Mobile health for Cardiovascular disease risk screening and management in resource-constrained environments

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Abstract. Cardiovascular disease (CVD) is a leading cause of mortality and morbidity worldwide. Over 80% of these deaths occur in lower and middle-income countries where preventive measures are inadequate to control the rising burden of chronic disease. Novel approaches are therefore needed for incorporation of appropriate technology into the public health system. In this study, we present an mHealth platform for the screening and management of CVD in resource-constrained regions. The platform comprised a CVD risk prediction application (*HealthTracker*) that also provided point-of-care decision support for disease management to both physicians and health workers, as well as a server-side electronic medical record. The risk prediction algorithm was developed based on the World Health Organisation's CVD risk charts while treatment and management recommendations were taken from country-specific guidelines. This was followed by a stringent validation process including validation by an external physician. The end-to-end system was field-tested using 11 Accredited Social Health Activists (ASHAs) and 3 Primary Health Centre (PHC) doctors, who screened a total of 292 adults aged 40 years and above. Participants who were at a high-risk of developing CVD over a 10-year period were identified and flagged for referral. In over 72% of the screening procedures done, the HealthTracker application was found easy to use. No user gave the application a rating below 3 on a scale of 4, with 4 being most useful and 1 being least useful. The mHealth system was found acceptable for use amongst the local communities, ASHAs and PHC doctors. Technical and system-level barriers were identified to optimise design for a randomized controlled trial involving 54 villages and 16000 people.

Keywords: mobile health, cardiovascular disease risk, clinical decision support tool, primary care, LMIC, India

1 Introduction

Cardiovascular disease (CVD) implies a range of disorders that may affect the heart, arteries and circulation of blood. It includes heart ailments such as coronary heart disease (CHD), stroke, atherosclerosis and peripheral heart disease [1]. According to the World Health Organization (WHO), CVD accounts for the majority of deaths worldwide, much more than any other cause of mortality [2]. In 2008, deaths due to CVD amounted to 17.3 million with over 80% of them occurring in Lower and Middle Income Countries (LMIC) [3]. This number is expected to rise up to 23.6 million deaths per year by 2030 [3]. In developing countries like India where 70% of the population lives in rural regions, the doctor-to-patient ratio stands at 1:20000 [4] and access to prevention and control of chronic disease at primary care level is poor. Furthermore, the epidemiological transition from communicable to chronic disease as the primary cause of mortality has posed a substantial challenge to the health systems of LMICs - one of prioritising limited resources to manage the exponential demands of the health system [5]. Physician-centric, western style care is unsustainable in these regions and there is a need for more innovative solutions.

With 6 billion mobile phone subscribers in the world today and over 76% of them in developing countries [6], the penetration of mobile phones worldwide is substantial, with appreciable growth in developing nations in recent years. This is an enabler for the delivery of healthcare services through mobile technology (mHealth). In a 2011 World Bank study, over 500 mHealth studies were reported [7]. The most common mHealth interventions reported in the literature are based on text messages and phone reminders to encourage healthy behaviour, attendance at follow-up appointments and healthcare data collection [8]. However, after the completion of these initiatives, there is little evidence of adoption, best strategies for engagement, efficacy and effectiveness [9]. The other key challenge has been to move beyond pilot projects to nationally scalable programs [8]. Also, there are few mHealth studies which have demonstrated an impact on clinical outcomes in low income countries so far [8].

In this study, we have pilot tested a multifaceted healthcare worker intervention utilising a mobile health platform that comprises a clinical decision support tool in rural India. The outcomes focussed on a preliminary evaluation of the tool for utility, effectiveness and acceptability by the community, ASHAs and Primary Health Centre (PHC) physicians in this setting in order to inform large-scale evaluation.

2 Methods

2.1 Design of study

The mHealth platform was deployed across three villages in South-east India, involving 3 PHC physicians and 11 ASHAs.

The following methodology was followed during the study (as illustrated in Fig. 1):

1. The ASHA screens adults in her village using the *HealthTracker* application on the Android tablet. Information on the participant's demographics and medical history (including family history, treatment history) are collected using the application. CVD risk factors such as blood pressure and blood glucose levels are acquired using Bluetooth-enabled medical devices.
2. Point-of-care decision support is provided to the ASHA, who subsequently delivers management advice to the participant. Those at high-risk are advised to visit the PHCs.
3. Data is uploaded securely to a server hosting the electronic medical record. Relevant participant data of those who have been advised follow-up are available to the physicians.
4. Decision support is provided to PHC physician including the advice and treatment to be given to the individual. Physician reviews this and approves follow-up care plan.

mHealth system The mobile health system comprises, on the client side, the *HealthTracker* application and SanaMobile [10][11], an open-source telemedicine application. An Interprocess communication framework was developed for both these applications to share tasks and asynchronously exchange data. SanaMobile acted as the data management application and queued patient data for uploading to a middleware server which subsequently sent information to the online medical record system, OpenMRS [12][13]. *HealthTracker* was optimised to run on a higher-end version of a low-cost tablet($\approx$ £120) for use by ASHAs, and a Samsung Galaxy 7-inch tablet($\approx$ £240) to be used by physicians. A validated Blood Pressure device (Stabil-O-Graph [14]) was used which could interface with the tablet via Bluetooth. Blood Glucose was measured using the OneTouch Ultra2 glucometer. The application was designed to support the local language (Telugu) despite non-availability of the language within the standard framework of the Android Software Development Kit.

2.2 CVD risk prediction

The World Health Organisation/International Society of Hypertension (WHO/ISH) provide colour-coded charts for the prediction of a 10-year risk of fatal or non-fatal cardiovascular event (myocardial infarction or stroke) in different epidemiological subregions in the world [15]. There are different risk charts based on information on the absence or presence of diabetes. Also, depending on the availability and usage of cholesterol information, Low Information (LI) or High Information (HI) versions of the CVD risk charts are available. The colour-coded ranges in the WHO risk charts indicates five levels of CVD risk for different values of risk factors. The following information is necessary for the risk to be estimated:

- Presence or absence of diabetes
- Gender
- Smoking status
- Age
- Systolic blood pressure (SBP)
- Total blood cholesterol (TC), if known.

However, little is in the public domain about the underlying model and the corresponding risk prediction equations behind the WHO risk charts [16]. We therefore developed a model to mimic the WHO risk charts that gave a continuous score instead of a coarse risk range. The WHO charts can be represented by a logistic function, given by:

$$h(\mu) = \frac{1}{1 + e^{-\mu}} \tag{1}$$

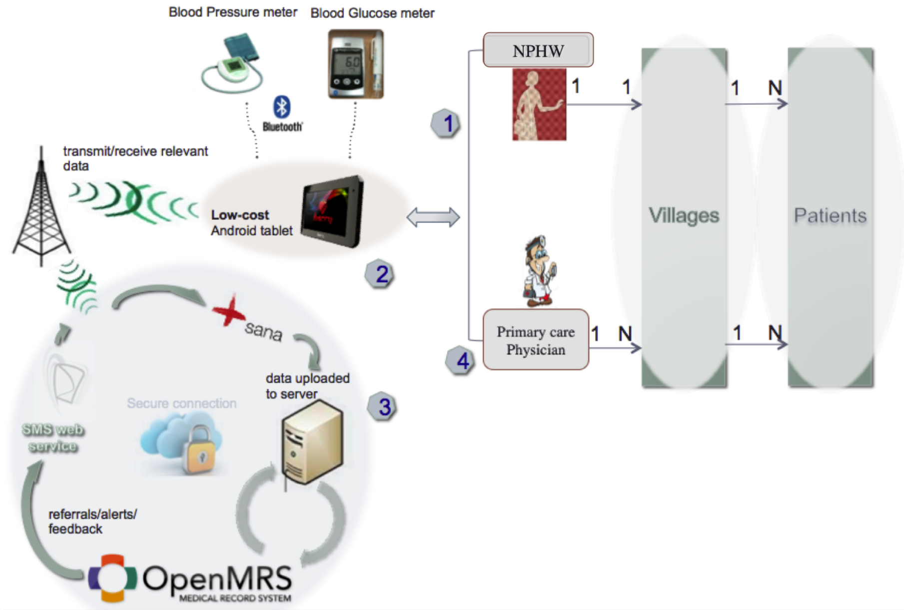

Fig. 1. Schematic diagram of the SMARThealth study

where μ is a linear function of the risk factors $x_1, x_2 \ldots x_k$ with the coefficients $\beta_0, \beta_1 \ldots \beta_k$, given by:

$$\mu = \beta_0 + \beta_1 x_1 + \ldots + \beta_k x_k \qquad (2)$$

The β coefficients for the HI continuous CVD risk model are described in Table 1. The 10-year CVD risk can be calculated by using the β coefficients for the corresponding risk factors in Equation 2.

Treatment and recommendations for the management of CVD were based on Indian national and international guidelines. The prediction and management applications were validated in two stages. The first stage involved using a large external dataset from the Andhra Pradesh Rural Health Initiative[17] based on which iterative refinements were made to the algorithm. In the second stage, correlation between the outputs from the algorithm and assessments from an external physician on 100 individuals was determined.

Table 1. Coefficients for HI WHO CVD risk charts. SBP stands for Systolic Blood Pressure (mmHg) and TC stands for Total cholesterol (mmol/L). Age is in years.

Variable	**Without diabetes** β	**With diabetes** β
Intercept	-0.5874	0.5926
Age		
18 to <40	-0.9558	-1.7805
40 to <50	-0.6842	-1.3741
50 to <60	-0.0368	-0.4561
>60	Referent	
Current Smoker	0.8628	0.8658
Female	-0.0174	0.0522
SBP		
>160	Referent	
140 to <160	-1.0957	-1.0507
120 to <140	-1.9991	-1.9687
<120	-2.8775	-2.8345
TC		
4 to <5	Referent	
5 to <6	0.4178	0.4930
6 to <7	0.9136	0.9610
7 to <8	1.3516	1.7822
>8	2.2018	2.3294

3 Results

Field evaluation was performed with 11 ASHAs screening 227 individuals (mean age of 51.42 ±13.09 years), while 3 PHC physicians independently used *HealthTracker* as a clinical decision support tool to screen 65 in-patients (mean age of 55.33 ± 11.66 years) who visited their clinic (total N=292).

CVD Risk profile Fig. 2 shows the distribution of a 10-year risk of developing CVD for the participants from rural India. It may be observed that most individuals were either at low risk (<10%) or high risk (due to a previous incidence of CVD or had a clinically high condition or both). This could be useful in terms of identifying and treating high-risk individuals for population-wide strategies to manage chronic disease.

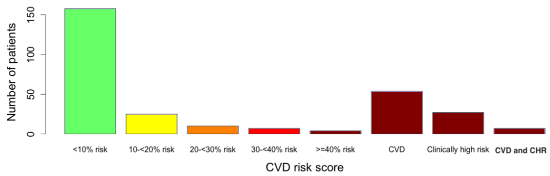

Fig. 2. Distribution of CVD risk scores (N=292). CHR denotes clinically high-risk.

Evaluation of mHealth platform The end users of the application (ASHAs and PHC physicians) were asked to complete a questionnaire at the end of every risk assessment procedure. In over 72% of the screening procedures done, the HealthTracker application was found easy to use for that particular procedure. Users concurred similarly on the usefulness of a graphic bar that visualised risk scores in communicating the meaning of absolute CVD risk reduction to the community participants. No user gave the application a rating below 3 on a scale of 4, with 4 being most useful and 1 being least useful. In less than 2% of the procedures done, the ASHAs recorded difficulties with collection of risk factors (such as blood pressure, height and weight, blood glucose). In-depth qualitative interviews with the ASHAs and focus group discussions were undertaken to identify barriers to the adoption of mobile technology.

4 Discussion

Community participants, ASHAs and PHC physicians agreed on the overall usefulness of the tool. PHC physicians particularly felt that *HealthTracker*'s graphical depiction of absolute risk generated enthusiastic responses from the participants and prompted them to take control of their condition. Community participants expressed satisfaction with the ability of the tool to be used on their doorstep for what they felt was a general 'check-up' of their condition. ASHAs felt that the tablet-based application enhanced their capacities as healthcare workers and their influence on communities to prompt lifestyle changes.

Barriers to scaling up of the mHealth system

1. **Technical barriers** There were instances from which the participant's data from the client did not reach the server. Retrospective analyses of uploads from the client side revealed flaws in the ability of the low-cost tablet to pick up the mobile signal. Software on the client side could not handle recurrent fluctuations in signal (such as between HSDPA and GPRS). In-depth interviews revealed that both ASHAs and PHC physicians expressed difficulty in operating Bluetooth medical devices during the initial period. However, continuous reinforcement through training and pictographic handouts proved useful to increase adoption and towards the completion of the study, end users felt they had few problems in operating devices. The widespread presence of CVD across all age groups may also indicate discrepancies in the participant's answer to questions related to their past history of CVD. This shows the need for refinement of the questions to get the best possible accuracy from the participants, without any misunderstandings.

2. **System-level barriers** *HealthTracker* referred high-risk individuals to consult a physician. However, access to a physician was a major barrier due to a variety of reasons such as limited availability. Competing priorities of ASHAs and PHC physicians reduced the adoption of the mHealth platform. Infrastructural barriers such as power constraints (as power supply was limited to fixed times of the day) had implications (for instance, the low-cost tablets had to be charged frequently or would not function optimally).

5 Conclusion

In this study, we designed and developed an mHealth platform in rural India for CVD screening and management with proper engagement of health care providers and local communities. Field evaluation found the platform to be acceptable and feasible for use. Technical and system-level barriers to the adoption of the mHealth system were identified which helped inform further optimisations needed for scaling up of the platform. A two year cluster randomised trial covering 54 villages in southern India will further evaluate the clinical impact of this mHealth platform.

Acknowledgments This study was funded by the NHMRC-Australia and Global Alliance for Chronic Diseases grant. Arvind Raghu is supported by the Wellcome Trust/EPSRC Centre for Excellence in Medical Engineering, Oxford, United Kingdom.

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