Feasibility, acceptability, and adoption of fingerprint scanning during contact investigation for tuberculosis in Kampala, Uganda: A parallel-convergent, mixed-methods analysis

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Abstract

Background

In resource-constrained settings, challenges with unique patient identification may limit continuity of care, monitoring and evaluation, and data integrity. Biometrics offer an appealing but understudied potential solution.

Methods

We conducted a mixed-methods study to understand feasibility, acceptability, and adoption of digital fingerprinting for patient identification in a study of household TB contact investigation in Kampala, Uganda. We tested associations between demographic, clinical, and temporal characteristics and failure to capture a digital fingerprint. We used generalized estimating equations and a robust covariance estimator to account for clustering. We evaluated clustering of outcomes by household and community health worker by calculating intra-class correlation coefficients. To understand determinants of intended and actual use of fingerprinting technology, we conducted fifteen in-depth interviews with community health workers and applied a widely used conceptual framework, the Technology Acceptance Model 2.

Results

Digital fingerprints were captured in 74% of participants, with extensive clustering by household (ICC = 0.99) arising from hardware (XX%) and software (XX%) failures. Clinical and demographic characteristics were not significantly associated with fingerprint capture. Community health workers successfully fingerprinted all contacts in 70% of households, with modest clustering of outcomes by CHW (ICC = 0.18). Fingerprinting success at the household level declined over time (Spearman's rho = 0.30, $P < 0.001$). In interviews, CHWs reported that fingerprinting non-capture events lowered their own perception of the quality of the technology, threatened their social image, and made the technology more difficult to use.

Conclusions

We found digital fingerprinting to be feasible and acceptable for indvidual identification, but problems implementing the hardware and software led to a high failure rate. Although CHWs found fingerprinting to be acceptable in principle, their intention to use the technology was tempered by perceptions that it was inconsistent and of questionable value. We emphasize the need for routine process evaluation of biometrics and other digital technologies during implementation in resource-constrained settings.

Introduction

The ability to uniquely identify individuals in health care settings is important for patient care, health system monitoring, and health research. For patients, unique identifiers may facilitate continuity of care, linking of encounters into a longitudinal health record, and prevention of errors during treatment. For health systems, these linkages provide richer evidence for monitoring and evaluation than aggregated data (Beck et al., 2018). In clinical and public health research, unique identification helps preserve the integrity of data and protects against misclassification (SonLa Study Group, 2007). In resource-constrained settings, however, there are many barriers to unique patient identification: lack of national identification systems, inconsistent spelling of names, uncertainty about date of birth, continually changing phone numbers, a lack of street addresses or phone numbers, and intentional avoidance of identification procedures in order to escape stigma. A reliable identification method that circumvents these barriers could improve data accuracy and patient retention in care in resource-constrained settings.

Biometric identification techniques offer a novel and appealing solution to these challenges. Biometric methods rely on an individual's physical characteristics such as fingerprints, facial structure, iris geometry, or actions including handwriting or gait pattern (Jain, 2007). Of these, fingerprint scanning has become the most widely used with development of portable, low-cost technologies for digital capture (SonLa Study Group, 2007) and its high sensitivity and specificity for verification(Wall et al., 2015). Others have reported that fingerprinting is feasible (Harichund, Haripersad, & Ramjee, 2013; Odei-Lartey et al., 2016; Serwaa-Bonsu et al., 2010; SonLa Study Group, 2007; Wall et al., 2015; Weibel et al., 2008) and acceptable (Serwaa-Bonsu et al., 2010; van Heerden et al., 2017). However, there is little evidence regarding actual use of fingerprinting technologies in resource-constrained settings. Therefore, we sought to perform a detailed process evaluation of digital fingerprint scanning by community health workers (CHWs) in urban Uganda in order to understand its feasibility, acceptability, and adoption for patient identification (G. F. Moore et al., 2015). Additionally, we sought to better understand the determinants of

CHWs' intended and actual use of fingerprint scanning technology by applying a widely used conceptual framework, the Technology Acceptance Model 2 (TAM2) (Venkatesh & Davis, 2000).

Methods

Study Design, Setting, and Population

We conducted a parallel-convergent, mixed-methods study of digital fingerprinting in the context of a household-randomized trial of enhanced tuberculosis (TB) contact investigation. Specifically, the trial (called the parent study) sought to evaluate the effects of home sputum collection and SMS messaging on completion of evaluation for TB among household contacts living with index TB patients. The parent study took place in Kampala, Uganda from July 2016 to July 2017. In the parent study, we employed digital fingerprinting to avoid duplicate registrations of index patients and contacts and to verify follow-up visits at clinics for those needing additional evaluation. In this sub-study, we analyzed quantitative data from participants enrolled in the parent study and qualitative data from interviews with CHWs who carried out digital fingerprinting and other study procedures. Children under the age of 5 were not eligible for fingerprint scanning because digital fingerprints are difficult to capture and less accurate in young children (Jain, Arora, Cao, Best-Rowden, & Bhatnagar, 2016; Joint Research Centre of the European Commission, 2013).

Study procedures

Prior to implementation, all CHWs completed a course educating them about the rationale and basis for the use of fingerprints as biometric identifiers, describing different fingerprint patterns, and training them on the best methods to acquire high quality fingerprints using a digital scanner. CHWs participated in a hands-on training or "role-play" session so that CHWs had ample practice acquiring good quality fingerprints and learned how to solve common problems. CHWs performed digital fingerprinting and collected individual age, sex, and self-reported HIV status from household members during contact investigation visits. Fingerprinting was performed using multi-spectral fingerprint scanners (Lumidigm M301, HID Global, Austin, Texas) linked to proprietary matching software (Biometrac, Louisville, KY), which was deployed offline and integrated with a customized survey application (CommCare, Dimagi, Boston, MA, USA). The application logged each health worker and time-stamped each encounter. Data were uploaded to a cloud-based server (CommCareHQ, Dimagi, Boston, MA, USA). Fingerprint images were not stored but instead recorded as a series of unique characters decipherable only using a secured, proprietary algorithm.

Quantitative Analysis

For individual contacts, the outcome of interest was failure to record a complete fingerprint scan in the database, categorized as a binary outcome. A complete scan required successful capture of right and left thumbprints, followed by right and left index fingerprints; any scan that failed to capture all four fingerprints was deemed unsuccessful. For a household, a complete fingerprint scan was defined as successful scanning of all contacts in the household; if at least one contact failed to be scanned, fingerprinting was classified as a failure. If a household required multiple visits in order to enroll all contacts, we included only the first household encounter in our analyses. Two investigators (EBW, DB) independently reviewed free text explanations from CHWs for fingerprinting failures and classified each as a hardware problem, a software problem, or as another unclassified problem. We described the population characteristics of individual study participants, including age, sex, and HIV status, as well as characteristics of households, including which CHW captured fingerprints and the time period of enrollment. We examined differences in success by age, using the standard categories employed by the WHO Stop TB Department (5-14 years and ≥15 years); sex; and HIV status. We examined changes in fingerprinting success over time by quarter of study enrollment using Spearman's test for trend. We examined differences in fingerprinting success by CHW using the Chi-squared test of significance. To test associations between individual characteristics and fingerprinting success, we fit bivariate models using generalized estimating equations and a robust covariance estimator to account for clustering by household. We report p-values based on cluster-robust standard errors. To estimate the extent of clustering of outcomes by household and CHW, we calculated intra-class correlation coefficients (ICC). We calculated Spearman's Rho to test for trend by study quarter to estimate fingerprinting success over time.

Qualitative Interview Procedures

During the last two months of the study, we carried out parallel in-depth interviews with each of the fifteen CHWs who conducted study procedures using a semi-structured interview guide. We developed the guide to elicit responses related to three overarching topics: the CHWs' first interactions with digital fingerprinting; their experiences using digital fingerprinting during the study; and their opinions regarding the usability of digital fingerprinting. The guide was developed in English and is reported in Appendix 1. One English-speaking investigator (EBW) interviewed all fifteen CHWs who conducted study procedures. All but one reported feeling comfortable completing the interview in English. A native Luganda-speaking investigator (JG) re-interviewed the one CHW who did not feel comfortable in English in Luganda to give the respondent the opportunity to elaborate on experiences and opinions in her native language. During the interview, each CHW was also asked to mock-fingerprint the interviewer as a means of eliciting the user's experiences and interactions with digital fingerprinting. All interviews were recorded, transcribed, and uploaded to a secure online server for qualitative data analysis (Dedoose, Manhattan Beach, CA). In addition, interviewers used a structured debriefing form (Appendix 2) to organize emergent themes immediately following each interview. Additional details were added iteratively after reviewing interview recordings and transcripts.

Qualitative Analysis

We carried out the qualitative analysis using the debriefing forms to identify key themes. (Simoni et al., 2017). Using the TAM2 framework, one investigator (EBW) categorized themes into pre-specified antecedents of "behavioral intention" to use fingerprinting technology (Figure 1). TAM2 theorizes that behavioral intention precedes and predicts actual use. Behavioral intentions are influenced by perceptions of the technology's usefulness and ease of use. Finally, five domains independently contribute to the perceived usefulness of a technology: the perception that important others expect one to use the technology (*subjective norm*); the perception that social status is enhanced through its use (*image*); the perception that the technology supports an important job function (*job relevance*); the performance of the technology (*output quality*); and tangible results of its use (*result demonstrability*) (Davis, 1989; Fishbein & Ajzen, 1975; Holden & Karsh, 2010; G. C. Moore & Benbasat, 1991; Venkatesh & Davis, 2000).

Human Subjects Considerations

Each participant or the parent/guardian of minors provided written informed consent as part of the parent study. Participants aged 8-17 years old also provided written assent. For this sub-study, CHWs provided verbal consent prior to the interview. Institutional review boards at the Makerere College of Health Sciences, the Uganda National Council for Science and Technology, and Yale University approved the study protocol.

Results

Study Population

Of the 919 household contacts eligible for the parent study, 694 (75.5%) individuals aged 5 and above were eligible for digital fingerprinting (Figure 2). Of those eligible, 515 (74.2%) had a successful fingerprint scan during the household visit. Of the 179 contacts without successful fingerprint scans during the household visit, 108 (60.3%) fingerprint scan failures were classified as software problems, 65 (36.3%) as hardware problems, and 6 (3.4%) as unclassified problems. None were classified as refusals.

We found similar baseline fingerprinting success rates and failure reasons among index patients; because these were unclustered data and collected in a clinic setting, we report them separately in the Online Supplement. Only 1 (3%) of the contacts fingerprinted at the household visit and referred to the clinic for evaluation was identified via fingerprint at the follow-up visit. Among individual contacts, clustering of unsuccessful scans by household was extensive (ICC = 0.99). Household contacts who were not successfully fingerprinted did not differ significantly with respect to sex, age, or HIV status from those who were successfully fingerprinted (Table 1).

CHWs successfully fingerprinted all consenting contacts in 213 (70%) households. Among households, clustering of this outcome by CHW was modest (ICC = 0.18). The frequency of successfully fingerprinting all contacts in a household by CHW ranged from 45% to 97%, with a median of 71% ($P <$ 0.001). The proportion of households where all contacts were successfully fingerprinted decreased over time: 87% in Quarter 1, 77% in Quarter 2, 68% in Quarter 3, and 51% in Quarter 4 (Spearman's rho = 0.30, $P < 0.001$).

Qualitative Interviews

All fifteen CHWs who carried out fingerprint scans were interviewed. The median interview length was 37 minutes (IQR: 33.5-42 minutes). CHWs ranged in age from 24 to 54 years with a median of 33 years, and 80% were female. Most (87%) had completed ordinary secondary education (O-Level) or higher. Most of the CHWs had prior experience using information technology, including smartphones (14, 93%), but fewer had previously used computers (8, 53%), or tablets (5, 33%). All fifteen CHWs had worked in a lay health worker role prior to joining the study.

In the interviews, CHWs emphasized how specific experiences with the fingerprinting technology affected their sense of identity, their interactions with household contacts, and their ability to carry out their work. These experiences informed CHWs' perceptions of the fingerprinting technology's ease of use and usefulness, two key determinants of intention to use, or acceptance, in the TAM2 model.

Idealized views of fingerprinting

CHWs described the usefulness of fingerprinting in an idealized way, reflecting many of the potential applications of fingerprinting that were introduced during training. CHWs consistently said they believed that fingerprinting would prevent duplicate enrollment and help identify patients who came for follow-up, even if they visited a different study facility.

> *"It's useful. I get to know exactly I am with the right patient. And if he has ever, for example you have so many facilities, maybe that patient has ever been to [a different health center], and they have ever scanned, so the scanner will refuse or it will tell me already the patient is in the system."*- Female (CHW6)

Even while acknowledging that the technology did not work perfectly, many CHWs said they believed that fingerprinting could be useful and should continue.

> *"Me I just wish [the use of fingerprinting] would continue and it could be stable, it could not stop, you know you go to the field and it stops, and you have to do restart, do things, it takes a lot of time. […] So me, I just wish in case [fingerprinting] continues, let us do those challenges so we can remove those."* – Female (CHW8)

By expressing a desire for fingerprinting to continue, despite substantial challenges with the technology, the CHWs revealed how much their perceptions of its potential usefulness were driven by their optimism to make it work.

Postitive and negative consequences of digital fingerprinting for the self-image of CHWs

The CHWs described their role in the community with pride. They said they felt that they were providing important services to their patients, whom they often referred to as "clients". However, fingerprint scanning had complicated implications for CHWs' self-image. CHWs explained that the technology could both elevate and threaten their social status. On one hand, fingerprint scanning represented an additional service they could offer to their clients, which elevated the capabilities they projected as CHWs. They perceived digital fingerprinting to be an important technology because it is associated with registering for a National ID and for identification at commercial banks. The excitement of getting to use this important technology in their work helped motivate the CHWs to learn and implement fingerprint scanning.

> *"So I was so excited, and I even asked myself, "Who am I, to be in this?" So, I put on my brains in there to really understand what is going to be done. And it took me only two days to get everything in the tablet because I was so attached to it, I wanted it so much."- Female (CHW12)*

On the other hand, when the CHWs struggled to use the fingerprinting technology in front of clients, they felt that their credibility was diminished.

> *"When you're 'printing someone and it fails? They just look at you like you don't know what you're doing."- Female (CHW13)*

CHWs placed high importance on their competence in carrying out contact investigation, and a failed fingerprinting attempt could damage one's credibility. Thus, CHWs perceived that the technology enhanced their social and professional status when it worked smoothly but threatened their status when it failed in the presence of a client.

Variable views on the need and appropriateness of digital fingerprinting

While CHWs generally acknowledged the need for some way to identify patients and contacts in order to carry out contact investigation, views were mixed regarding whether fingerprinting was necessary. These mixed opinions arose from different perceptions of the job relevance of fingerprinting, or the belief that fingerprinting is important to contact investigation. Some CHWs thought that fingerprinting could be the best way to uniquely identify people:

> *"[…] even if you give three names, someone might come with, another person might come with three names which are the same. Yet here the fingerprints identify the very person you want." – Female (CHW3)*

However, others suggested that the name, health center, patient identification number, signatures, photos, or voice recordings would suffice as alternatives. In practice, most CHWs described using some combination of name and other identifiers to identify contacts at follow-up, rather than using the fingerprint. One CHW distinguished between the usefulness of fingerprinting for identifying contacts versus index patients. He said that it was more useful for contacts, who are numerous and who come to the clinic months after the CHW meets them. Because index patients are fewer in number, sicker when the CHW meets them, and come back to the clinic often, the CHW felt that they were more memorable and that there was no need to rely on a fingerprint to identify them.

Impact of failures to capture fingerprints digitally

Even before interviewers asked about technology failures that prevented the successful capture of fingerprints, the CHWs repeatedly turned the discussion toward their experiences with technology failure. The CHWs linked the output quality, or how well the technology performed, to their perceptions of its usefulness. A small number of CHWs who reported never having issues with the technology described fingerprinting as being useful. Most CHWs, however, described an increase in technology failures over time, preventing them from capturing fingerprints and adding unnecessary time to the study procedures. When asked whether fingerprinting was useful and should continue in the future, almost all of these CHWs still responded yes, but only if it worked consistently and did not take too much time.

> *"It would be good, like I've told you, but the technical issues around it can make the work difficult." – Female (CHW9)*

Thus, the perceived usefulness of digital fingerprinting depended on it being reliable, fast, and free from technology problems.

Voluntary abandonment of digital fingerprinting

Most CHWs described instances when they chose to "bypass" the fingerprint scan during contact investigation enrollment; this option was built into the software to allow them to continue with the encounter even when fingerprint scanning failed. They did not indicate any negative impacts of failing to capture a fingerprint on contact investigation procedures. These descriptions suggest that result demonstrability was low and the effect of capturing a fingerprint was not tangible to the CHW.

> *"When it has refused. That's when I decide to go back and I bypass the fingerprint scanner, and I continue with my patients. I jump it and go to the next question." – Female (CHW5)*

CHWs described troubleshooting measures that they used when the fingerprint scanner failed: disconnecting and reconnecting the cable linking the scanner to the tablet, powering the tablet off and back on again, and asking a colleague for help. However, most CHWs said that they only attempted to troubleshoot one to three times before bypassing the fingerprint scan altogether. Whether a fingerprint was successfully captured or not did not seem to change the contact investigation procedures, in the view of CHWs.

Variable confidence in using the technology

CHWs differed in their perceptions of the ease of use of the technology, including the scanner itself and the tablet that they used to control the scanner. Some said that it was consistently easy to navigate through the application on the tablet and obtain a fingerprint using the scanner. Others described relying on colleagues or study staff for support when they had problems, which were frequent and which they came to anticipate.

> *"I'm expecting I will go and then I will call [the technology support officer] that this thing has blacked out. So it's expected. […] I don't think I'm the only one complaining about the scanner. They disturb us a lot." – Female (CHW9)*

This range of comfort with the technology was also reflected during the interview prompt exercise, in which the CHWs demonstrated the fingerprinting process. Some worked quickly while others were hesitant when navigating through the application; some were able to describe the process in their own words while others read directly from the text on the screen. Individuals' confidence using the tablet and scanner varied greatly.

Personal risks to health workers attributed to digital fingerprinting

CHWs described two forms of risk that they associated with digital fingerprinting and that influenced their perceptions of its ease of use. First, some CHWs worried about risk of infection through close contact with patients during the fingerprinting procedure, exacerbated by lack of adequate space and ventilation while performing fingerprinting.

> *When you're doing this and this [demonstrating placing fingers on the scanner], you're kind of getting closer to the patient who is HIV – I mean TB positive, so somehow you are risking. Just try to demonstrate, just try to put your finger here [on the scanner]. So as I'm a community health worker and you have to get closer to me, I'm also breathing in.* – Female (CHW9)

Second, CHWs said they worried about personal security when carrying the tablet and scanner to household visits. The risk of infection and lack of personal security introduced psychological and logistical challenges that the CHWs had to overcome in order to carry out fingerprinting.

Discussion

The inability to uniquely and accurately identify individuals in resource-constrained settings remains a major barrier to improving the quality of health information management and public health research. We found that digital fingerprint scanning was feasible but not reliable – failing to capture fingerprints in about one-quarter of cases – during household contact investigation for TB. Importantly, we found evidence that failures were tightly clustered by household, that they increased substantially over the course of the study, and that there were no systematic differences by clinical or demographic factors. The low rate of fingerprinting at follow-up suggests that CHWs saw little value in the digital fingerprinting system's usefulness as a verification tool. A rigorous qualitative analysis indicated that, despite the technology's inconsistent reliability, CHWs continued to accept digital fingerprinting, although accumulating experience with technology failures decreased their confidence in its usefulness in this setting.

The patterns of fingerprinting failures during the household visit pointed towards problems with the implementation of both software and hardware. Fingerprinting outcomes were almost completely clustered at the household level, suggesting that rather than being driven by sporadic, individual-level failures or refusals, the fingerprinting technology either worked or did not work on a given visit to a household. Furthermore, the predominance of software and hardware issues as explanations for failure and the modest clustering by CHW implies that technology failures were responsible rather than the skills of individual health workers. Finally, the significantly increasing trend of fingerprinting failures reflects the declining usefulness of the technology over time, whether due to health worker disengagement from the technology, software issues, hardware issues – or perhaps all three.

Previous studies have shown that CHWs without prior experience with digital fingerprinting describe the technology as acceptable in principle (van Heerden et al. 2017). However, we observed that CHWs' assessments of fingerprint scanning can change as they gain experience with the technology. We found that technology failures lowered CHWs' perception of the quality of the system, threatened CHWs' social image, and made the technology more difficult for CHWs to use. Although the technology worked as intended in the majority of interactions, workarounds and a lack of a tangible benefit of fingerprinting ultimately limited its job relevance and perceived usefulness among CHWs. After regular use, CHWs continued to express enthusiasm for fingerprint scanning in principle, but their intention to use the technology was tempered by perceptions that it was inconsistent and of questionable value, ultimately undermining their intention and usage behaviors.

Our findings add to a relatively limited literature on the use of digital fingerprinting for public health applications in sub-Saharan Africa. Our findings differ from a study of the same technology among female sex workers in Zambia, where digital fingerprinting was feasible for and acceptable to clients in the clinic setting, but not acceptable to clients in the field (Wall et al., 2015). Perhaps because participants were at greater risk for stigma or arrest and prosecution, the most common reasons for refusal related to clients' concerns about a potential loss of confidentiality and/or privacy. In contrast, we found that a majority of community members underwent fingerprinting during study registration without differences by demographic or clinical characteristics or documented refusals. Similar to a previous study of a mobile health tool for reporting adverse effects of treatments for drug-resistant TB in South Africa, we found that reported enthusiasm for technology – fingerprinting in this case – did not translate into usage (Chaiyachati et al, 2013). The acceptance of fingerprinting technology among CHWs serving these clients may decline if they experience technology failures during their work and may be more impactful in terms of its use than the perceived acceptability by community members.

Finally, the almost universal failure of lay health workers in our study to use digital fingerprinting at follow-up contrasts with the findings of a study of a biometric identification system for monitoring TB treatment in rural Uganda, which found that fingerprinting improved follow-up among patients engaged in daily directly-observed therapy at the clinic (Snidal, Barnard, Atuhairwe, & Ben Amor, 2015). A low background rate of follow-up in our study limited opportunities for digital fingerprinting for follow-up, and perhaps therefore its utility. In settings where digital fingerprinting has been shown to be feasible and acceptable, researchers should conduct larger, well-controlled studies to assess whether fingerprinting can be used as a tool for monitoring and as a way to increase adherence to follow-up through the development of feedback communications.

This study had a few limitations. First, incomplete data for household-level covariates such as income limited our ability to identify predictors of failure to capture fingerprints digitally, although the lack of reported refusals and the very small number of unattributable explanations for failure make patient factors an unlikely explanation. Second, we had limited data on the technical reasons for each fingerprinting failure. While we were able to categorize failures broadly as related to hardware or software problems, these groupings are not specific enough to guide improvement strategies. Detailed logs itemizing the circumstances of each fingerprinting failure should be included in future evaluations.

This study also had several strengths. First, the mixed-methods design enabled complementary analyses of the use of fingerprint scanning during household contact investigation for TB. The quantitative analysis tested associations between individual client characteristics and fingerprint failure, while the qualitative analysis explored the adoption of the technology by CHWs. Second, we were able to interview the entire CHW population involved in the study rather than relying on a sample. Third, we evaluated a multi-spectral fingerprinting technology integrated with and offered as a standard commercial product by a leading global health software platform, increasing generalizability.

The ability to accurately collect and link individual data to preserve privacy and enhance the generate quality measures for patients moving through complex care pathways should be a major global health priority (Davis JL et al, 2011). Despite the feasibility and acceptability of biometric identification methods as a means of bringing unique patient identification to resource-constrained settings, the technology we evaluated was not widely adopted by health professionals tasked with using it. As biometric technologies are increasingly introduced in resource-constrained health contexts, our findings point to the importance of real-time monitoring for quality assurance and evaluation. Evaluation techniques may include mixed-methods research with users that is grounded in theory, such as the TAM2 model. Mixed-methods data may guide iterative improvements to hardware, software, and the user interface to ensure that the technology aligns with tasks that users find useful and important, and engages health workers so that they voluntarily apply the technology to improve the experience of patients. Future studies should also consider whether detailed process evaluation using mixed methods can be applied to other biometric technologies.

TABLES AND FIGURES

Figure 1: Technology Acceptance Model 2 (TAM2), Adapted from Venkatesh and Davis 2000

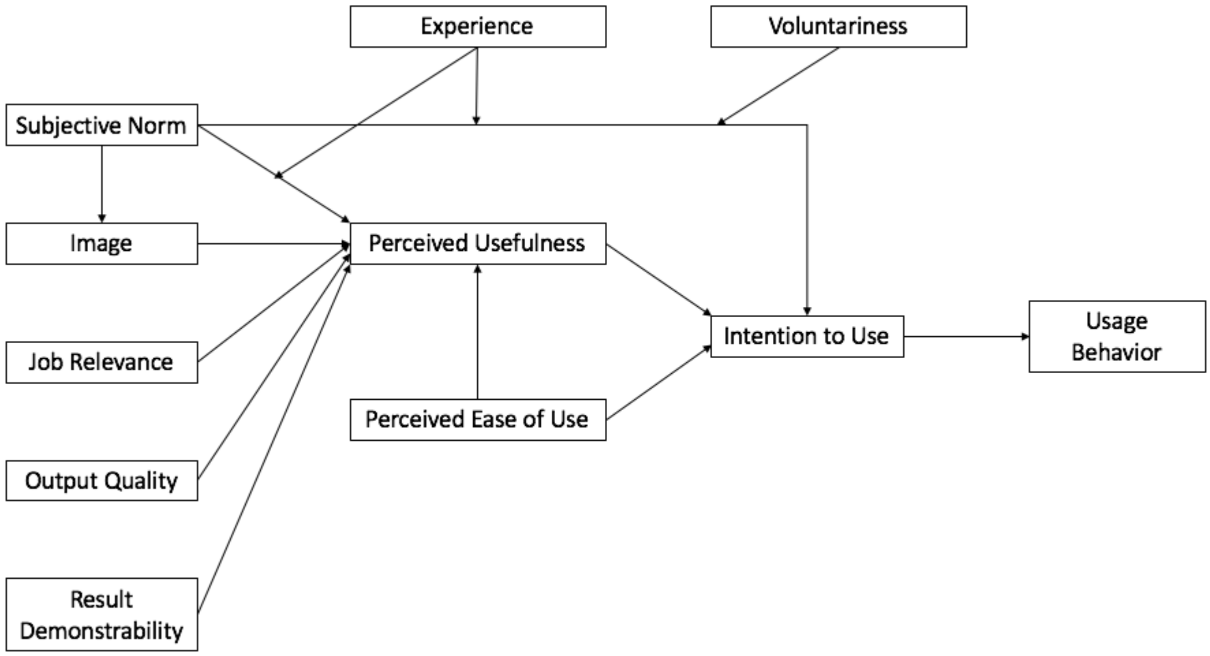
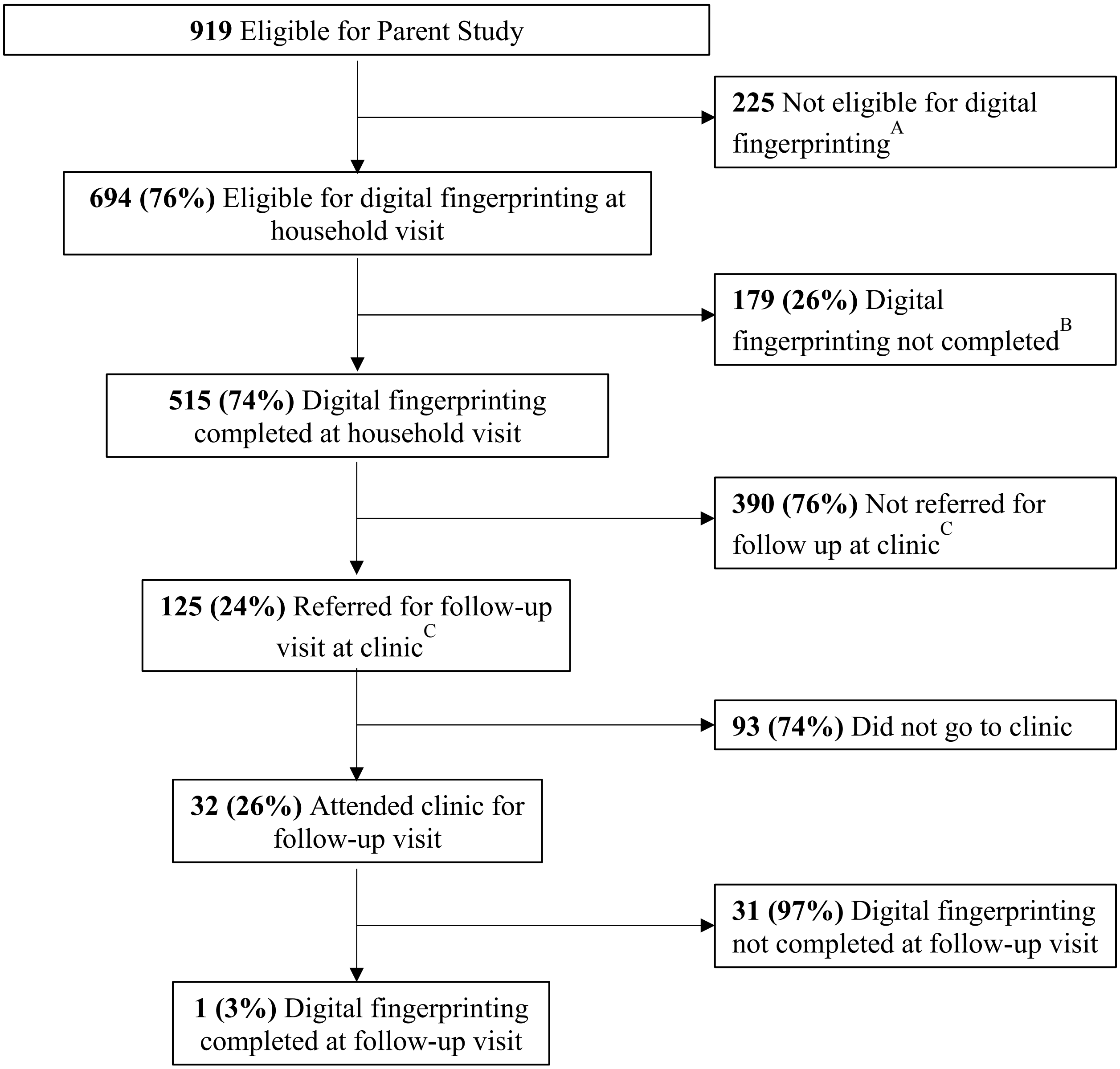


Figure 2: Flow diagram showing enrollment of household contacts



[A] Children under the age of 5 were not eligible for digital fingerprinting.

[B] 108 (60.3%) fingerprint scan failures were classified as software problems, 65 (36.3%) as hardware problems, and 6 (3.4%) as unclassified problems.

[C] Those referred for follow up evaluation at the clinic included contacts who were persons living with HIV; contacts who had TB symptoms but did not produce a sputum sample at the household visit; and those who had an inconclusive diagnostic result for sputum collected during the home visit. All others were not referred for a follow-up visit.

Table 1: Characteristics of Study Participants (n=694)

Characteristic **n (%)**	**Fingerprint Scan** **(n=515)**	**No Fingerprint Scan** **(n=179)**	**p-value[A]**
Age			
Children 5-14 years	162 (31)	59 (33)	0.56
Adults 15 and older	353 (69)	120 (67)	
Sex (%)			
Female	336 (65)	108 (60)	0.83
Male	179 (35)	71 (40)	
Proportion living with HIV (%)			
Positive	41 (8)	17 (9)	0.87
Negative or Unknown	474 (92)	162 (91)	

Legend: [A]Corrected for clustering of fingerprint scan outcomes by household with robust standard errors.

REFERENCES

Beck, E. J., Shields, J. M., Tanna, G., Henning, G., de Vega, I., Andrews, G., … Low-Beer, D. (2018). Developing and implementing national health identifiers in resource limited countries: why, what, who, when and how? *Global Health Action*, *11*(1), 1440782. https://doi.org/10.1080/16549716.2018.1440782

Chaiyachati KH, Loveday M, Lorenz S, Lesh N, Larkan L-M, Cinti S, Friedland GH, Haberer JE. (2013) A Pilot Study of an mHealth Application for Healthcare Workers: Poor Uptake Despite High Reported Acceptability at a Rural South African Community-Based MDR-TB Treatment Program. PLOS ONE. 8(5):e64662.

Davis, F. D. (1989). Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly*, *13*(3), 319–340. Retrieved from http://links.jstor.org/sici?sici=0276-7783%28198909%2913%3A3%3C319%3APUPEOU%3E2.0.CO%3B2-E

1Davis JL, Katamba A, Vasquez J, Crawford E, Sserwanga A, Kakeeto S, Kizito F, Dorsey G, den Boon S, Vittinghoff E, Huang L, Adatu F, Kamya MR, Hopewell PC, Cattamanchi A. (2011) Evaluating tuberculosis case detection via real-time monitoring of tuberculosis diagnostic services. Am J Respir Crit Care Med. 184(3):362-7. PMID: 21471088; PMCID: 3175538.

e-Compliance – Operation ASHA. (2016). Retrieved May 31, 2018, from http://www.opasha.org/2016/09/20/ecompliance-biometric-tracking-system/

Fishbein, M., & Ajzen, I. (1975). *Belief, Attitude, Intention, and Behavior: An Introduction to Theory and Research*. Reading, MA: Addison-Wesley. Retrieved from http://people.umass.edu/aizen/f&a1975.html

Harichund, C., Haripersad, K., & Ramjee, G. (2013). Participant verification: Prevention of co-enrolment in clinical trials in South Africa. *South African Medical Journal*, *103*(7), 491. https://doi.org/10.7196/SAMJ.6674

Holden, R. J., & Karsh, B.-T. (2010). The technology acceptance model: its past and its future in health care. *Journal of Biomedical Informatics*, *43*(1), 159–72. https://doi.org/10.1016/j.jbi.2009.07.002

Jain, A. K. (2007). Are biometric techniques the future of personal identification? *Nature*, *449*, 38–40. Retrieved from https://www.nature.com/articles/449038a.pdf

Jain, A. K., Arora, S. S., Cao, K., Best-Rowden, L., & Bhatnagar, A. (2016). Fingerprint Recognition of Young Children. *Technical Report, Michigan State University*. Retrieved from http://biometrics.cse.msu.edu/Publications/Fingerprint/Jainetal_ChildFingerprintRecognition_TechRep_MSU-CSE-16-5.pdf

Joint Research Centre of the European Commission. (2013). *Fingerprint Recognition for Children*. https://doi.org/10.2788/3086

Moore, G. C., & Benbasat, I. (1991). Development of an Instrument to Measure the Perceptions of Adopting an Information Technology Innovation. *Information Systems Research*, *2*(3), 192–222. https://doi.org/10.1287/isre.2.3.192

Moore, G. F., Audrey, S., Barker, M., Bond, L., Bonell, C., Hardeman, W., … Baird, J. (2015). Process evaluation of complex interventions: Medical Research Council guidance. *BMJ (Clinical Research Ed.)*, *350*, h1258. https://doi.org/10.1136/BMJ.H1258

Odei-Lartey, E. O., Boateng, D., Danso, S., Kwarteng, A., Abokyi, L., Amenga-Etego, S., … Owusu-Agyei, S. (2016). The application of a biometric identification technique for linking community and hospital data in rural Ghana. *Global Health Action*, *9*, 29854. https://doi.org/10.3402/gha.v9.29854

Serwaa-Bonsu, A., Herbst, A. J., Reniers, G., Ijaa, W., Clark, B., Kabudula, C., & Sankoh, O. (2010). First experiences in the implementation of biometric technology to link data from Health and Demographic Surveillance Systems with health facility data. *Global Health Action*, *3*. https://doi.org/10.3402/gha.v3i0.2120

Simoni, J. M., Beima-Sofie, K., Amico, K. R., Hosek, S., Johnson, M. O., & Mensch, B. (2017). Can "Debrief" Reports Expedite Qualitative Studies? In *Adherence*. Miami, FL. Retrieved from https://www.hanc.info/Documents/4_Adherence 2017 Qual Debrief poster_27 May 2017 kra

JMS-KBS SH JMS_submitted.pdf
Snidal, S. J., Barnard, G., Atuhairwe, E., & Ben Amor, Y. (2015). Use of eCompliance, an innovative biometric system for monitoring of tuberculosis treatment in rural Uganda. *The American Journal of Tropical Medicine and Hygiene*, *92*(6), 1271–9. https://doi.org/10.4269/ajtmh.14-0413
SonLa Study Group, T. S. S. (2007). Using a fingerprint recognition system in a vaccine trial to avoid misclassification. *Bulletin of the World Health Organization*, *85*(1), 64–7. https://doi.org/10.2471/blt.06.031070
van Heerden, A., Harris, D. M., van Rooyen, H., Barnabas, R. V., Ramanathan, N., Ngcobo, N., … Comulada, W. S. (2017). Perceived mHealth barriers and benefits for home-based HIV testing and counseling and other care: Qualitative findings from health officials, community health workers, and persons living with HIV in South Africa. *Social Science & Medicine*, *183*, 97–105. https://doi.org/10.1016/J.SOCSCIMED.2017.04.046
Venkatesh, V., & Davis, F. D. (2000). A Theoretical Extension of the Technology Acceptance Model: Four Longitudinal Field Studies. *Management Science*, *46*(2), 186–204. Retrieved from http://www.jstor.org/stable/2634758
Wall, K. M., Kilembe, W., Inambao, M., Chen, Y. N., Mchoongo, M., Kimaru, L., … Allen, S. A. (2015). Implementation of an electronic fingerprint-linked data collection system: a feasibility and acceptability study among Zambian female sex workers. *Globalization and Health*, *11*(1), 27. https://doi.org/10.1186/s12992-015-0114-z
Weibel, D., Schelling, E., Bonfoh, B., Utzinger, J., Hattendorf, J., Abdoulaye, M., … Zinsstag, J. (2008). Demographic and health surveillance of mobile pastoralists in Chad: integration of biometric fingerprint identification into a geographical information system. *Geospatial Health*, *3*(1), 113. https://doi.org/10.4081/gh.2008.237