-000755 [PubMed: 22729390]
- Vella V (2012, 7 6). Evaluation of the use of the smartphone system in Ethekwini Metropolitan Area, South Africa United States Agency for International Development Tuberculosis Program South Africa Retrieved from http://www.epidemiologicalconsulting.com/pdf/report_smartphones_final.pdf.
- World Bank. (2014a). Incidence of tuberculosis (per 100,000 people). Retrieved from <http://data.worldbank.org/indicator/SH.TBS.INCD>
- World Bank. (2014b). Prevalence of HIV, total (% of population ages 15–49). Retrieved from <http://data.worldbank.org/indicator/SH.DYN.AIDS.ZS>
- World Health Organization. (2012). Recommendations for investigating contacts of persons with infectious tuberculosis in low- and middle-income countries. Geneva, Switzerland: Author.
- World Health Organization. (2014). Global tuberculosis report 2014. Geneva, Switzerland: Author.
- World Health Organization. (2015, 3). *Tuberculosis fact sheet No. 104*. Geneva, Switzerland: Author.

Fig. 1.
Screenshots of the mobile phone/tablet app.

Table 1.

Operational considerations for implementing the mHealth approach.

Need or problem	Solution(s)
Need for ensuring the safety of the tuberculosis (TB) contact tracing team members during home visits	The two TB contact tracing team members operated as a unit and carried the mobile device on their persons.
Need for preventing theft or loss of the mobile device	At the end of each workday, the mobile device was stored in a locked research office.
Need for a fully charged mobile device at the start of each workday	The mobile device was charged every evening in the research office.
Submission of data from the app to the online database depended on the availability of a mobile network or wireless Internet connection	Data were submitted to the online database at the end of each TB contact tracing session or whenever a connection could be established.
Access to the online database and report generation and dissemination depended on the availability of the local server	Data were submitted to the online database at the end of each TB contact tracing session or whenever a connection could be established.
Need for optimal mobile device global positioning system (GPS) functionality	The TB contact tracing team members reported that the HTC Flyer™ tablet's GPS functionality worked more effectively when the mobile device was used outdoors. As a result, the TB contact tracing team members recorded the geographic coordinates of cases' homes immediately outside the residences.
Need for preparing for mobile device malfunctioning	The TB contact tracing team members carried spare paper forms in their vehicle.