Vaccine xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Vaccine

journal homepage: www.elsevier.com/locate/vaccine

Review

Use of m-Health in polio eradication and other immunization activities in developing countries

Sara S. Kim *, Manish Patel, Alan Hinman

Task Force for Global Health, Atlanta, GA, USA

ARTICLE INFO

Article history:
Received 3 October 2016
Received in revised form 16 January 2017
Accepted 20 January 2017
Available online xxxx

Keywords:
mHealth
Mobile health
Vaccine
Immunization

ABSTRACT

Introduction: Reaching the children that are chronically missed by routine immunization services has been a key pillar of success in achieving progress toward polio eradication. The rapid advancement and accessibility of mobile technology (“mHealth”) in low and lower middle income countries provides an important opportunity to apply novel, innovative approaches to provide vaccine services. We sought to document the use and effectiveness of mHealth in immunization programs in low and lower middle income countries. We particularly focused on mHealth approaches used in polio eradication efforts by the Global Polio Eradication Initiative (GPEI) to leverage the knowledge and lessons learned that may be relevant for enhancing ongoing immunization services.

Methods: In June 2016, the electronic database PubMed was searched for peer reviewed studies that focused on efforts to improve immunization programs (both ongoing immunization services and supplemental immunization activities or campaigns) through mobile technology in low and lower middle income countries.

Results: The search yielded 317 papers of which 25 met the inclusion criteria. One additional article was included from the hand searching process. mHealth was used for reminder and recall, monitoring and surveillance, vaccine acceptance, and campaign strategic planning. Mobile phones were the most common mobile device used. Of the 26 studies, 21 of 26 studies (80.8%) reported that mHealth improved immunization efforts.

Conclusion: mHealth interventions can effectively enhance immunization services in low and lower middle income countries. With the growing capacity and access to mobile technology, mHealth can be a powerful and sustainable tool for enhancing the reach and impact of vaccine programs.

Contents

* Corresponding author.
E-mail address: saraskim12@gmail.com (S.S. Kim).

http://dx.doi.org/10.1016/j.vaccine.2017.01.058
0264-410X/

1. Introduction

Infectious diseases are major causes of morbidity and mortality worldwide. Although immunization already averts some 2–3 million deaths annually, the World Health Organization (WHO) estimates that an additional 1.5 million deaths could be avoided per year if vaccine coverage improves globally. In 2015, an estimated 19.4 million infants worldwide (nearly one out of five) failed to receive the most basic childhood immunizations [1]. In 2015, WHO's Strategic Advisory Group of Experts identified several factors that would reduce these gaps in coverage including improving quality and use of data, community involvement, access to immunization services for marginalized and displaced populations, strengthening health systems, and securing and sustaining supply of vaccines at all levels. Given the rapid advancement, increased accessibility, and improved capacity of mobile technology in low and lower middle income countries, it is ethical and necessary to take advantage of mobile health (mHealth[1]) to address these factors and to increase global vaccine coverage. The need is more urgent in low and lower middle income countries [2]. Of those missing vaccines, most live in low and lower middle income countries with more than 60% living in the following 10 countries: Angola, the Democratic Republic of Congo, Ethiopia, India, Indonesia, Iraq, Nigeria, Pakistan, the Philippines, and Ukraine [1]. Mobile technology has the potential to help alleviate the remaining burden caused by vaccine preventable diseases.

As access to mobile technology continues to grow, mHealth's potential to enhance immunization programs also increases. Worldwide, 95% of the population now lives in an area with access to a mobile-cellular network while mobile-broadband subscriptions have grown at double digit rates in developing countries [3]. mHealth's capacity to reduce human error, expedite tasks, and expand an intervention's reach can provide researchers and program managers with the tools needed to address challenges that thwart the progress of immunization programs. mHealth may be an important component of enhancing access to immunization services, data quality and use, and identification of marginalized populations [1].

The purpose of this review is to determine both how mHealth has been used thus far in immunization programs and whether these initiatives have been effective tools for improving immunization programs in low and lower middle income countries. Reaching the children that are chronically missed by routine immunization services has been a key pillar of success in achieving progress toward polio eradication. Thus, we particularly focused on mHealth approaches used in polio eradication efforts by the Global Polio Eradication Initiative (GPEI) to leverage the knowledge and lessons learned that may be relevant for enhancing routine immunization services.

2. Methods

In June 2016, the electronic database PubMed was searched for peer reviewed studies that focused on efforts to improve immunization programs (both ongoing immunization services and supplemental immunization activities or campaigns) through mobile technology in low and lower middle income countries. The key search terms included (cell phone OR cell phones OR mobile phone OR mobile phones OR "mhealth" OR telemedicine OR text message OR sms message OR personal technology OR telehealth OR "ehealth" OR digital health OR ICT OR mobile device) AND (immunization OR immunized OR immunize OR vaccination OR vaccine). A filter that limited the results to studies published within the last 10 years was applied to acknowledge rapid development and implementation of new technologies. Additionally, we hand searched the references section of each eligible paper for relevant articles that may not have emerged in the search term results.

Studies that mentioned a mobile technology and its impact on immunization were included (Fig. 1). Both the title and abstract of each search term result were scanned for eligibility. Common reasons for excluding studies included using technology that was not mobile or use of mobile technology for purposes other than immunization. Articles that did not involve a low or lower middle income country (as defined by the World Bank [4]), or were not complete were also excluded from this review.

3. Results

3.1. General characterizations of included publications

The search yielded 317 papers of which 26 met the inclusion criteria (Fig. 1). One additional article was identified through the hand searching process. Mobile phones were the most common mobile device used among these studies with 21 out of 26 studies using mobile phones, 3 using mobile tablets, 1 using a personal digital assistant (PDA), and 1 unspecified.

Of the 26 studies, 21 (80.8%) reported that mHealth improved immunization efforts (Table 1); 4 studies reported no significant impact as a result of using mobile technology while 1 study found that the standard intervention was more effective than the mHealth intervention. While most studies provided evidence that mHealth is an effective strategy to improve immunization programs, authors generally suggested that studies on larger scale should be conducted before widespread implementation of these initiatives and that external factors not corrected for could have contributed to the reported outcomes.

Among the 26 studies, mHealth was used for reminder and recall (n = 8), monitoring and surveillance (n = 7), campaign strategic planning (n = 5), and vaccine acceptance (n = 1). Five studies were literature reviews on similar but not identical topics. The results of these studies are summarized in Table 1.

3.2. Reminder and recall

Vaccination reminder and recall text messages to patients or mother of patients was the most common use of mHealth (Table 1). The purpose of using mHealth for reminder and recall was not only to increase vaccination coverage overall but also to reduce vaccination delays. Of the eight reminder recall specific studies, eight found that the mHealth intervention increased vaccination coverage [5–11]. A Guatemalan study found a non-significant increase in vaccine coverage among study participants [30]. Additionally, all 4 studies that mentioned timely vaccination found that the text

[1] The World Health Organization defines mHealth as the use of "mobile technologies and their advancements in their innovative application to address health priorities." (WHO 2011).

Please cite this article in press as: Kim SS et al. Use of m-Health in polio eradication and other immunization activities in developing countries. Vaccine (2017), http://dx.doi.org/10.1016/j.vaccine.2017.01.058

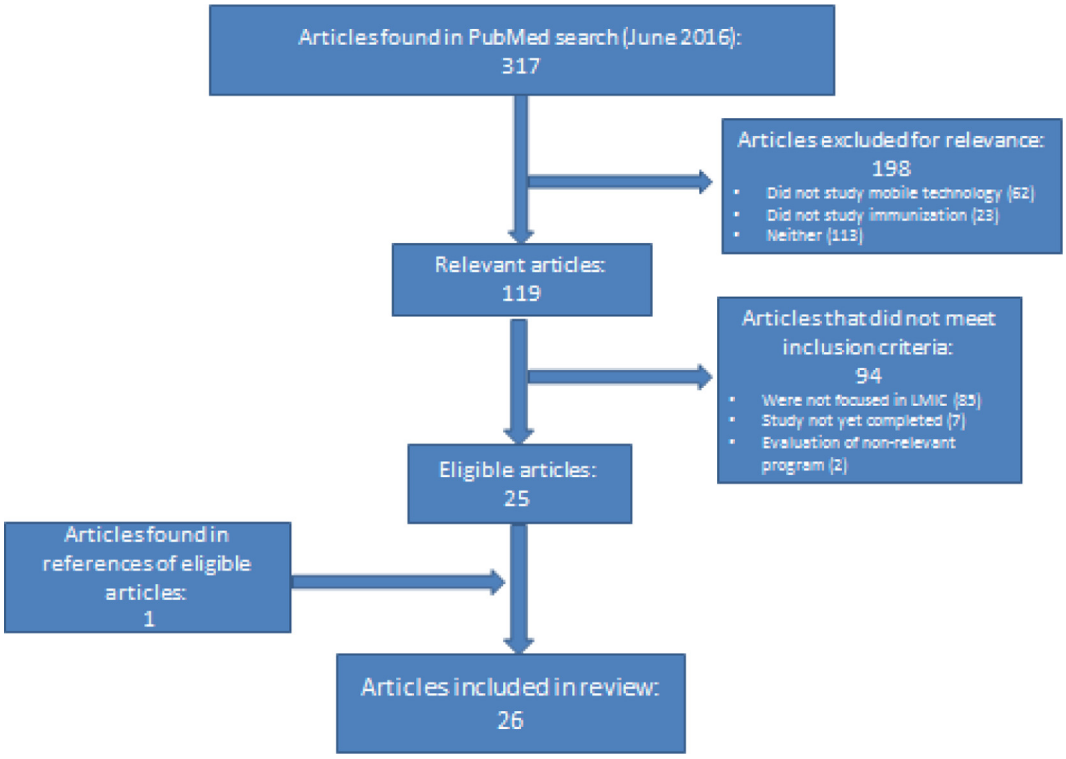

Fig. 1. Flow diagram of article identification for inclusion.

message reminders increased on-time vaccinations [5,7,8,11]. Sending SMS text reminders for vaccination was an effective and low cost strategy for bringing children into clinics to receive their immunizations on time [5–14,28].

3.3. Monitoring and surveillance

The review demonstrated that mobile technology may have important applications in monitoring and surveillance of immunization related activities (Table 1). Researchers used bidirectional text messaging to collect data on adverse events following immunization (AEFI) by sending study participants a text message that prompted a response. One study found that in-person visits were more effective than text messages for gathering responses, while another study found that texting was an effective tool for active surveillance of adverse events [15,16]. In Kenya, researchers utilized geospatial mapping of mobile phone signals to monitor the mobility of local populations and found that mobile populations with frequent travel were the least likely to receive vaccines [17]. mHealth was also used for recording of general data collection including information collected during surveys. Two studies that focused on general data collection related to vaccines found that there was no significantly different error rate between electronic data collection and standard data collection [18,19]. A study in Tanzania found that using personal digital assistants enhanced data collection by providing accurate, real time data from registration and surveys during the oral cholera mass vaccination campaign [20]. On the Myanmar-Laos-Thailand border, data collected that could be shared from one mobile phone to another proved to be an effective strategy for identifying and reaching vulnerable populations and improving childhood immunization [21].

3.4. Campaign strategic planning

Five studies that involved polio, cholera, and measles campaigns applied mHealth to improve the organization and planning for mass vaccine campaigns (Table 1). Electronic data collection for pre-campaign surveys helped identify areas that were missed by previous campaigns and establish a strategy for isolated communities [22–26]. In one study from Haiti, geospatial mapping of campaign activity proved to be a useful tool for campaign strategy planning [23]. Investigators successfully mapped each vaccine post and overlapped the information with the population size and vaccine coverage of the targeted area to create a visual analysis for campaign planning [23].

3.5. Vaccine acceptance

One paper aimed to bring about higher rates of vaccine acceptance (Table 1). In Nigeria, an audio-visual video clip on vaccine safety that was shared via blue tooth paired mobile phones [27]. Although the authors could not determine whether the increased acceptance of the oral polio vaccine was attributed to the video alone, they did find that the video was shared over 100 times per day [27].

4. Discussion

The growing global access to technology and widespread mobile connectivity offer a tremendous opportunity for the immunization community to leverage these efforts to improve and sustain immunization services, particularly for populations currently not reached and at the highest risk of vaccine preventable diseases. Our review illustrates the capacity of mHealth to address a wide array of challenges and improve several components of immunization programs in developing countries – improving reminder and recall, planning campaigns and outreach, and enhancing monitoring and surveillance. With the broad range of available technologies, immunization programs are likely faced with the challenge of determining the most efficient and effective mHealth approaches for improving and sustaining vaccine coverage. Implementation of mobile technologies that improve patient records and

Please cite this article in press as: Kim SS et al. Use of m-Health in polio eradication and other immunization activities in developing countries. Vaccine (2017), http://dx.doi.org/10.1016/j.vaccine.2017.01.058

Table 1
Summary of results.

First Author	mHealth Use	Location	Date	Vaccine(s)	Mobile Device	Result
Haji A	Reminder and Recall	Kenya	16-Feb-16	Pentavalent	Mobile phone – SMS text	Vaccine coverage was significantly higher in the intervention group. (OR 0.2, CI 0.04, 0.8)
Uddin MJ	Reminder and Recall	Bangladesh	4-Jan-16	BCG, Pentavalent, MR	Mobile phone – SMS text	Vaccine coverage increased 18.8% in rural areas and 16.5% in urban areas
Schlumberger M	Reminder and Recall	Burkina Faso	Dec-15	EPI immunizations	Mobile phone – SMS text	Significant increase in vaccine coverage and quickness to come
Bangure D	Reminder and Recall	Zimbabwe	12-Feb-15	OPV, Pneumococcal, Pentavalent	Mobile phone – SMS text	Vaccine coverage (97% v 82.0% at 6 weeks old, 95.0% v 75.0% at 14 weeks old) and quickness to come (82.0% v 8.0% did not delay at 14 weeks) were significantly higher in intervention group
Wakadha H	Reminder and Recall	Kenya	30-Jan-13	Pentavalent	Mobile phone – SMS text	91.0% of mothers reported that text reminder influenced them to bring child in for immunization
Lund S	Reminder and Recall	Tanzania	Jan-13	Tetanus	Mobile phone – SMS text	44.0% of women in intervention group received antenatal care v. 31.0% in the control group
Kaewkungwal J	Reminder and Recall	Myanmar-Thailand border	3-Nov-10	BCG, Hep B, DTP, OPV, MMR, Japanese Encephalitis	Mobile phone – SMS text	44.2% of children received vaccines on time v 34.5% before the intervention
Domek GJ	Reminder and Recall	Guatemala	5-May-16	Pentavalent, Pneumococcal, Polio, Rotavirus	Mobile phone – SMS text	SMS text reminders led to a non-significant increase in percentage of children with complete immunization (90.1% to 95.0%)
Ateudjieu J	Monitoring and Surveillance	Cameroon	29-Sep-14	Meningitis	Mobile phone – SMS text	In-person visits were more effective than SMS texts in monitoring adverse events following immunization
Baron S	Monitoring and Surveillance	Cambodia	16-Apr-13	Not specified	Mobile phone – SMS text	Bidirectional text messaging is an effective tool for monitoring AEFIs with 71.7% response rate
Wesolowski A	Monitoring and Surveillance	Kenya	Mar-15	Childhood immunization schedule vaccines	Mobile phone – anonymous phone data to track travel patterns	High correlation between immunization and average radius of gyration ($p = 0.03$)
Giduthuri JG	Monitoring and Surveillance	India	18-Sep-14	Influenza	Tablet – electronic survey	Error rates between standard method (2.01%) and tablet (1.99%) were not significantly different
Kazi AM	Monitoring and Surveillance	Pakistan	1-Mar-14	Polio	Mobile phone – SMS text	Data collected on vaccine coverage through SMS text were similar to data collected by phone interviews (See Table 1 in original article)
Ali M	Monitoring and Surveillance	Tanzania	10-Jul-10	Cholera	Personal Digital Assistant (PDA) – electronic survey	PDAs provided point of contact digital data that could be quickly summarized and prepared to analyze. No data were lost
Kaewkungwal J	Monitoring and Surveillance	Myanmar-Thailand border	14-Jan-15	BCG, Hep B, DTP, OPV, MMR, Japanese Encephalitis	Tablet – electronic survey	After implementing tablets for data collection, 44.22% of children were recorded to receive immunizations on time compared to 34.49% ($p < 0.001$)
Haskew J	Campaign Planning	South Sudan	7-Aug-15	Polio	Mobile phone – Geomapping and electric survey	Pre-campaign surveys with geocoding helped recognize, visualize, and analyze previously missed areas
Teng JE	Campaign Planning	Haiti	31-Jul-14	Reactive oral cholera	Tablet – geospatial mapping	Facilitated timely analysis of campaign's reach and establish vaccine strategy for isolated communities
Touray K	Campaign Planning	Nigeria	25-Nov-15	Polio	Mobile Phone - GPS	Tracking campaign activity through GPS led to an overall decrease in missed settlements with Kano, the biggest state of 7 states included, decreasing missed settlements by 1133 settlements
Brown AE	Campaign Planning	Nigeria	1-Nov-14	Polio	Mobile Phone – Geomapping and electronic survey	No loss of data and less than 1% error rate. Helped visualize on map where data was collected which could facilitate SIAs and improved quality of SIAs
Mbabazi WB	Campaign Planning	Kenya	Jun-15	Measles	Mobile Phone – electronic survey	Technology provided real time data that helped shape campaign strategy
Birukila G	Vaccine Acceptance	Nigeria	21-Mar-16	Polio	Mobile phone – Bluetooth pairing	Vaccine coverage increased by roughly 100.0% after mobile sharing of health video but unclear if causal. Also Bluetooth pairing of devices allowed widespread transmission of video

Table 1 (*continued*)

First Author	mHealth Use	Location	Date	Vaccine(s)	Mobile Device	Result
Watterson J	Review	LMIC	25-Aug-15	N/A	Mobile Phone – SMS text	All studies included in review indicate some evidence that text or voice messages can influence positive behavior towards vaccines
Sondaal SF	Review	LMIC	4-May-16	N/A	Mobile phone – multiuse	mHealth interventions increased maternal and neonatal service utilization shown through increased vaccination and other factors such as decreased morbidity and mortality for infants and mothers
Hartzler A	Review	LMIC	15-Aug-14	N/A	Mobile phone – multiuse	mHealth is overall successful in increasing vaccine coverage, screenings, and other preventative measures, but not universally due to remaining infrastructural challenges in LMICs
Poorman E	Review	N/A	May-15	N/A	Mobile phone – SMS text	Effective for promoting preventative behaviors such as adherence to medication, decrease in appointment delay, and appointment reminder towards hard to reach populations due to the growing popularity of SMS text use
Tozzi AE	Review	N/A	8-Mar-16	N/A	Not specified	Only small progresses have been made to incorporate digital tools into immunization programs despite evidence that they can greatly enhance immunization programs

reminders have shown to increase vaccination in both routine vaccine and mass campaign settings [28]. On the basis of the published literature, limited progress has been made to assess the impact of mobile technologies on immunization services in developing countries on a large scale [29]. With the majority of (smaller scale) studies in this review demonstrating the positive impact of mHealth technologies, researchers and program managers should explore how to use these innovations to improve vaccine coverage on a large scale in low resource settings.

Geospatial mapping proved to be an innovative approach for enhancing surveillance and campaign planning. In a study tracking mobile populations through anonymous cellular phone data, the authors determined that geospatial mapping could identify vulnerable populations who lack access to vaccinations [17]. Such strategies could be applied to prompt local public health officials to adapt immunization strategies for capturing difficult to access and mobile populations. Similarly, electronic pre- and post- campaign surveys with mapping identify chronically missed areas that shape the trail of the campaign and help visualize the reach of the campaign.

Utilizing mHealth for data collection provides valuable real time data that public health officials can use for programs and responding to challenges. Although accuracy was similar, using mobile technology for surveillance and monitoring provides more convenient and expedited data collection and analysis compared to standard paper-based systems [13,18,19]. Furthermore, real time data can help shape campaign delivery strategy depending on the results of pre-campaign surveys [22,25,26].

Although data are limited, mHealth may also serve as a useful tool for influencing vaccine acceptance to sustain and close gaps in immunization coverage. By providing positive messages directly to people's mobile devices through messaging and Bluetooth pairing, people have immediate access to information that may influence their decision to partake in vaccine activities [27]. The strategies that the studies used to promote vaccine acceptance may additionally be useful for disseminating health information through mobile technology. Sending text or video messages directly to mobile phones to alert upcoming vaccine activities or spread positive health information could help recipients retain the information better compared to mass broadcasts [9]. Even persons who do not own mobile phones often have immediate access to one, highlighting that spreading important information through mobile phones can be extremely effective [9]. Mobile technology also has the benefit of facilitating social outreach in addition to traditional approaches such as village meetings to display videos on non-mobile devices (such as television or screens). Sharing of videos on mobile phones via bluetooth pairing may prove to be an effective strategy for spreading display of health information rapidly and efficiently [27].

The tragic reemergence of wild polio virus in Nigeria in August 2016 highlights the urgent need to apply new innovations towards the global fight against polio. The five studies that solely focused on enhancing polio programs demonstrate the capacity to utilize these technologies in the field [19,22,24,25,27]. Using mobile devices equipped with geospatial mapping technologies for pre- and post- campaign evaluations shows promise in reducing chronically missed communities, identifying where people are most vulnerable to the disease [22,24,25]. Additionally, a Nigerian study that aimed to combat negative attitudes towards polio vaccine showed that Bluetooth pairing technology can be an effective method for spreading health information. This use of mHealth could influence vaccine acceptance and serve as an additional strategy for informing communities of upcoming vaccination activities to reduce missed opportunities for immunization [27]. The new wild polio cases in Nigeria could be a result of previous campaigns missing hard to reach communities, but m-Health

Please cite this article in press as: Kim SS et al. Use of m-Health in polio eradication and other immunization activities in developing countries. Vaccine (2017), http://dx.doi.org/10.1016/j.vaccine.2017.01.058

may provide new strategies to ensure children like these are not missed again.

5. Limitations

Though widely improving, remaining challenges in mobile technology access may hinder mHealth uptake. Studies have identified a growing capacity for health workers in developing countries to adapt and use smartphones for health related interventions as well as a variable willingness to abandon their old system to a new one [6,11]. However, unreliable or spotty networks may be a barrier in remote settings [21–25]. Some of the examples where connectivity issues impeded vaccine activity efforts include settings where more than one-half of households at a site did not have GPS coordinates for geospatial mapping and campaign planning. In addition, time consuming data transfer from mobile device to web-based databases, and text messages not reaching recipients, can impede success [22,23]. The impact of mHealth may also be inflated as a result of potential bias for the demographic of people who have mobile phones and respond to text messages. One study reported ownership of mobile phones was biased towards wealthier, urban-dwelling males [17]. Another found that texting was not a popular feature for mobile phone owners in that region and that those who were more likely to know how to send text messages were more likely to be affluent, young, and well-educated [16]. These issues and biases are dissipating and likely to become less important over time [17].

Although the most studied and perhaps the most simplistic use of mHealth in immunization programs, sending text messages in mass volumes in low and lower middle income areas raises specific challenges. If a mother takes her child to different clinics for different doses, some doses may be left out of the reminder/recall message sent [9]. Additionally, not all people in a given area speak the same language, and mass text messages sent to the local population must accommodate that diversity [8]. One study reported that it could not verify whether or not a text message was actually received, only if it was sent [30]. This issue could be resolved if a bidirectional system was implemented.

The findings in this review may not accurately represent the full global impact of m-Health on immunization programs due to the limited number of studies included in this review. The absence of grey literature and limiting the search to one electronic database may have contributed to the small yield of studies and the relative heterogeneity of outcomes. Furthermore, excluding studies that did not focus on LMICs greatly reduced the number of relevant studies that otherwise met the inclusion criteria. Additionally, the results may have been biased towards mobile phone interventions because it was the only mobile technology that was specifically named in the search terms.

We must treat the conclusions of these studies with caution due to unforeseen factors that may have contributed to the results. In some instances, other factors aside from mHealth were reported as potential confounders but not controlled for. In the Kenyan study that analyzed the impact of SMS reminders and conditional cash transfers on immunization, the investigators did not control for the cash transfer incentive so that we could evaluate the impact of mHealth on immunization alone [9].

Finally, comparing the quantitative impact of mHealth across studies was difficult because the investigators used different methods to analyze their data, including percent changes, odds ratios, p-values, and crude estimates. Some authors also reported qualitative results regarding mobile technologies, citing their experiences with mHealth to describe its impact. Several investigators used mHealth to collect data for their studies on immunization and anecdotally reported how effective or feasible it was for such purposes but did not necessarily report changes before and after the use of mHealth to enhance their research.

6. Conclusions and recommendations

mHealth interventions that aim to improve immunization programs can effectively provide greater access to vaccine services. Educational activities surrounding mHealth can empower the health community to utilize mobile technology to their fullest potential. Strategies for network security and personal identification protection should be researched and implemented to prevent security concerns when expanding mHealth interventions. Our review of the literature demonstrates that with the growing capacity and access to mobile technology, mHealth is a powerful and sustainable tool for enhancing the reach and impact of vaccine programs.

Financial interest

The authors do not have a financial or proprietary interest in a product, method, or material or lack thereof.

Funding

AH and MMP were supported by a grant from the Bill & Melinda Gates Foundation (Grant OPP1095024).

Conflicts of interest

The authors declare that there are no conflicts of interest.

The findings and conclusions of this report are those of the authors and do not necessarily represent the official positions of the Task Force for Global Health.

Previous presentation

None.

Contributors

Sara S. Kim (evaluation of study eligibility, drafting of the article); Manish Patel (revising of article for critically important intellectual content and final approval of the version to be published); Alan Hinman (revising of article for critically important intellectual content and final approval of the version to be published).

References

[1] World Health Organization. WHO | Immunization coverage. <http://www.who.int/mediacentre/factsheets/fs378/en/>; July 2016.
[2] WHO, UNICEF, World Bank. State of the world's vaccines and immunization, 3rd ed. Geneva, World Health Organization; 2009.
[3] International Telecommunication Union, ICT Facts and Figures 2016; June 2016.
[4] The World Bank. Low and Middle Income. <http://data.worldbank.org/income-level/low-and-middle-income>.
[5] Haji A, Lowther S, Ngan'ga Z, Gura Z, Tabu C, Sandhu H, et al. Reducing routine vaccination dropout rates: evaluating two interventions in three Kenyan districts, 2014. BMC Public Health 2016;16:152. http://dx.doi.org/10.1186/s12889-016-2823-5.
[6] Uddin MJ, Shamsuzzaman M, Horng L, Labrique A, Vasudevan L, Zeller K, et al. Use of mobile phones for improving vaccination coverage among children living in rural hard-to-reach areas and urban streets of Bangladesh. Vaccine 2016;34(2):276–83. http://dx.doi.org/10.1016/j.vaccine.2015.11.024.
[7] Schlumberger M, Bamoko A, Yaméogo TM, Rouvet F, Ouedraogo R, Traoré B, et al. Positive impact on the expanded program on immunization when sending call-back SMS through a computerized immunization register, Bobo Dioulasso (Burkina Faso). Bull De La Société De Pathologie Exotique (1990) 2015;108(5):349–54. http://dx.doi.org/10.1007/s13149-015-0455-4.

[8] Bangure D, Chirundu D, Gombe N, Marufu T, Mandozana G, Tshimanga M, et al. Effectiveness of short message services reminder on childhood immunization programme in Kadoma, Zimbabwe – a randomized controlled trial, 2013. BMC Public Health 2015;15:137. http://dx.doi.org/10.1186/s12889-015-1470-6.

[9] Wakadha H, Chandir S, Were EV, Rubin A, Obor D, Levine OS, et al. The feasibility of using mobile-phone based SMS reminders and conditional cash transfers to improve timely immunization in rural Kenya. Vaccine 2013;31 (6):987–93. http://dx.doi.org/10.1016/j.vaccine.2012.11.093.

[10] Lund S, Nielsen BB, Hemed M, Boas IM, Said A, Said K, et al. Mobile phones improve antenatal care attendance in Zanzibar: a cluster randomized controlled trial. BMC Pregnancy Childbirth 2014;14:29. http://dx.doi.org/10.1186/1471-2393-14-29.

[11] Kaewkungwal J, Singhasivanon P, Khamsiriwatchara A, Sawang S, Meankaew P, Wechsart A. Application of smart phone in "Better Border Healthcare Program": a module for mother and child care. BMC Med Inform Decis Mak 2010;10:69. http://dx.doi.org/10.1186/1472-6947-10-69.

[12] Poorman E, Gazmararian J, Parker RM, Yang B, Elon L. Use of text messaging for maternal and infant health: a systematic review of the literature. Matern Child Health J 2015;19(5):969–89. http://dx.doi.org/10.1007/s10995-014-1595-8.

[13] Hartzler A, Wetter T. Engaging patients through mobile phones: demonstrator services, success factors, and future opportunities in low and middle-income countries. Yearbook Med Inform 2014;9:182–94. http://dx.doi.org/10.15265/IY-2014-0022.

[14] Sondaal SFV, Browne JL, Amoakoh-Coleman M, Borgstein A, Miltenburg AS, Verwijs M, et al. Assessing the effect of mHealth interventions in improving maternal and neonatal care in low- and middle-income countries: a systematic review. PLoS ONE 2016;11(5):e0154664. http://dx.doi.org/10.1371/journal.pone.0154664.

[15] Ateudjieu J, Stoll B, Nguefack-Tsague G, Tchangou C, Genton B. Vaccines safety; effect of supervision or SMS on reporting rates of adverse events following immunization (AEFI) with meningitis vaccine (MenAfriVac™): a randomized controlled trial. Vaccine 2014;32(43):5662–8. http://dx.doi.org/10.1016/j.vaccine.2014.08.012.

[16] Baron S, Goutard F, Nguon K, Tarantola A. Use of a text message-based pharmacovigilance tool in Cambodia: pilot study. J Med Internet Res 2013;15 (4):e68. http://dx.doi.org/10.2196/jmir.2477.

[17] Wesolowski A, O'Meara WP, Tatem AJ, Ndege S, Eagle N, Buckee CO. Quantifying the impact of accessibility on preventive healthcare in sub-Saharan Africa using mobile phone data. Epidemiol (Cambridge, Mass) 2015;26(2):223–8. http://dx.doi.org/10.1097/EDE.0000000000000239.

[18] Giduthuri JG, Maire N, Joseph S, Kudale A, Schaetti C, Sundaram N, et al. Developing and validating a tablet version of an illness explanatory model interview for a public health survey in Pune, India. PloS One 2014;9(9): e107374. http://dx.doi.org/10.1371/journal.pone.0107374.

[19] Kazi AM, Murtaza A, Khoja S, Zaidi AK, Ali SA. Monitoring polio supplementary immunization activities using an automated short text messaging system in Karachi, Pakistan. Bull World Health Organ 2014;92(3):220–5. http://dx.doi.org/10.2471/BLT.13.122564.

[20] Ali M, Deen JL, Khatib A, Enwere G, von Seidlein L, Reyburn R, et al. Paperless registration during survey enumerations and large oral cholera mass vaccination in Zanzibar, the United Republic of Tanzania. Bull World Health Organ 2010;88(7):556–9. http://dx.doi.org/10.2471/BLT.09.070334.

[21] Kaewkungwal J, Apidechkul T, Jandee K, Khamsiriwatchara A, Lawpoolsri S, Sawang S, et al. Application of mobile technology for improving expanded program on immunization among highland minority and stateless populations in northern Thailand border. JMIR mHealth uHealth 2015;3(1):e4. http://dx.doi.org/10.2196/mhealth.3704.

[22] Haskew J, Kenyi V, William J, Alum R, Puri A, Mostafa Y, et al. Use of mobile information technology during planning, implementation and evaluation of a polio campaign in South Sudan. PLoS ONE 2015;10(8):e0135362. http://dx.doi.org/10.1371/journal.pone.0135362.

[23] Teng JE, Thomson DR, Lascher JS, Raymond M, Ivers LC. Using Mobile Health (mHealth) and geospatial mapping technology in a mass campaign for reactive oral cholera vaccination in rural Haiti. PLoS Neglected Trop Dis 2014;8(7): e3050. http://dx.doi.org/10.1371/journal.pntd.0003050.

[24] Touray K, Mkanda P, Tegegn SG, Nsubuga P, Erbeto TB, Banda R, et al. Tracking vaccination teams during polio campaigns in northern Nigeria by use of geographic information system technology: 2013–2015. J Infect Dis 2015: jiv493. http://dx.doi.org/10.1093/infdis/jiv493.

[25] Brown AE, Okayasu H, Nzioki MM, Wadood MZ, Chabot-Couture G, Quddus A, et al. Lot quality assurance sampling to monitor supplemental immunization activity quality: an essential tool for improving performance in polio endemic countries. J Infect Dis 2014;210(Suppl 1):S333–40. http://dx.doi.org/10.1093/infdis/jit816.

[26] Mbabazi WB, Tabu CW, Chemirmir C, Kisia J, Ali N, Corkum MG, et al. Innovations in communication technologies for measles supplemental immunization activities: lessons from Kenya measles vaccination campaign, November 2012. Health Policy Plann 2015;30(5):638–44. http://dx.doi.org/10.1093/heapol/czu042.

[27] Birukila G, Babale SM, Epstein H, Gugong V, Anger R, Corkum M, et al. Reducing resistance to polio immunisation with free health camps and Bluetooth messaging: an update from Kaduna, Northern, Nigeria. Global Public Health 2016:1–12. http://dx.doi.org/10.1080/17441692.2016.1152283.

[28] Watterson JL, Walsh J, Madeka I. Using mHealth to improve usage of antenatal care, postnatal care, and immunization: a systematic review of the literature. BioMed Res Int 2015;2015:153402. http://dx.doi.org/10.1155/2015/153402.

[29] Tozzi AE, Gesualdo F, D'Ambrosio A, Pandolfi E, Agricola E, Lopalco P. Can digital tools be used for improving immunization programs? Front Public Health 2016;4:36. http://dx.doi.org/10.3389/fpubh.2016.00036.

[30] Domek GJ, Contreras-Roldan IL, O'Leary ST, Bull S, Furniss A, Kempe A, et al. SMS text message reminders to improve infant vaccination coverage in Guatemala: a pilot randomized controlled trial. Vaccine 2016;34(21):2437–43. http://dx.doi.org/10.1016/j.vaccine.2016.03.065.

Please cite this article in press as: Kim SS et al. Use of m-Health in polio eradication and other immunization activities in developing countries. Vaccine (2017), http://dx.doi.org/10.1016/j.vaccine.2017.01.058