Mobile Phone Tools for Field-Based Health care Workers in Low-Income Countries

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ABSTRACT

In low-income regions, mobile phone–based tools can improve the scope and efficiency of field health workers. They can also address challenges in monitoring and supervising a large number of geographically distributed health workers. Several tools have been built and deployed in the field, but little comparison has been done to help understand their effectiveness. This is largely because no framework exists in which to analyze the different ways in which the tools help strengthen existing health systems. In this article we highlight 6 key functions that health systems currently perform where mobile tools can provide the most benefit. Using these 6 health system functions, we compare existing applications for community health workers, an important class of field health workers who use these technologies, and discuss common challenges and lessons learned about deploying mobile tools. ***Mt Sinai J Med 78:406–418, 2011.*** *© 2011 Mount Sinai School of Medicine*

Key Words: CHW, CommCare, community health workers, ICT4CHW, mHealth, mobile field workers, mobile health, mobile phones.

Many personal digital assistant (PDA)- and phone-based systems have been developed for health workers in low-income settings. Applying mobile devices and applications to health problems in low- and middle-income countries (LMICs) is commonly referred to as mHealth. Using mobile technology to address these problems provides many advantages compared with traditional approaches. For example, mobile data collection is much faster than collecting data on paper and later entering the results into a computer database, and has a reduced risk of transcription error. Mobile applications for data collection or decision support ensure branching logic is correctly followed

and that only valid data values are accepted. Mobile devices allow rich forms of data to be captured, including pictures, audio, video, or geoposition information. Linking mobile workers through a central server helps manage referrals to other health facilities and aids interclinician communication. These are just a few examples of how mobile phone–based systems can help improve health care in LMICs.

During the last few years, there has been work that extends these advantages to community health programs; this is informally known as ICT4CHW (Information and Communication Technology for Community Health Workers).[1] Despite the many projects in the ICT4CHW space,[2–10] relatively little has been formally published and there has been no comprehensive effort to describe the systems relative to one another in an effort to determine what factors influence the success or failure of each. The objective of this article is to identify trends, challenges, and opportunities in this new field.

Despite the many projects in Information and Communication Technology for Community Health Workers (ICT4CHW), relatively little has been formally published and there has been no comprehensive effort to describe the systems relative to one another in an effort to determine what factors influence the success or failure of each.

In this article we first identify 6 important health system functions (HSFs), or common functions that a health system must perform, where mobile applications have been used. Second, we discuss common challenges for deploying mHealth tools. Third, we provide a brief overview of community health programs, illustrating the relevance of each of the 6 HSFs. Fourth, we present a comprehensive review of mobile applications designed for use by community health workers (CHWs) that incorporate many of these different HSFs. We also identify a set of Information and Communication Technology (ICT)-based systems that are meant to be used in every visit, and target many or all of the HSFs. Finally, we elaborate on lessons learned and potential benefits of ICT-based systems.

OVERVIEW OF MOBILE SUPPORT FOR HEALTH WORKERS

Mobile phones increasingly offer many features beyond voice and text messaging. Such phones are rapidly becoming cheaper, more powerful, and more common in remote areas of low-income regions. These phones bring increased Internet connectively through general packet radio service and other cellular technologies, which have contributed to the increased adoption of mobile tools for supporting health workers. We identify the following 6 HSFs in which mobile tools support health workers in LMICs: data collection, training and access to reference material, communication between health workers, decision support, supervision, and promoting healthy behaviors in the population.

Health System Function 1: Data Collection

Health systems require many forms of data collection, such as household surveys, routine reporting from clinics, and supervisory reports. Typically, these data are collected on paper forms and later entered into a computer database. If high accuracy is needed, 2 data clerks will digitize the forms and discrepancies are resolved. Mobile data collection systems have the benefit that users capture data directly into a PDA or phone and it is uploaded directly to a centralized server.

There are a number of PDA- and phone-based systems that have been developed to improve data collection and decision support in LMICs. Table 1 summarizes the advantages, as well as the challenges, of mobile phone–based survey instruments. These systems offer many advantages compared with paper-based data collection. The data are collected more quickly and with reduced risk of transcription error. Additionally, the data-collection software running on the mobile device can ensure that branching logic–eg, only ask the pregnancy question if the gender is female–is correctly followed and that only valid data values are accepted.

Recent advances in mobile phone capabilities are making many innovative data-collection strategies possible. Global positioning system (GPS) technology built into a mobile phone can be used to track the health worker and identify the location of homes in the absence of mapping systems.[11] Mobile phone–based applications have been used in a wide variety of surveillance activities.[12] These include gathering data on respiratory illness,[13] maternal and child health,[14] and child nutrition.[15]

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Table 1. *Advantages and Challenges of Mobile Phone–Based Data Collection.*

Advantages	Challenges
Reduced errors from transcription	Data exchange and interoperability issues between different systems
More timely survey completion and access to data	Coordination and communication constraints leading to duplication of functionality across systems
Support for complex branching logic, making surveys easier to administer	Complexity in deploying workflow management in systems developed for data collection
Automatic constraints on questions (eg, no temperature >110°F)	Privacy concerns with wireless transmission
Better adherence to survey questions	Loss or theft of mobile devices
Reduced cost per survey over long term	Poor or absent connectivity
	Difficulty keeping batteries charged

Several open-source data-collection systems for phones have emerged recently. Open source means that the original source code is available for download free of charge so that anyone can modify or expand upon the original application. Companies who release the source code of their products often make their money by supporting the software, making custom modifications, or handling the installation and infrastructure requirements for customers.

EpiSurveyor[16] from DataDyne enables its users to create a data-collection form, download it onto a Java-enabled cell phone to collect data, and send that data to a central database. It is cloud-based, and at the time of writing in early March 2011, has >3200 users around the world with >134,000 forms collected. EpiSurveyor allows for geo-tagging of forms and has advanced logic functionality. Open Data Kit (ODK)[17] is a free and open-source collection of tools that help organizations collect, aggregate, and visualize the data. Built on the Android platform, ODK can replace paper forms to enable capture and playback of multiple data types, including text, location, photos, video, audio, and barcodes. It also supports editing saved forms, question grouping, constraints, complex logic, and multiple languages. Many of the mobile-phone data-collection projects are based on a few core open-source technologies, including JavaRosa and RapidSMS. For example, both EpiSurveyor and ODK are built upon the JavaRosa software platform. The consistent use of these platforms for data collection has enabled communities of developers and implementers to collaborate and build on each other's experiences.

Health System Function 2: Training and Access to Reference Material for Health Workers

A core activity of any health system is the initial and continuous training of its health workers. Health workers of every cadre need to be trained before they begin their work and retrained frequently as new procedures are introduced. Technologies that have the potential to make training more efficient, less expensive, or more effective can greatly benefit a health system.

In Uganda, AED-SATELLIFE is delivering clinical content to health care providers working out of community health centers in remote areas of Uganda using handheld computers, wireless access points, and wireless communications infrastructure.[18]

Health System Function 3: Facilitating Communication among Health Workers

Health workers must often talk to each other for advice or expertise, or to manage referrals to other clinics. Mobile phones provide an obvious benefit for facilitating communication among distributed workers in LMICs. Various studies have documented the use of cell phones by medical residents,[19] health workers,[20] and nurse midwives[21] to communicate with peers, supervisors, or patients on health issues. World Vision's Aceh Besar Midwives with Mobile Phones Project was started to use mobile communications and technology to facilitate, accelerate, and improve the quality of health services by connecting midwives to obstetrician-gynecologists.[22]

Mobile phones are used for coordination in responding to emergencies, consulting with subspecialists, accessing second-line staff, obtaining consent or permission for action, and receiving and discussing results from lab tests. In other instances, birth attendants coordinate care with delivery nurses and physicians in cases of complicated births. Physicians are also using smartphones to access sensor or image data on their mobile phones.

Telemedicine is an important example of how health providers can communicate remotely. Projects have used phones to capture images for assessment by specialists,[23,24] and have even been used to help assess stroke victims.[25] Dimagi, along with the Centre

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for Infectious Disease Research in Zambia and others, implemented a cervical screening project where nurses were trained to perform visual inspection with acetic acid aided by a mobile phone application that sent images of the cervix for cervical cancer screening by an expert.[26] University of Pennsylvania, in partnership with ClickDiagnostics, has implemented pilots in Botswana in dermatology, radiology, cervical cancer, and oral medicine. Using cell-phone cameras, images are transmitted to remote physicians for interpretation and diagnosis.[27] The mobile health care services mQure in India[28] and Telemedicine Reference Center Ltd in Bangladesh[29] provide access to health care providers over cell phones along with short message service (SMS)-based reminders. These services have enabled patients in rural and remote areas access to quality medical care.

Health System Function 4: Providing Job Aids and Decision Support

Numerous studies have shown that health care can be improved through job aids and decision support. Several mobile applications have been designed to help clinicians adhere to the clinical guidelines. This is important, because improved adherence to clinical guidelines can reduce mortality rates. In Tanzania it was shown that the Integrated Management of Childhood Illness (IMCI) guideline reduced child mortality.[30] Unfortunately, it is also commonly observed that health workers do not fully adhere to the procedures they have been trained to perform.[31]

Mobile applications can guide health workers through complex decision-support protocols and clinical algorithms by presenting one question at a time, with a question automatically determined by the answer to the preceding question. For example, the e-IMCI program running on a PDA was shown to significantly improve clinicians' adherence to protocols for treating childhood illness in a small study in rural Tanzania compared with clinicians using traditional methods.[32]

Health System Function 5: Supervision of Health Workers

In order for a service-delivery system to run effectively, the workers must be consistently and adequately supervised. Improved supervision has been shown to have a substantial impact on the performance of a health care system.[33] Supportive supervision has been show to "consistently [have] moderate to large effects" in combination with other "managerial tools."[34]

For community health programs, supervision is often a neglected and under-resourced component.[11] In most cases, supervision is performed by staff who "may not understand the CHWs or their own role properly and. . .may resent the additional task."[35] The need for supervision also holds true in high-resource settings in order to maintain CHW performance.[36] The majority of supervision of CHWs occurs during follow-up in the field, where supervisors often accompany CHWs on home visits and review any data collected by the CHWs. There are a number of challenges for supervisors. They are generally unskilled, they lack tools and transport to perform their duties, they are often burdened with administrative and reporting responsibilities, they may miss planned supervision visits, and people seem to become demoralized to the point that "no one seems to care whether supervision is done."[34]

Mobile applications have the potential to enable more effective supervision. When health workers use mobile tools, their activity can be monitored in near real-time, providing supervisors with the ability to more quickly react to changes in health worker behavior and provide corrections or positive feedback. Remote guidance can be provided from supervisors, as well as automatic supervision in terms of motivating messages or reminders.

Health System Function 6: Promoting Healthy Behaviors in the Population

In addition to treatment, most health systems promote preventive care and other healthy behaviors in the population, as well as provide post-treatment support. Mobile phones offer an attractive way to quickly reach large populations through the phones they own. A number of SMS- and mobile application–based interventions, including games, incentive programs, and chronic disease–management tools, have been deployed for preventive health.

The Claim Mobile project in Uganda[37,38] is incorporating a mobile-payment system for health care payments and claims adjudication to speed up the process of reimbursements for sexually transmitted infection tests. Johnson & Johnson's BabyCenter provides advice and information to parents before, during, and after pregnancy through weekly SMS delivered based on the mother's delivery date. Voxiva offers mobile solutions designed to educate participants, encourage behavior change toward healthy lifestyles, and promote adherence to their treatment protocol in the areas of maternal health, smoking

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cessation, diabetes, human immunodeficiency virus (HIV)/acquired immune deficiency syndrome (AIDS), flu, and fibromyalgia. Dimagi is running a National Institutes of Health–funded study at Boston Medical Center in which HIV/AIDS patients are sent customized text messages to improve their compliance with antiretroviral therapy (ART) regimens. In a similar project by WelTel Kenya, patients on ART who received weekly SMS messages from a clinic nurse and were required to respond within 48 hours to those messages had significantly improved ART adherence and rates of viral suppression compared with individuals in a control group.[39]

CHALLENGES FOR MOBILE TOOLS

Table 1 lists many common challenges for deploying mobile phones. There is no single solution to these problems, but most of these must be addressed for any mHealth deployment. The challenges and solutions presented here are pulled from experiences of the authors and those shared on the ICT4CHW mailing list.[1]

Some of the challenges relate to maintaining and operating the handsets, including keeping the phones charged, dealing with areas of low connectivity, and managing the loss or theft of the mobile phones. The extent of these operational challenges varies depending on the country and the implementing program, and must be taken into account in terms of calculating the total cost of introducing a mobile application into a health system.

Mobile applications may introduce or alter privacy concerns. Any system that captures patient data electronically introduces risk during transmission and storing of the data. Some mobile applications also present the challenge of having patient data available on multiple handsets, and many phone software platforms make it difficult to protect access beyond basic passwords.

Another challenge for organizations deploying electronic solutions is how to link different tools together and how to link them to existing databases. Even within the same health program, there might be different data systems developed at different times or from different funding sources. This leads to separate platforms being run by government-supported, private, and grant-funded health care infrastructure. Many open standards have been proposed to address this issue; however, no single set of standards has become universally accepted.

Even if we ignore data exchange between different systems, organizations utilizing the same core platform often find it hard to leverage each other's software modifications due to the increased overhead of coordination and communication. More commonly, organizations are able to share best practices and lessons learned, but end up writing their own new modifications no matter how similar in functionality they may be to another existing effort.

Finally, the goals of many organizations are unclear when they deploy applications. They may begin with a focus on mobile data collection to improve an existing paper process, but they quickly want to support actions resulting from the data collected. This presents a challenge for organizations adopting mobile data collection technologies, as the technologies that are easy to deploy for data collection may not be suitable for creating customized workflow support.

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NEED FOR MOBILE TOOLS IN COMMUNITY HEALTH PROGRAMS

Despite large differences between programs and countries where CHWs "can be men or women, young or old, literate or illiterate,"[40] several elements are common across community health programs. The vast majority of the programs involve training CHWs to visit homes and promote healthy behaviors. In some programs the CHWs visit every household in their catchment area, whereas in others they visit target demographics (eg, newborns or HIV+ individuals). Some visits are routine, and others are targeted visits (eg, following up with lab results). But in almost

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all cases, the CHWs themselves are mobile, and thus mobile applications represent the primary means to provide electronic support.

Additionally, all 6 uses of mobile phones mentioned above (HSFs) are applicable to community health programs. For example, the majority of programs collect data (HSF 1) during visits to provide longitudinal care, track client health over time, and fulfill monitoring and reporting requirements. However, in traditional CHW programs, much of the data collected by CHWs is never analyzed and reported back to the community where it was collected. Thus, ICT4CHW systems have the potential to provide a new source of health surveillance data.

The CHWs must be trained appropriately and continuously (HSF 2). Targeted follow-up training has been shown to lead to CHW performance improvements.[34] Computer-based trainings have been found to be potentially less expensive and "as effective as traditional methods."[33]

Access to health experts and health information is another major challenge facing all levels of health workers (HSF 3). They "lack access to basic, practical information to enable them to deliver safe, effective care."[41] Written reference materials are the traditional way of supplying this information.

A job aid (HSF 4), such as a checklist, worksheet, communication aid, or other set of short instructions, can be useful for CHWs to perform their routine tasks. In Zambia, CHWs were able to use rapid diagnostic tests more quickly with the assistance of a job aid explaining the steps.[42]

Rowe *et al*. found that "dissemination of written guidelines without additional interventions was generally ineffective" with CHWs.[33] The written guidelines being referred to are a verbose explanation of a task, as opposed to a job aid that summarizes the task. This reinforces the point that adequate training is required and that CHWs need to be linked to health expertise, as opposed to only health information.

Furthermore, a review found that poor performance of CHWs was not due to only a lack of knowledge and skills.[33] One longitudinal study of CHW performance found that although the first follow-up training intervention was successful, performance decreased after a second refresher training.[35]

As discussed in the section on supervision (HSF 5), there are a number of challenges facing supportive supervision of CHWs. Difficulties with reporting, managing geographically distributed workers, and automation of mundane tasks are all areas to address when improving supervision with mobile tools.

Finally, one primary role of CHWs is to promote healthy behavior among their clients (HSF 6). Mobile phones have the potential to increase CHW effectiveness by providing educational tools or supplementing their efforts with automated outreach in between CHW visits to clients who own phones.

SURVEY OF INFORMATION AND COMMUNICATION TECHNOLOGY SYSTEMS FOR COMMUNITY HEALTH WORKERS

In this section, we review ICT projects that specifically aim to address the needs of community health worker programs. In Table 2, we categorize the projects discussed in this section by the HSFs that they target. We also compare the projects to one another in Table 3, where we look at the higher-level properties that emerge.

Discretionary Systems

One class of ICT4CHW systems are those that can be used at the discretion of the CHW and tend to target one particular use of mobile phones within health care.

Medic Mobile is an example of an ICT4CHW system that helps facilitate communication among health workers (HSF 3). Medic Mobile is built on top of the FrontlineSMS platform[43] and provides a new communication medium over SMS for health facilities.[7] The SMS messages are generally unstructured, freeform text. As an example, messages from the CHW might contain updates about patients, double-checking drug dose and use, questions about a patient, or a note to alert clinics of a referral. Clinics may send messages to check on the status of a CHW or patient or ask the CHW to mobilize the community. One lesson from Medic Mobile is the value of allowing a flexible system that the CHWs can decide how to use. Patterns of usage emerge as the CHWs send messages that can be acted upon by clinic staff.

HealthLine provided low-literate CHWs access to health expertise (HSF 2) through an automated interactive voice recognition system that would provide health information.[8] Although it was never deployed, the system was evaluated by CHWs in the Sindh province of Pakistan.[44] The authors ran 3 different pilot studies with 10 users each before running a more formal user study with 18 participants. There were 2 main conclusions: the literacy of a user directly impacts his/her ability to complete a task, and a well-designed speech interface can outperform a touch-tone interface, independent of literacy.

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Table 2. *HSF Improvement for ICT4CHW Systems.*

Project	HSF 1 Data Collection	HSF 2 Reference	HSF 3 Communication	HSF 4 Decision Support	HSF 5 Supervision	HSF 6 Behavior
Medic Mobile HealthLine GuideView	Unstructured	SMS expert IVR system Multimedia guides	SMS			
First Days						Educational and testimonial video
ChildCount	Child registration		Weekly printed sheet, (planned) automated reminders			
ClickDoc	Multimedia data collection	Send to remote expert		Yes		
CommCare	Case registration*		Automated reminders	Yes	Automated reminders	

Abbreviations: HSF, health system function; ICT4CHW, Information and Communication Technology for Community Health Workers; IVR, integrated voice response; SMS, short message system.
*Each CommCare deployment can specify cases to be registered and followed up (eg, pregnant mothers, households, or suspected cases of tuberculosis).

Table 3. *Comparing Properties of ICT4CHW Systems.*

Project	License	Status	Used Every Visit	Structured Data	Register Cases	Phone Type
Medic Mobile	Free	Pilot/development		(optional plug-in)		Basic*
HealthLine	Unreleased†	Pilot				Basic
GuideView	Unknown	Pilot	✓			Feature,‡ smart§
First Days	Unreleased†	Pilot	✓			Feature
ChildCount	FOSS	Deployed	✓	✓	✓	Basic
ClickDoc	Unknown	Pilot	✓	✓	✓	Android
CommCare	FOSS	Deployed	✓	✓	✓	Feature, Android

Abbreviations: FOSS, free and open source software; ICT4CHW, Information and Communication Technology for Community Health Workers.
*Basic phones support only voice, SMS, and the SIM Application Toolkit (very basic menu-only applications).
†Unreleased means that the code is not publicly available, but it is free if the authors of the respective project are contacted.
‡Feature phones support custom applications, often written in Java.
§GuideView is available on the feature phones and the iPhone, with more smartphone platforms planned.

GuideView provides automated job aids to CHWs (HSF 4). Originally designed for astronauts needing to provide medical support for one another, it allows practitioners to design multimedia clinical guides for use on phones and other devices.[45] In a controlled study of 10 users, it was found that voice advice was considered "indispensable," though text with still pictures and video were favored as well.[46] Most recently, the system has been adapted for a study with 50 CHWs in Colombia, where it was found that using GuideView reduced errors by 35% and increased adherence to protocols by 35%.[47]

The First Days project helps CHWs promote healthy behaviors in the population (HFS 6). First Days aims to "mobilize health workers to improve maternal and child health in rural India."[48] CHWs are given phones with educational and testimonial videos. The goal is that during a household visit, the videos will prompt discussion and encourage a client to adopt healthy practices. Drawing

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on work in persuasive technologies and tutored video instruction, a pilot of the First Days project aimed to persuade village women to adopt healthier practices and to increase the self-efficacy of CHWs in order to motive them to improve their performance. Researchers found that videos engaged both CHWs and clients, CHW self-efficacy showed "marginally significant gains ($P = 0.06$)" and there were "modest learning gains" by the CHWs. It was also found that making the videos was very engaging and important individuals in the community participated "to a surprising extent."[6]

Information and Communication Technology–Based Systems

The second set of systems we label ICT-based CHW systems and define them as having the following properties: (1) Every visit is captured electronically (no visits without the mobile phone), (2) structured data is collected, (3) data are sent in real time, and (4) the system allows CHWs to register and track clients.

The properties of ICT-based CHW systems are restated in Table 4 and the benefits of such systems are detailed. Each ICT-based system tends to support many of the mobile functions described above.

One ICT-based system that relies on SMS is the ChildCount project.[2] It was designed for use with simple phones, but was also extended to support manual paper-based data collection as well in the event that a phone is not available. The CHWs follow a worksheet to generate structured texts that are either sent via SMS or recorded on paper entered at a later time by data entry clerks. For example, sending "new diallo fatimata f 080408 Amie" via SMS would register a new female child named Fatimata Diallo. Her mother's name is Amie and she was born on August 4, 2008.

Table 4. *Properties and Benefits of ICT-Based Systems.*

Properties of ICT-Based Systems	Benefits of ICT-Based Systems
Application used for every visit	Automated reports on CHW activity for supervisors
Structured data is collected	Data can be used for health surveillance
Data is sent in real time	Reports available in real time for monitoring and evaluation
CHWs can register and track cases	Automated reminders about following up on cases

Abbreviations: CHW, community health worker; ICT, information and communication technology.

ChildCount supports registering children aged <5 years, reporting measurements from a nutritional screening and reporting the result of a malaria rapid-diagnostic test. The system is being expanded to include capturing child deaths, pregnancies, and births; support for diarrheal illness through oral rehydration salts and zinc; drug-inventory management for CHWs and clinics; and an alert system for clinics to dispatch CHWs to follow up on sick patients.[2] ChildCount is built on top of RapidSMS[49] to automatically receive and parse incoming SMS from the CHWs. The server will process and respond to SMS in real time. For example, when it receives a nutritional screening data form, the system will classify the child and recommend a treatment, if any. Finally, the server generates reports on CHWs and their clients to enable better supervision by identifying CHWs who are struggling and more targeted interventions by looking for trends in the population data.

One of the interesting findings from ChildCount was the value of providing printed lists to the CHWs each week, with a list of each of the CHW's clients and their status. The list would include any updates made by the CHW that week to their clients. This provided a useful overview for a CHW, allowing them to see which clients needed further attention. More important, this feedback loop would motivate the CHW to continue to use the system.

ClickDoc is an ICT-based system that runs on the Android operating system.[50] It allows the health worker to fill out surveys and capture pictures so that complex cases can be sent to remote experts. A tele-dermatology solution was built in Egypt and preliminary results show that remote and on-site experts came to the same diagnosis in 75% of cases.[51] In Botswana the software was extended to add cervical cancer screening, with almost 77% of screenings diagnosed the same between remote and on-site.[52] In both the Egypt and Botswana studies, the disagreement was the result of "insufficient history" of the patient's situation being communicated to the remote professional. In Bangladesh, CHWs visiting households collect data on mothers and children. Results are automatically analyzed and categorized so that doctors can review cases with high-risk profiles. Information is then returned to the CHW (and then the client) either immediately or the next day, depending on doctor availability.[52]

CommCare, which several of the authors have worked on, runs on feature phones or Android and supports various modules so that it can be customized to a particular CHW program.[4] For example, a CommCare deployment run by Pathfinder International and D-Tree International in Dar es Salaam, Tanzania,

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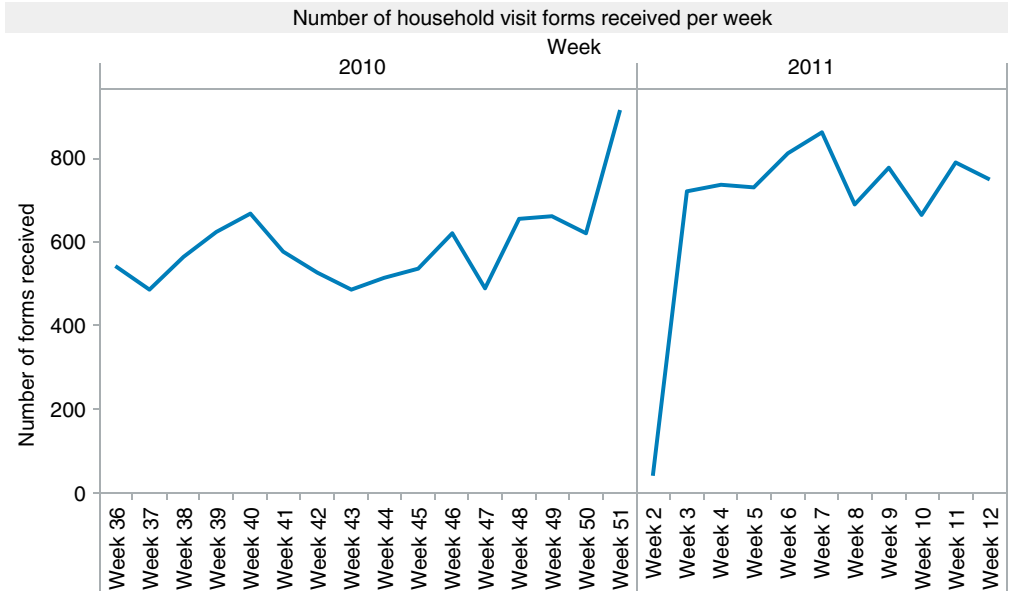

Fig 1. Number of household follow-up forms received.

supports CHWs who are registering and following up with patients who need chronic care–the vast majority being HIV+.

A CommCare deployment in Dodoma, Tanzania, supports a module for routine household visits and a module for pregnant women. The household visit module allows households to be registered and tracked over time. If there is a serious illness or wound, a referral can be generated to refer the household member to the health facility. These referrals are also tracked so that the CHW follows up with the household to ensure care was received.

The pregnancy module allows CHWs to register pregnant women and track them over time. It includes a checklist of healthy actions to complete before the woman gives birth. Danger signs are assessed at every visit in order to identify high-risk pregnancies, and the case is closed once the woman gives birth.

In Dodoma, there are 35 CHWs using CommCare. In the first 9 months that the deployment was running, we received >12,600 home-visit follow-up forms. Figure 1 shows the number of household follow-up forms received, broken down by week during the fourth quarter of 2010 and the first two weeks of 2011. As expected, there was a decrease in activity during the holiday period. Out of all of the household follow-up visits captured, a member of the household is referred to the health facility 24% of the time, with 90% of the referrals being about sickness or a wound. The remaining 10% are for pregnant women being referred for antenatal care or for birth registration of newborns.

The mobile phones send their data to a server called CommCareHQ. This is a Django-based platform to be used by supervising staff of the implementing partner to view the status of the CHWs and the clients. It can produce automated reports for staff and is being expanded to produce and send automated reminders. Similar to FrontlineSMS,[43] CommCareHQ also allows SMS messages to be sent and received using RapidSMS as a backend support.

An important shift in CommCare has been to introduce multimedia elements to reinforce each step in the forms, including both audio and icon or images. This helps CHWs with lower literacy who might not able to use a text-based system. It also turns the application into a powerful educational tool, borrowing elements from the First Days project described in the previous section. The CHWs show their clients the images and play the audio clips to help reinforce the points and also stimulate more discussion.

Computer-Supported Supervision for Information and Communication Technology–Based Systems

Improved supervision (HSF 5) is an area of great promise for ICT4CHW systems, which can address several of the challenges of supervision, including communication difficulties between supervisors and

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Improved supervision (Health System Function 5) is an area of great promise for ICT4CHW systems, which can address several of the challenges of supervision, including communication difficulties between supervisors and community health workers.

CHWs. These systems can provide higher-quality information about the CHWs and offer a communication medium, given that supervisors and CHWs rarely see one another.

Capturing data immediately from the field avoids the delay of using paper records that are later entered by a data-entry clerk. This enables data to be aggregated in real time, allowing organizations to make informed decisions and respond more promptly to needs in the field. The data from ICT-based system can be used to support supervisors in a variety of ways, including:

Client Status

As a result of capturing structured data during routine visits, the status of clients can be computed, making it easy to construct reports showing which of those clients have been visited recently—or not—and which are routinely having trouble. Communicable disease incidence can also be explored on an aggregate level across locations.

For example, if the CHWs were collecting sickness data at a household level with GPS, it would be possible to map the incidence of sickness to look for hot spots. Even if GPS is not used, the data could still be mapped by CHW catchment area.

CHW Status

Similar to client status, the performance of individual CHWs can be tracked. The number of visits per day can be computed, and supervisors can look at the most recent visits to ensure the CHWs are visiting their clients regularly enough.

As an example, CommCareHQ, the backend for the CommCare project, generates email reports indicating the activity of each CHW using CommCare. Authorized users can receive reports as frequently as desired. The reports show the number of forms submitted over each of the last several days, as well as the total number of active clients for each CHW, and how many of those clients are overdue for a visit.

Automated Reminders

In rural areas, time to care is extremely important. In Uganda in 2008, Källander *et al*. looked at fatal pneumonia cases in children and cited "delays in seeking care" as one of 3 primary reasons for the deaths.[53] Timeliness was also one of the metrics used by Shankar *et al*. when measuring CHW performance.[54]

Automated reminders can be sent to ensure the CHWs make timely visits. These reminders are enabled because the application captures every visit, allowing important events to be tracked. For example, a reminder could be sent to a CHW who has overdue visits, as defined above, requesting that he or she follow up with those clients. Similar reminders can be sent to CHWs who have referred clients to the health facility to ensure the client was able to receive care.

Activity Reports

Ramachandran *et al*.[6] reported that CHWs are often are not performing the required number of home visits. Sending activity reports that briefly state the amount of work done (eg, number of households visited or number of overdue clients) to a group of CHWs may be a way to take advantage of social persuasion to improve CHQ performance, though further exploration and design is required.

Lessons Learned

There are a number of lessons learned from these early deployments of ICT4CHW systems. Similar to the challenges listed earlier, the lessons presented here are pulled from experiences of the authors and those shared on the ICT4CHW mailing list.[1]

An important lesson learned is not to automate broken systems. If a community health program is not functioning well, then it is unlikely that adding an ICT4CHW component will solve the underlying problems. These systems are best seen as tools that can strengthen a program, rather than salvage it.

Another important lesson pulled from our review of these systems is the gap between how a CHW program was originally designed to work and how it is functioning in the field. This has a significant impact when trying to introduce automation, because automating the original design will fail if what is happening in the field deviates significantly. As an example, a community health program is often designed to include a large number of visits and material to be covered at each visit. However, CHWs

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may find it impractical to follow the program design fully. When an automated system that provides more tools for supervision is introduced, this tension is brought to the surface. Ultimately, this is an advantage because it forces the CHWs and the program to converge. The CHWs must more closely follow the program and the program must become more practical. However, it also entails a lot of programmatic work to revise the overall community health program to be more practical.

A related lesson is the need to allow substantial time to iterate on any new system with real users. A typical CommCare deployment will schedule several months of "refinement," which takes place after an initial prototype has been designed with input from experts and users, but before a pilot. The refinement period can have as few as 5 users who meet with a field implementer frequently. During this stage, the system is modified frequently and new ideas are tested. After the refinement period, the pilot might be run with 30–40 users. During this time, the application is changed much less frequently.

An important, albeit common, observation is that context matters. It is important to understand the dynamics of how people use phones. For example, it can create excitement as well as conflict to give a CHW a phone if her husband does not have one. Similar to context, content matters as well. One lesson that has come up repeatedly is that getting the messages, images, or audio clips right can make a difference in how well an ICT4CHW system functions.

Almost all of the lessons above are variations on a commonly stated theme: technology is not the difficult part—what matters most is how the technology is used. Incentives must also be aligned properly, and a mechanism to adapt the system over time must be present.

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CONCLUSION

Community health workers have the potential to provide health information, encourage healthy practices, and be an accessible point of entry into the national health system for rural and low-income populations. However, CHW programs are difficult to maintain because of challenges in monitoring and supervising a large number of geographically distributed health workers. Mobile applications provide an opportunity to address these challenges by strengthening CHW programs and making them more efficient.

In this article, we identified 6 key HSFs where mobile phone applications are providing benefit. We surveyed peer-reviewed and grey literature publications about mobile-phone applications, discussing them in the context of the identified HSFs. We also discussed the challenges and lessons learned from mHealth systems. Finally, we identified criterion for ICT-based applications CHW systems and enumerated the benefits of such applications.

It is clear that using mobile phones to increase CHW performance is an important area and that there is a lack of work evaluating such interventions. One way to address this is for funding agencies to require an evaluation component in the mHealth projects they fund. The technology providers can also promote research about health outcomes by educating their clients about research design and analysis and collaborating with the implementation partners for such studies. The results of studying the impact of technology in this setting will help organizations design and implement more effective interventions. Not only will they generalize across CHW programs, but they will also benefit mobile field workers in other domains, such as agriculture, microfinance, and livestock.

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REFERENCES

1. ICT4CHW Google group. http://groups.google.com/group/ict4chw. Accessed July 7, 2010.
2. Berg M, Wariero J, Modi V. *Every Child Counts–The Use of SMS in Kenya to Support the Community Based Management of Acute Malnutrition and Malaria in Children Under Five.* http://www.childcount.org/reports/ChildCount_Kenya_InitialReport.pdf. Published October 15, 2009. Accessed June 29, 2010.
3. ClickDiagnostics. http://clickdiagnostics.com. Accessed July 7, 2010.
4. Mhila G, DeRenzi B, Mushi C, et al. Using mobile applications for community-bsed social support for chronic patients. Presented at: Health Informatics in Africa Conference (HELINA); April 16–18, 2009; Abidjan, Cåo te d'Ivoire.
5. eMOCHA. http://emocha.org. Accessed July 13, 2010.
6. Ramachandran D, Canny J, Das P, et al. Mobile-izing health workers in rural India. Presented at: ACM Conference on Human Factors in Computing Systems; April 10–15, 2010; Atlanta, GA. http://portal.acm.org/citation.cfm?id=1753326.1753610.
7. Medic Mobile. http://medicmobile.org. Accessed March 7, 2011.
8. Sherwani J, Ali N, Mirza S, et al. HealthLine: speech-based access to health information by low-literate users. Presented at: IEEE/ACM International Conference on Information and Communication Technologies and Development; December 2007; Bangalore, India.
9. Chib A. The Aceh Besar midwives with mobile phones project: design and evaluation perspectives using the information and communication technologies for health care model. *J Comput Mediated Commun* 2010; 15: 500–525.
10. Mobile Technology for Community Health (MoTeCH). http://www.grameenfoundation.applab.org/section/ghana-health-worker-project. Accessed June 27, 2010.
11. Krishnamurthy R, Frolov A, Wolkon A, et al. Application of pre-programmed PDA devices equipped with global GPS to conduct paperless household surveys in rural Mozambique. *AMIA Annu Symp Proc* 2006; 991.
12. Shirima K, Mukasa O, Schellenberg JA, et al. The use of personal digital assistants for data entry at the point of collection in a large household survey in southern Tanzania. *Emerg Themes Epidemiol* 2007; 4: 5.
13. Diero L, Rotich JK, Bii J, et al. A computer-based medical record system and personal digital assistants to assess and follow patients with respiratory tract infections visiting a rural Kenyan health centre. *BMC Med Inform Decis Mak* 2006; 6: 21.
14. Anantraman V, Mikkelsen T, Khilnani R, et al. Handheld computers for rural health care: Experiences from research concept to global operations. Presented at Development by Design Conference; December 1–2, 2002; Bangalore, India:1–10.
15. Blaschke S, Bokenkamp K, Cosmaciuc R, et al. *Using Mobile Phones to Improve Child Nutrition Surveillance in Malawi.* UNICEF Malawi and UNICEF Innovations; May 2009.
16. EpiSurveyor. http://www.episurveyor.org. Accessed March 6, 2011.
17. Open Data Kit. http://www.opendatakit.org. Accessed June 25, 2010.
18. AED-SATELLIFE. Empowering health workers to save lives: Uganda Health Information Network. http://www.healthnet.org/uhin. Updated February 28, 2011. Accessed March 5, 2011.
19. Scott RE, Ndumbe P, Wootton R. An e-health needs assessment of medical residents in Cameroon. *J Telemed Telecare* 2005; 11(suppl 2): S78–S80.
20. Mechael PN. *Exploring Health-Related Uses of Mobile Phones: An Egyptian Case Study* [PhD thesis]. London, UK: London School of Hygiene and Tropical Medicine; 2006.
21. Mechael PN; with the Dodowa Health Research Center. *MoTeCH: mHealth Ethnography Report.* http://www.grameenfoundation.applab.org/uploads/Grameen_Foundation_Final. The Grameen Foundation; August 1, 2009.
22. Chiba A, Lwina MO, Anga J, et al. Midwives and mobiles: using ICTs to improve health care in Aceh Besar, Indonesia. *Asian J Commun* 2008; 4: 348–364.
23. Gormley RH, Quinley KE, Shih T, et al. Use of mobile telemedicine for cervical cancer screening in Gaborone, Botswana. http://clickdiagnostics.com/wp/press/documents. Published November 2009. Accessed March 7, 2011.
24. Tsai HH, Pong YP, Liang CC, et al. Teleconsultation by using the mobile camera phone for remote management of the extremity wound: a pilot study. *Ann Plast Surg* 2004; 53: 584–587.
25. Schwamm LH, Holloway RG, Amarenco P, et al. A review of the evidence for the use of telemedicine within stroke systems of care: a scientific statement from the American Heart Association/American Stroke Association. *Stroke* 2009; 40: 2616–2634.
26. Parham GP, Mwanahamuntu MH, Pfaendler KS, et al. eC3–a modern telecommunications matrix for cervical cancer prevention in Zambia. *J Low Genit Tract Dis* 2010; 14: 167–173.
27. McWilliams J. Connecting cell phones with medicine in Botswana. http://www.upenn.edu/pennnews/current/features/111110-4.html. Published November 11, 2010. Accessed January 11, 2011.
28. mQure. http://www.mqure.com/about.html. Accessed March 5, 2011.
29. Telemedicine Reference Center Ltd. http://www.trclcare.com/products.php. Accessed March 5, 2011.
30. Schellenberg JA, Bryce J, de Savigny D, et al. The effect of Integrated Management of Childhood Illness on observed quality of care of under-fives in rural Tanzania. *Health Policy Plan* 2004; 1: 1–10.

DOI:10.1002/MSJ

31. Kelly JM, Osamba B, Garg RM, et al. Community health worker performance in the management of multiple childhood illnesses: Siaya District, Kenya, 1997–2001. *Am J Public Health* 2001; 10: 1617–1624.
32. DeRenzi B, Lesh N, Parikh T, et al. e-IMCI: improving pediatric health care in low-income countries. Presented at ACM Conference on Computer-Human Interaction (CHI 08); April 2008; Florence, Italy.
33. Rowe A, de Savigny D, Lanata C, et al. How can we achieve and maintain high-quality performance of health workers in low-resource settings? *Lancet* 2005; 9490: 1026–1035.
34. Rennert W, Koop E. Primary health care for remote village communities in Honduras: a model for training and support of community health workers. *Fam Med* 2009; 9: 646–651.
35. Rowe SY, Olewe MA, Kleinbaum DG, et al. Longitudinal analysis of community health workers' adherence to treatment guidelines, Siaya, Kenya, 1997–2002. *Trop Med Int Health* 2007; 5: 651–663.
36. Gilson L, Walt G, Heggenhougen K, et al. National community health worker programs: how can they be strengthened? *J Public Health Policy* 1989; 4: 518–532.
37. Martins HM, Jones MR. What's so different about mobile information communication technologies (MICTs) for clinical work practices? A review of selected pilot studies. *Health Informatics J* 2005; 11: 123–134.
38. Ho MR, Owusu EK, Aoki PM. Claim mobile: engaging conflicting stakeholder requirements in health care in Uganda. Presented at: International Conference on Information and Communication Technologies and Development; April 17–19, 2009; Doha, Qatar.
39. Lester RT, Ritvo P, Mills EJ, et al. Effects of a mobile phone short message service on antiretroviral treatment adherence in Kenya (WelTel Kenya1): a randomised trial. *Lancet* 2010; 376: 1838–1845.
40. Lehmann U, Sanders D. *Community Health Workers: What Do We Know About Them? The State of the Evidence on Programmes, Activities, Costs and Impact on Health Outcomes of Using Community Health Workers*. Geneva: World Health Organization; March 2007.
41. Pakenham-Walsh N, Bukachi F. Information needs of health care workers in developing countries: a literature review with a focus on Africa. *Hum Resour Health* 2009; 7: 30.
42. Harvey SA, Jennings L, Chinyama M, et al. Improving community health worker use of malaria rapid diagnostic tests in Zambia: package instructions, job aid and job aid-plus-training. *Malar J* 2008; 7: 160.
43. FrontlineSMS. http://www.frontlinesms.com. Accessed June 29, 2010.
44. Sherwani J, Palijo S, Mirza S, et al. Speech vs. touch-tone: telephony interfaces for information access by low literate users. Presented at: International Conference on Information and Communication Technologies and Development; April 17–19, 2009; Doha, Qatar.
45. Iyengar M, Florez-Arango J, Garcia C. GuideView: a system for developing structured, multimodal, multi-platform persuasive applications. Presented at: Persuasive 09: Proceedings of the Fourth International Conference on Persuasive Technology; April 26–29, 2009; Claremont, CA. http://portal.acm.org/citation.cfm?id=1541948.1541990.
46. Iyengar MS, Sarkar S, Bacal K, et al. GuideView: structured multi-modal delivery of clinical guidelines. *AMIA Annu Symp Proc* 2005; 992.
47. Iyengar MS. The GuideView mHealth system. http://www.slideshare.net/gueste312b0/the-guideview-mhealth-system. Accessed July 8, 2010.
48. First Days. http://www.cs.berkeley.edu/~divya/research/firstdays. Accessed June 29, 2010.
49. RapidSMS. http://www.rapidsms.org. Accessed June 27, 2010.
50. Zimic M, Coronel J, Gilman RH, et al. Can the power of mobile phones be used to improve tuberculosis diagnosis in developing countries? *Trans R Soc Trop Med Hyg* 2009; 6: 638–640.
51. Gormley RH, Kovarik C. The use of mobile telemedicine for remote diagnosis of mucocutaneous and cervical lesions. Presented at: Health Informatics in Africa Conference (HELINA); April 16–18, 2009; Abidjan, Cåo te d'Ivoire.
52. Khan R. ClickDiagnostics experiences from Bangladesh. http://groups.google.com/group/ict4chw/browse_thread/thread/96dd344a921f124e. Published May 12, 2010. Accessed July 7, 2010.
53. Källander K, Hildenwall H, Waiswa P, et al. Delayed care seeking for fatal pneumonia in children aged under five years in Uganda: a case-series study. *Bull World Health Organ* 2008; 5: 332–338.
54. Shankar AV, Asrilla Z, Kadha JK, et al. Programmatic effects of a large-scale multiple-micronutrient supplementation trial in Indonesia: using community facilitators as intermediaries for behavior change. *Food Nutr Bull* 2009; 30(2 suppl): S207–S214.

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