Engaging Patients through Mobile Phones: Demonstrator Services, Success Factors, and Future Opportunities in Low and Middle-income Countries

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Summary

Objectives: Evolving technology and infrastructure can benefit patients even in the poorest countries through mobile health (mHealth). Yet, what makes mobile-phone-based services succeed in low and middle-income countries (LMIC) and what opportunities does the future hold that still need to be studied. We showcase demonstrator services that leverage mobile phones in the hands of patients to promote health and facilitate health care.

Methods: We surveyed the recent biomedical literature for demonstrator services that illustrate well-considered examples of mobile phone interventions for consumer health. We draw upon those examples to discuss enabling factors, scalability, reach, and potential of mHealth as well as obstacles in LMIC.

Results: Among the 227 articles returned by a PubMed search, we identified 55 articles that describe services targeting health consumers equipped with mobile phones. From those articles, we showcase 19 as demonstrator services across clinical care, prevention, infectious diseases, and population health. Services range from education, reminders, reporting, and peer support, to epidemiologic reporting, and care management with phone communication and messages. Key achievements include timely adherence to treatment and appointments, clinical effectiveness of treatment reminders, increased vaccination coverage and uptake of screening, and capacity for efficient disease surveillance. We discuss methodologies of delivery and evaluation of mobile-phone-based mHealth in LMIC, including service design, social context, and environmental factors to success.

Conclusion: Demonstrated promises using mobile phones in the poorest countries encourage a future in which IMIA takes a lead role in leveraging mHealth for citizen empowerment through Consumer Health Informatics.

Keywords

Consumer Health Informatics, mobile health, low and middle-income countries (LMIC)

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1 Introduction

IMIA, in its capacity as an association of health informatics organizations worldwide, has equal responsibilities to foster health care in high-income countries as well as in low and middle-income countries (LMIC). The aim of our work is to study how evolving technology and infrastructure are benefiting patients even in the poorest countries [1] – more specifically, how mobile phones in the hands of patients or lay persons in need of health-related information can be leveraged in care management, prevention, health awareness, and disaster management. Mobile health (mHealth) is defined as the medical and public health practice supported by mobile technology, such as mobile phones, personal digital assistants, and other wireless devices [2]. Mobile health provides a powerful platform for health interventions [3, 4], but evidence is critical for implementation and "scaling up" of mHealth [5]. Using such information and communication technology to empower individuals to play an active role in healthcare is a core driver of Consumer Health Informatics and the respective IMIA working group.

Although mHealth presents significant opportunities for delivering interventions that facilitate disease management and health behavior change, the vast majority of controlled trials are limited to high-income countries [4]. Benefits of mHealth, such as short message service (SMS) appointment reminders [4], could be demonstrated in LMIC where growing opportunities flourish with expanded access to mobile technology. Of nearly 7 billion mobile phone subscribers worldwide, three quarters reside in LMIC where penetration is expected to reach 90% by the end of 2014 [6]. Yet, mobile broadband remains the fastest growing market segment, particularly in LMIC that makes up to 55% of the 2.3 billion mobile broadband subscriptions worldwide [6]. To leverage this growing opportunity for mobile technology, it is important to understand not only the potential effects of mHealth interventions in LMIC, but also the contextual factors that can influence success, ranging from local resource constraints to language, cultural beliefs, and customs.

To expand our understanding of mHealth opportunities, we surveyed related research conducted in LMIC. Our goal was to identify illustrative examples that we call "demonstrator services", and to synthesize insights about opportunities, enabling factors, and pitfalls that shape success in the LMIC mHealth landscape. Because of the broader penetration of traditional mobile phones in LMIC relative to emerging wireless broadband devices such as smart phones, our literature survey highlights mobile-phone-based health interventions that make up the breadth of prior mHealth research. We discuss opportunities for the application of mHealth as the penetration of mobile technology in LMIC grows. We selected demonstrator services with the intention to provide recommendations for future mHealth efforts by examining (i) what research has demonstrated positive outcomes in the health application of

mobile phones in LMIC, (ii) what opportunities show the most promises for future mHealth research and practice in LMIC, and (iii) what challenges and safeguards developers should have in mind.

2 Methods

We identified demonstrator services through a survey of biomedical research published in the years 2008-13, during which the application of mHealth has globally expanded. We restricted our search to articles reporting studies conducted in LMIC, and then filtered articles in a 3-step process to identify demonstrator services across a breadth of regions, mHealth service types, and health domains.

2.1 Identification of Low and Middle Income Countries (LMIC)

To limit our survey to LMIC for which evidence of mHealth effect has been least explored [4], we identified the poorest countries according to the following indicators:

- *Inequality-adjusted Human Development Index* (IHDI) is sponsored by the United Nations Development Program and captures life expectancy, education, and income, discounted for inequality [7];
- *Life expectancy* (LE) refers to the anticipated number of years of remaining life at a given age and captures the risks associated with maternal and child health (e.g., infant mortality, infections, malnutrition), and health care [8];
- *Per Capita Gross Domestic Product* (GDP) is the basic financial endowment of a national economy that can support health care, health education, and nutrition expenditure [9];
- *Economic development ranking* provided in the World Economic Outlook by the International Monetary Fund [10].

We found that these four indicators identified a consistent set of 125 poorest countries in which ranks correlated near 1.0. We decided to rank countries using GDP. We used the World Bank 2011 list of countries to split the 125 lowest GDP countries into five tiers of 25 countries each. We then used those groups to compare the prevalence of mHealth research by tier and to select representative demonstrator services from each tier. As we describe next, we used LMIC names in our search strategy.

2.2 Search Strategy

The bibliographic search was handled using PubMed. Because the wide dissemination of technology in LMIC began over the past decade with a recent surge in research published on health-related services that use mobile communication technology ("mHealth services") [11], we restricted our search to articles publishing studies conducted in the 125 LMIC between 2008-2013 using the following query: [LMIC name] AND (cellular phone[MeSH] OR text messaging[MeSH] OR texting[TIAB] OR short text message[-TIAB] OR text messaging[-TIAB] OR mobile phones[TIAB] OR mobile phone[TIAB] OR cell phones[TIAB]) research about.

Although PubMed includes research about emerging mHealth technologies, no MeSH terms specifically target "smart phones" or "mHealth". In our query development and preliminary searches, we found that the latter terms, less consistently used than "mobile phones", returned a highly inhomogeneous set of articles inappropriate for systematic treatment. Thus, we narrowed our search to mobile-phone-based mHealth services.

2.3 Article Filtering

We used a 3-step method to filter the articles returned from the query. For each step, we used a challenge-response process whereby one author made conjectures that the other author either confirmed or challenged before moving to the next step.

Step 1: Screening: Except when full text was unavailable in English, we screened all abstracts, and we included articles that reported on a specific service (i.e., mobile-phone-based features, such as SMS, or phone communication features) and that were pertinent to Consumer Health Informatics, including services targeted to health consumers (e.g., patients, clients, general public). We included articles describing primary studies and reviews for detailed review in Step 2. We excluded articles that described services targeted to only health professionals or researchers.

Step 2: Detailed review: We collected the full text of articles screened for inclusion in Step 1 for a detailed review of service types, study designs, health domains, populations, and outcomes. We combined the review of articles in which authors describe the same service and then selected one article as the most representative for that service. We differentiated articles by study quality (e.g., study design, sample size), meaningfulness and impact of the achieved outcome, and other noteworthy features (e.g., unique perspective or insight) from which we could select illustrative examples in Step 3.

Step 3: Arbitration: In Step 3, we conducted a process of arbitration among the articles of good methodological quality where we sought to balance the selection of demonstrator services across LMIC tier and health domain.

3 Results

We first summarize the characteristics of the collection of articles we surveyed (3.1). Then, we describe insights emerging from the current landscape of mobile-phone-based services in LMIC through a detailed analysis of the articles selected in Step 3, including illustrative demonstrator mobile-phone-based services (3.2) and contextual factors that influence success (3.3).

3.1 Characteristics of Surveyed Articles

Our PubMed search resulted in a total of 227 articles, which after filtering resulted in 21 articles representing 19 demonstrator services (Table 1). During screening (Step 1), we excluded 161 articles based on their abstracts. The lack of the MeSH keyword "Consumer Health Informatics" led to the unfiltered retrieval of non-pertinent articles that described mobile phone technology

designed for health professionals rather than for patients or where environmental effects of mobile technology (e.g., radiation risks, unsafe driving, addiction) were investigated. The remaining 66 articles were included for the detailed review (Step 2).

During the detailed review of full texts (Step 2), we excluded 12 articles that did not meet inclusion criteria. Analysis of the remaining 54 articles by study type revealed 14 randomized controlled trials (RCTs), five other quasi-experimental designs, seven reviews, eleven observational studies on social fabric or other factors that enable or impede mHealth, 14 feasibility studies, and three articles that applied big data analytics in which mobile phone usage data was used to analyze pathways for infections.

Through arbitration (Step 3), we purposively sampled 21 articles that showcased 19 distinct demonstrator services. Our goal was to report on a breadth of services across LMIC tiers and health domains. For example, multiple articles described SMS reminders. We selected a balance of studies across tiers in which SMS reminders were applied in different health domains (e.g., childhood vision, chronic illnesses, HIV). We focused our selection of demonstrator services to illustrate both the best quality studies (e.g., RCTs) as well as studies that showed noteworthy factors, which enabled or challenged success. In two instances [12; 13], we selected one of two separate articles reporting on the same demonstrator service. For example, two articles described the "SMS Turkey" smoking cessation program: mHealth service design [12] and evaluation [14]. We chose the latter article as a demonstrator service because it reported associated outcomes.

Table 1 Articles screened, reviewed, and selected

Tier	Screened	Reviewed	Selected articles (services)
(1) Lowest	52	10	4 (3)
(2) Second lowest	80	20	5 (5)
(3) Middle	18	4	3 (3)
(4) Second highest	30	8	3 (3)
(5) Highest	47	13	6 (5)
TOTAL	227	55	21 (19)

3.2 Demonstrator Services

Table 2 provides details of the 19 selected demonstrator services and supporting articles. We distinguish the study designs used to assess the interventions deployed through the demonstrator services, including a range of experimental and feasibility studies [15]. Mobile-phone-based interventions varied widely across the 19 demonstrator services, and several services offered combinations of interventions that provided mobile education, reminders, reporting, peer support, epidemiologic case reporting, and mobile care management such as phone communication and messages. We describe demonstrator services across 4 emergent categories, including service use for *complex clinical care* (6 services), *health attitudes and primary prevention* (7 services), *infectious diseases* (4 services), and *population health* (2 services).

3.2.1 Enhancing Complex Clinical Care

Treatment for congenital and developmental cataracts can reduce avoidable blindness, but postsurgical follow up is crucial to restoring vision. In China, severe visual impairment is a common consequence of insufficient follow up in pediatric patients. The impact of short message service (SMS) reminders sent to parents of pediatric cataract patients about follow up appointments was examined to support timely management of cataract post-surgical care [16]. The RCT with children treated at an ophthalmic center found that SMS reminders (n=135) led to higher attendance rates than standard follow up appointments without reminders (n=123), with the most pronounced increases after longer-term use of SMS. Largely due to differences in follow up attendance, the authors found SMS reminders were associated with a greater number of potentially sight saving post-operative interventions. Although the study did not examine barriers to follow up, the convenience and low cost of mobile phones may help address common barriers to communication with healthcare providers. The nonattendance rate in the control group was considerably higher than the one measured in studies using similar interventions in high income countries, which the authors attribute to adherence challenges faced by LMIC parents responsible of small children.

A long-standing project from Nigeria [17] demonstrates the potential of mobile phones for cancer patients to communicate directly with their oncologists for their care management. Patients often have trouble getting answers to disease-related questions and often miss follow up appointments. A two-year cohort study with cancer patients recruited from a University teaching hospital found that 98% of patients who were offered mobile phone communication with providers kept their appointments, whereas only 20% of patients in the control group, without mobile phone access, maintained appointments (n=219). In the intervention group only 20% had more than primary education, only 7% preferred calling in English over their local language, 2 in 3 lived more than 200 km from the hospital, less than 1 in 2 owned a mobile phone, and all but 28 made calls to their provider. Yet, this positive outcome was not achieved by any kind of reminder. Rather, patients took the opportunity to contact their provider whenever they wished. Patients made nearly 20,000 calls in the two years to discuss their illness (in more than 70% of the cases) or to schedule visits. This communication empowered patients in their follow up care and helped doctors to identify emergencies comprising 14% of the calls. Interviews conducted when patients reached their 2-year endpoint revealed that communicating with the provider served as a "morale booster" and eliminated transportation costs, including time spent travelling long distances to the hospital..

In Malaysia, SMS and phone call reminders were tested to increase the follow up attendance of patients with chronic diseases [18]. Patients recruited from two primary care clinics were randomly assigned to SMS reminders (n=308), phone call reminders (n=314), or no reminder (n=309). SMS and phone calls were deployed by a research assistant, and attendance was defined as showing at the appointed time or rescheduling and then showing. Reminders were significantly associated with higher attendance, including 86% attendance with phone calls and 84% with SMS, as compared to 77% with no reminder. Cost effectiveness was not evaluated, but future work could weigh the increased human effort for multiple phone calls required to reach patients against implementation through automatically deployed low-cost SMS.

Table 2 Demonstrator services and supporting articles

Article	Service type	Study design	Health domain	Population	Key Outcome*	Country (Tier)
[16]	SMS appointment reminders	RCT	Childhood vision	Parents of pediatric cataract patients	Appointment attendance$^{B,O,+}$	China (4)
[17]	Mobile phone communication	Cohort study	Cancer	Cancer patients	Appointment attendance$^{B,O,+}$	Nigeria (2)
[18]	SMS appointment reminders	RCT	Chronic illness	Patients with chronic conditions	Appointment attendance$^{B,O,+}$	Malaysia (5)
[19]	IVR-based education	Pre-post study	Type II diabetes	Diabetic patients	Blood glucose level$^{C,O,+}$	Honduras (3)
[20]	SMS reporting & peer support	Pre-post study	Type II diabetes	Diabetic women	Blood glucose level$^{C,O,-}$	South Africa (5)
[21]	Mobile phone communication, mobile phone messages, SMS reminders	RCT	Suicide prevention	Suicide attempters	Self harm^{B}	Sri Lanka (3)
[22]	SMS education	RCT	Iodized salt consumption	Housewives	Urinary salt concentration^{C,O}	Iran (5)
[23]	SMS appointment reminders	Prospective observational study	Childhood immunization	Mothers of newborns	Vaccination status$^{B,S,+}$	Kenya (2)
[24]	SMS education	RCT	HIV awareness & prevention	General public with mobile phone numbers	HIV testing uptake$^{B,S,+}$	South Africa (5)
[25]	SMS education	Feasibility survey	HIV awareness & prevention	Convenience sample of general public	SMS usage and perceptions^{B,S}	Papua New Guinea (3)
[26]	Phone reporting	Behavioral survey	Sexual behavior	Female sex workers	Condom breakage^{B,S}	India (2)
[27]	SMS education upon request	Prospective observational study	Family planning	General public	Change in family planning methods^{B,S}	Tanzania (1)
[12, 14]	SMS education	RCT	Smoking cessation	Smokers willing to quit	Abstinence^{B,S} verified with carbon monoxide readings^{C,O}	Turkey (5)
[28]	SMS treatment reminder	RCT	Antiretroviral therapy	Patients with recently initiated therapy	Treatment adherence$^{B,O,+}$	Kenya (2)
[29]	SMS support reminder with prompts; mobile phone communication	RCT	Antiretroviral therapy	Patients with recently initiated therapy	Viral load$^{C,O,+}$ Treatment adherence$^{B,S,+}$	Kenya (2)
[30]	Mobile phone treatment reminders	RCT	TB	Patients recently diagnosed with TB	Sputum conversion$^{C,O,+}$ Cure$^{C,O,+}$	Thailand (4)
[31]	Mobile phone treatment reminders	Cost-effectiveness analysis	TB	TB Patients pooled from 5 investigations	Cost per DALY	Thailand (4)
[32]	Mobile phone usage data	Data analytics	Malaria	Mobile phone users in Zanzibar	Estimated malaria importation^{B,O}	Tanzania (1)
[13]	Mobile phone usage data	Data analytics	Cholera	Mobile phone users in Port Au Prince	Population movement during cholera outbreak^{B,O}	Haiti (1)

* Outcome type (C=clinical; B=behavioral), collection method (O=objectively measured, such as lab tests, S=subjectively measured, such as self-report survey), and direction (+ = improved, - = worsened)

RCT = Randomized controlled trial
IVR = Interactive Voice Response
DALY = Disability-Adjusted Life Years
TB= Tuberculosis

Diabetes is a growing problem globally, and limited healthcare services, inadequate transportation, and other barriers pose significant challenges to disease management. In Honduras, where 84% of the population has mobile phone access but where resources for maintaining local computing infrastructure are limited, a mobile education service was deployed to deliver recorded diabetes self-help messages aligned with patient-selected topics. Patients used touch-tone or verbal utterances for automated voice recognitionThis interactive voice response (IVR) resource was hosted in the United States as a cloud-based program [19]. Diabetic patients (n=85) were recruited from primary care visits in semi-rural Honduras to weekly receive IVR calls and tailored instructions for six weeks. Status updates were sent to patients' clinical teams and family members could receive IVR calls with support suggestions. IVR completion rates were logged and pre-post comparisons were made for A1c glycemic control and self-reported diabetes-related

behaviors (e.g., diet, foot care). Program use was associated with a reduction of A1c at 6 weeks, with larger reductions in patients that completed the majority of IVR calls. Patients with more diabetes–related distress, higher blood pressure, and longer travel time to the clinic had higher completion rates. However, lower completion rates were present for patients with poorer health and limited literacy. Beyond demonstrating technical feasibility for scaling up in computationally resource poor settings, the study found high satisfaction among participating patients.

In South Africa, where overeating an unhealthy diets co-exist with malnutrition, services to fight metabolic syndrome are emerging, such as transforming the "Power to Prevent" SMS reporting and peer support service developed for African-Americans in the US for a Township in Cape Town [20]. Twenty-two women with diabetes were recruited from a local health clinic to take part in a 6-month study to assess program feasibility. In addition to psycho-educational sessions over 12 weeks, mobile services included daily SMS probes to report achievements toward health goals and SMS peer support with a randomly paired buddy. Participants attended the majority of group sessions, reported on about half of the SMS probes and kept exchanging SMS with their buddies beyond the end of the program. However, BMI, blood pressure, and blood glucose worsened and no change was found in daily step count after 6 months. Hours of sleep increased significantly between onset and 3 months. With the exception of decreased spiritual hope, coping measures did not change between onset and the end of the study. The authors propose a number of barriers that may underlie this negative health impact, such as broken phones and time required to shift neighborhood norms, as well as cultural beliefs regarding the determinants of diabetes.

Although suicide can be prevented through effective therapy, suicide death rates in Sri Lanka are twice as high as the world average. Lack of health care workers for follow up care limits secondary prevention programs. The "Brief Mobile Treatment" (BMT) program was designed to augment conventional face-to-face therapy comprised of mental health assessment, introduction to meditation, problem solving, increasing social support, and reducing addictive substance use. A mobile service follows face-to-face therapy with ten mobile phone calls to the patient, continuous access to five-minute audio phone messages, and weekly SMS reminders that also encouraged the use of SMS or a call for help [21]. Sixty-eight patients released from inpatient treatment of a suicide attempt were recruited from a teaching hospital to receive a mobile phone and call credit. Participants were randomized to 26 weeks of either immediate BMT or 6 months waiting list followed by delayed BMT. Both groups improved significantly on assessments of suicidal ideation, depression, and social support at baseline, six months, and twelve months. However, no reduction in self-harm was observed.

3.2.2 Influencing Health Attitudes and Primary Prevention

Although controlling iodine deficiency prevents harmful effects on the developing brain, salt iodization programs are difficult to monitor and sustain. Over the past two decades, Iran has witnessed iodine deficiency demonstrating the need for public awareness on iodized salt consumption. An SMS campaign was designed to deliver education on iodine deficiency and proper storage of iodized salt [22]. Through an RCT with 205 women recruited when visiting a health center, investigators evaluated the impact of this SMS education service on knowledge, attitudes, behaviors, and clinical parameters through questionnaires and measurements related to iodine use. Both groups first received brief fixed-line phone education about iodized salt. The intervention group (n=95) subsequently received daily SMS messages for six weeks with information about iodine deficiency, and consumption and proper storage of iodized salt. Both groups improved on all outcomes at two weeks after the last SMS in the intervention group. Although the SMS intervention had a significant positive impact on knowledge and attitudes about iodized salt consumption, no significant group differences were found in storage practices or urinary iodine concentration after eight weeks. Thus SMS education may hold promise for increasing patient knowledge, which is an important enabler but not a guarantee of behavior change and health impact.

In rural Kenya, where childhood mortality affects one of five children under the age of five and infection remains a major health concern, early childhood vaccinations are a powerful preventive approach. However, many children remain unvaccinated or are vaccinated late. In a feasibility study with 72 enrolled mothers, investigators examined to what extent SMS reminders about scheduled immunizations could improve timely vaccination [23]. Mothers of newborns with access to mobile phones were recruited from 30 villages near a rural health center. Participants received SMS reminders three days in advance and on the day of the two scheduled vaccinations after birth. Participants were provided either cash or airtime worth the Kenyan average income for one day each time they brought their child to one of the two appointments. Fourteen weeks after birth, vaccination adherence was established by home visits. Investigators noted logistical challenges: some mothers were incorrectly registered, moved, or did not receive reminders; some husbands objected to study participation; for some participants vaccine was unavailable; others obtained vaccination at undesignated clinics; and others simply forgot appointments. Together, these hurdles contributed to a 35% loss of follow up rate. For the remaining, 65%, vaccination rates showed 90% coverage for the first vaccination and 86% for the second. Although this service appears effective when delivered accurately from end to end, scales up easily, and could benefit vaccination rates broadly, logistical challenges can greatly affect impact.

HIV counseling and testing (HCT) can address prevention and transmission, but uptake remains low in many parts of the world. In South Africa, rates of HIV morbidity and mortality are among the highest in the world, and the government campaigned to shift voluntary testing to provider-initiated testing. Yet, this strategy misses those who lack healthcare access. To address this gap, investigators evaluat-

ed the effectiveness of an SMS education campaign to encourage HCT [24]. A web service was used to send SMS that varied in style and frequency. From a random sample of 24,000 mobile phone holders contacted via SMS, 2,533 participants were randomly assigned to one of the four intervention groups that received 3 or 10 informational or motivational SMS, or to the control group that received no SMS. For each type of SMS, half of the intervention participants received three SMS in nine days and the other half received ten SMS in one month. Just over half of the participants responded to a query about their testing status three weeks later which showed that SMS with motivational style were more effective at encouraging testing than messages with informational style, and receipt of 10 messages was more effective than receipt of 3 messages. Investigators report on barriers elicited from participants who chose not to test, including lack of time, poor access to testing services, and fear of testing. Findings demonstrate the potential for SMS as an educational channel, but that simply applying mobile dissemination is not enough – message style and frequency also matter. By drawing from 105,000 mobile numbers in South Africa the methods show potential for substantial coverage, yet questions remain about reaching the target population and sustainability. Low turnout may be owed to the same reason found in other LMIC countries – people change SIM cards frequently and SMS may be sent to unattended numbers. The study used a "PCM" (free 'please call me' line) that bears no cost to the recipient and thus promotes adoption in resource-limited regions, but turnout was not compared to a condition where recipients face cost. Therefore, funding for the cost or recipient willingness to pay should be assured before implementation.

With a 30% yearly increase in HIV from 2003 to 2007, Papua New Guinea (PNG) is among the critical hotspots with greater than 10% HIV prevalence. A national initiative is planned to use SMS education to change attitudes and address misconceptions about HIV. The educational program built on demonstrated success factors to bridge local language and culture in supporting HIV/AIDS education, awareness, and information dissemination in rural PNG [25]. To serve this geographically diverse island state with multiple languages and low literacy, many governmental and industry stakeholders that promote HIV/AIDS awareness, including the Catholic Church, are encouraged to participate. Despite a common vision, stakeholder approaches differ such as whether or not to encourage contraception. To enable cooperative effort for HIV/AIDS education, a nationwide architecture is proposed to tailor HIV/AID content to different stakeholder groups. For example, quiz-based SMS education is tailored to public campaigns about the "ABCs' (i.e., abstinence, being faithful and condom use), and alternative SMS content is tailored to train health workers for programs in church-run health facilities. To assess the feasibility of mHealth as a practical deployment platform for this program, investigators conducted a survey to examine SMS usage trends and perceptions about mobile phone technology in a convenience sample of 365 citizens reflecting the geographical and cultural diversity of PNG. By collecting the number of text messages sent the previous day, the survey demonstrated the popularity of SMS use in PNG. The survey also identified seven factors pertaining to mobile phone perceptions, ranging from the utility as a personal aid to its diffusion in schools, business, and healthcare. These findings indicate that mobile phone technology in PNG shows potential to promote HIV/AIDS knowledge and awareness through remote SMS education across geographically dispersed PNG.

In India, investigators examined the feasibility of using mobile phones to survey female sex workers (FSW) about sexual practices with frequency of condom breakage in HIV hotspots as a primary outcome [26]. Participants included approximately 300 of the 20,000 FSW in Bangalore recruited from community-based sex worker organizations. Each participant received a mobile phone they could keep. A subsample of 32 participants engaged in focus groups to explore the acceptance of using mobile phones for reporting and the truthfulness of answers. Phone surveys were conducted daily for 2 months by 9 interviewers with training in establishing rapport and supervisors monitored calls for data quality. Findings showed 8% condom breaks with qualitative insights regarding sexual practices. Unintended benefits were the interviewers' caring attitude towards participants that built rapport and left participants feeling appreciated. Nearly 90% of participants stayed in the study and answered every survey question. Some participants found the study to increase their awareness for safe sex and condom quality, resulting in changed practices. However, 554 staff would be required to scale the program to the size of Bangalore with over 20,000 sex workers.

Mobile phones offer enormous potential for disseminating family planning education in LMIC countries where fertility rates remain high and obstacles, such as limited access, cost, and misconceptions about side effects, prevent contraception use. In Tanzania these barriers are being addressed through the Mobile for Reproductive Health (m4RH) initiative, an interactive SMS education service that disseminates information about family planning methods [27]. Over 10 months, data logs from the 2,870 unique users from the general public who accessed m4RH showed that natural family planning and emergency contraception were the most frequent types of contraception queried. One in five users responded to text questions about how the program changed their family planning practices, of which only 2% reported no change while 11% of responses could not be deciphered. Self-reported impact of m4RP on family planning practices reflected changes in contraceptive use, most frequently involving the use of injectables, implants, and condoms. Findings on behavioral impact should be interpreted with caution since the baseline contraceptive method was unknown and answers may be positively biased given the suggestive nature of asking about change.

Although the heaviest users were adolescents and young adults, m4RH reached a diverse range of the public. Study findings demonstrate that information about contraceptive methods can feasibly be delivered and accessed by individuals of reproductive age through mobile phones which points out the potential of the service to address

barriers to contraception use in Tanzania. Although the potential for scalability and reach appears high, the observed focus of queries on natural and emergency methods shows there is room to broaden knowledge about other methods.

Cigarette smoking remains a major contributor to morbidity and mortality, particularly in countries where smoking remains prevalent. To increase quit rates, smoking cessation programs need to be easily accessible and to reach a large number of people. In Turkey, where mobile phone use is common, SMS-based programs present an opportunity for scalable and cost-effective smoking cessation [12]. Investigators enrolled 151 citizens of Ankara willing to quit smoking and randomized 76 to "SMS Turkey" and 75 to the control group that received a smoking cessation brochure [14]. Grounded in cognitive behavioral therapy elements used for in-person smoking cessation programs, SMS Turkey sends SMS with content and frequency tailored to the individual's current phase of cessation. Through the RCT, investigators examined the efficacy of daily SMS over 6 weeks. Overall cessation rates were low and no group difference was reported three month after the beginning of the study. However, subgroup analysis found SMS were more effective for woman and light smokers. Although these results do not support broad efficacy, the investigators report a number of implementation barriers that can help guide future efforts. For example, the software program used to deploy SMS Turkey failed to send some messages, sent some duplicate messages, and was incompatible with some mobile phones. Although technology can provide cost-effective alternative for broad dissemination of health care services, this study points out the critical importance of ensuring a supportive technical infrastructure.

3.2.3 Treating Infectious Diseases when Prevention Fails

Despite worldwide efforts to prevent the spread of infectious diseases, the prevalence and incidence of HIV, tuberculosis, and other infections is high and growing in numerous LMIC. Although efforts aim to control HIV/AIDS through antiretroviral therapy (ART) and prevention programs, poor infrastructure and increasing health care costs represent significant barriers. Poor therapy adherence frequently causes relapse of the disease requiring 2nd line treatment. Wireless communication technologies including mobile phones are among strategies included in the strategic plans of the United Nations Joint Programme on HIV/AIDS (UNAIDS) and World Health Organization (WHO). Of the emerging evidence on the therapeutic benefit of such mHealth approaches, we first present two cases in which mobile services improved therapy adherence for HIV/AIDS, and then describe similar evidence for tuberculosis (TB).

In the first approach [28], adults with recently initiated ART at a rural clinic in Kenya received a mobile phone and were randomly assigned to the intervention arm with SMS treatment reminders (n=293) or to the control arm with no reminder (n=139). Patients receiving reminders were assigned to one of four groups in which SMS varied in style (i.e., reminder prompt with or without encouragement) and frequency (i.e., daily or weekly). Over 48 weeks, these messages reminded patients to take the medication. ART adherence was established through the number of missed doses and treatment interruptions (>48h) recorded through a medication event monitoring system (MEMS)—a bottle device where openings were registered electronically. MEMS readings were taken monthly at the clinic and new airtime was added to the mobile phone during those visits. Both control and intervention groups improved therapy adherence at onset, but after 12 weeks, treatment adherence was significantly greater for the group who received weekly reminders. Interestingly, providing SMS with encouragement was no more effective than short reminder prompts alone.

The second approach "WelTel Kenya1" is a mobile care management service that promotes treatment adherence by facilitating communication between health workers and patients starting ART [29]. Patients recruited from three clinics in Kenya were randomized to standard care (n=265) or WelTel Kenya1 (n=273). WelTel Kenya1 consisted of weekly SMS support reminders that inquired patients about their status, typically asking "Mambo?" which is Kiswahili for "How are you?". Patients that did not answer within 48 hours or answered with "Shida" (i.e., "problem") received a phone call from a clinician. Patients in the intervention group could also call the clinician during working hours. After 12 months, both self-reported therapy adherence (i.e., less than 5% missed doses) and viral load suppression were better in the intervention group, even significantly better in an intention to treat analysis with larger gains in the self-reported therapy adherence. Nurse workload to make follow up phone calls to the 3% of patients reporting problems was low and suggests that the approach scales up. For example, one nurse could potentially follow 1,000 patients by SMS, requiring follow up calls to about 33 patients each week. However, the fact that only few patients report problems to nurses does not necessarily reflect a "healthy" population that is largely problem-free. Nor does the 30% of weekly SMS that were not answered reflect dissatisfaction. Future work could explore why greater improvement was found in self-reported therapy adherence than in measured viral load. Furthermore, future implementations with more enrolled patients, or for which more problems are reported could impact the scalability of this approach.

We next turn to two cases in which similar mobile services improved adherence to TB therapy. TB control remains a major public health problem particularly in Thailand, which ranks 18th out of 22 high-burden countries. Ensuring adherence to self-administration of a strict daily treatment regimen over several months is challenging for many patients. Thus, WHO recommends strategies that use supervision for directly observed treatment (DOT) by health workers, community members, or family members. SMS reminders present a potentially lower cost alternative. We present two investigations to report on both the cost-effectiveness and treatment efficacy of these mobile services.

Successful TB treatment requires a rigorous assessment of multi drug resistance (MDR) with subsequent treatment and follow up. Given the complexity of delivering

treatment, it is no wonder that WHO targets are difficult to meet in remote regions of LMIC. In two Northern Thailand provinces, investigators compared conventional DOT short course (DOTS) according to WHO recommendations (model 1) with DOTS plus daily treatment reminders via mobile phone calls (model 2) [30]. Patients newly diagnosed with MDR (n=38) and non-MDR TB patients (n=60) were recruited from public hospitals and randomly assigned to each model. Patients treated with model 2 fared better. Their sputum conversion rate was much higher than for patients treated with model 1. 100% cure was achieved at 6 months (non-MDR-TB) and 18 months (MDR-TB) compared to 98% (non-MDR-TB) and 74% (MDR-TB) in model 1. The strongest effect was survival probability in the MDR-TB group, where no patients died after 3 months of treatment. The investigation pointed out a highly desirable carry over effect in which TB incidence declined dramatically outside the study population as well.

In the second case [31], the cost-effectiveness of different TB control strategies operated in Thailand, including a mobile service, was evaluated. Data from investigations over the past 15 years were used to relate efficacies reported for different interventions to cost and extrapolated utility of the outcomes. The analysis targeted HIV negative TB patients aged 15 and older, including 18,313 males and 7,502 females, to compare intervention success (i.e., 6 month adherence or cure) and failure (i.e., patient default or treatment failure). Five daily treatment adherence methods were compared over 6 months, including self-administration (no supervision), DOT by a health worker at a health-care facility, DOT by a volunteer in the patient's community, DOT by a family member, and mobile phone medication reminders from village volunteers who previously completed treatment. Efficacy results were mixed. Extrapolating those results to intervention costs and to the lifetime utility of achieved health outcomes did not favor one intervention over any other. Self-administration was most expensive for government because of the higher failure rate compared to DOT by health workers. However, the cost for patients was highest for DOT by health workers due to the expense of traveling to and time spent at the health care facility. Although mobile phone reminders and DOT by family member methods demonstrated cost savings, the mobile intervention was associated with less health gain than other methods. Nonetheless, this study provides insights into potential costs to different stakeholder groups and trade-offs between cost-savings and health gains among TB control strategies.

3.2.4 Using Mobile Data for Population Health

In the following two approaches, mobile phones are used to foster population health by supporting an emerging form of epidemiologic case reporting. Rather than conveying health information, large scale time and location data are extracted from mobile phones to establish movement patterns in order to inform health authorities about the whereabouts of people and the risks of communicable diseases propagation. We highlight two examples of data analytic approach, one focused on the control of malaria and the other on cholera.

An investigation of malaria control on the island of Zanzibar used mobile phone data to calibrate mathematical infection propagation models [32]. In Zanzibar, malaria is nearly extinct and investigators examined the feasibility of this mHealth approach for detecting imported cases and controlling onward transmission. The risk of importing malaria into Zanzibar depends on where travelers come from, where they stay in Zanzibar, and for how long. Tourists, for instance, are less likely than other travelers to carry the plasmodium parasite, and they have limited exposure to indigenous people. Tourists are also more likely to come by plane than by vessel. In contrast, returning residents typically stay longer and immerse themselves more. Yet, to inform malaria control, it is necessary to differentiate travelers, and measure how long they stay. By mapping call time and location data onto the parameters of infection models, investigators constructed travelers' movement trajectories over time. Malaria infections were found to largely result from imported cases and subsequent transmission, with an estimated importation rate of 1.6 infections per 1,000 inhabitants per year. Zanzibar residents traveling to malaria endemic regions were estimated to contribute between 1 and 15 times more imported cases than infected visitors. In particular, without imported malaria, the reproduction rate is below one and the disease would eventually be extinguished. More importantly, the investigators predict that even low importation rates that reach areas with a reproduction rate near one can trigger high local non-pandemic transmission. Together, these findings inform programs encouraging tighter malaria related control, particularly for inhabitants returning to the island. This research makes use of the fact that for regions where exchanges with the environment happen through few channels ("island models"), public health interventions can be precisely targeted. It also raises new questions regarding trade-offs between personal privacy and harvesting information about travelers for public health benefit.

Another illustrative case in which mobile phone usage data is leveraged for public health surveillance is cholera. Investigators report about aggregating location data from mobile phone cards in Haiti for a project that happened to start six weeks before the 2010 earthquake [13]. This timing provided an unexpected but highly productive test bed for observing and validating mobile phone movement patterns following the disaster. Investigators applied sophisticated inclusion criteria to select only the 55% highest-quality data sets representing approximately 2.6 million individuals present in Port au Prince on the day of the earthquake. From these data, dislocation patterns of approximately 600,000 individuals were produced and found more accurate than records available to the National Civil Protection Agency at the time of the disaster. Methods applied demonstrated efficient response capabilities when a cholera outbreak struck Saint Marc 10 months later. During that disaster, investigators produced movement patterns of the affected area within 12 hours. Although they showed that fewer people than expected had moved, they indicated where those that did move had gone, potentially carrying cholera to yet

unaffected areas. Again, trade-offs between personal privacy and public health benefit deserve attention with these large-scale data analytics approaches. This study raises awareness about anonymizing SIM card data that is otherwise traceable to individuals in disaster-affected areas. SIM card data can also present challenges to accurate modeling if SIM cards are changed frequently. Nonetheless, these cases illustrate emerging opportunities for the application of mobile phone use for disease control in population health.

3.3 Contextual Factors that Shape Success

Through our survey we identified a number of contextual factors regarding the design, implementation, and use of mHealth services that appear to impact success. We observed such factors among selected demonstrator services as well as among all 55 articles we reviewed. For example, we raised questions regarding insight needed into the target environment to prevent adverse effects or failure when transforming mHealth services to new target environments [20]. Various investigations began with systematic analyses of target environments for mHealth services well before deployment [e.g., 25]. Such efforts help to characterize and address expectations, opportunities, necessities and constraints of target users in their environmental context. We subsequently present a digest of observations drawn from the 55 articles we reviewed that appear most helpful for successful deployment. We organize these contextual factors in an inside-out manner from instincts and emotions innate to human nature to skills, knowledge, cultural beliefs, and societal influences.

3.3.1 Instincts and Emotions

Trust, privacy, and confidence related to the use of mHealth services were common themes that impacted success. In an ethnographic style investigation about providing mobile AIDS education to illegal Zimbabwean migrant workers to Botswana [33], investigators demonstrate the depth of basic needs in this vulnerable group and how those needs can be met through mHealth services. These migrant workers survive by constantly looking for jobs, avoiding arrest or eviction, and spotting valuable information in abundantly flowing rumor within local resource constraints. To safely survive, information sharing and trusted peers are essential assets. Sophisticated education about AIDS prevention will not reach such groups until there is room for AIDS in their long list of priorities. Educational campaigns may be ignored unless provided by a source known to be trustworthy. This work indicates that actively involving trusted peers as intermediaries may impact success more than the specific content or distribution technology.

Fear can reign when stigma is associated with a medical problem where end-to-end trustworthy communication is critical. The information provider, be it a person or an institution, must be trusted by the recipient. An mHealth service must also be configurable to minimize leakage of information at the patient end. Such protection of privacy is difficult when cell phone and SIM card ownership change frequently [24]. Trustworthiness was found necessary for adoption of HIV-related mHealth services by men who have sex with men in China [34] and for HIV positive persons in Vietnam who may or may not have disclosed their status to family and friends [35].

Access to mobile-phone-based information can be a source of confidence in its own right and many investigators found generally positive attitudes toward adoption of mHealth services. Among the Zimbabwean migrant workers, for example, owning a cell phone promoted opinion leader status [33]. Mobile phones were perceived as more of a status indicator than as a threat to privacy. Most obviously, individuals in flooding and cyclone doomed Bangladesh [36] had confidence in a communication structure that would transport disaster and escape information when severe weather strikes.

3.3.2 Skills, Knowledge, and Cultural Beliefs

Literacy, motivation, and cultural-appropriateness are important themes that surfaced in our review. Some investigations applied structured approaches to alter individual's thinking, such as the use of cognitive behavioral therapy for smoking cessation in SMS Turkey [12]. For such approaches to be effective, individuals must have the skills to process and use the information provided. Some investigations explicitly exclude people with low literacy [18], while in other investigations they have poorer outcomes [19]. However, family, friends, and other supporters can often step in to help. For example, both [17] and [23] explicitly encourage use of cell phones owned by family, while [19] suggests including family in the patient's educational campaign. In one case, [31], skill and knowledge of peers who have mastered a health condition are explicitly used to send mobile reminders to newly enrolled patients. Therefore, various forms of peer group knowledge can provide social support when individual skill and knowledge is developing.

In some investigations, simply targeting individuals who are willing to learn achieves good outcomes through provision of mobile content, such as family planning [27]. However, we also confront challenges deeply entrenched in cultural beliefs, such as witchcraft and retribution of sins as causes of disease [20]. Here, interventions show limited success without attention.

Conceptually simpler, but logistically harder is accommodating local language. Various investigations raise and substantiate [17] this demand, which can limit services to scale up easily, especially in LMIC with many local languages [25]. Conversely, technology adoption even among those which proficiency is limited to local language can be enhanced through well-designed user interfaces. For example, village elders in rural Kenya use mobile phones to reliably report births and birth weights unless the stigma of perinatal death or stillbirth encourages the families conceal the event [37].

3.3.4 Societal Influences

Material possession, belief systems, and societal leadership also emerged as important factors that shape the success of mHealth services. Material possession is a strong driver of behavior. In some studies [21, 23,

26, 28], participants received cell phones or airtime worth one day's income in exchange of service use. Because no study compared the same service package with and without incentives, it is unclear whether mobile information or money serves as a stronger therapeutic agent.

Religious beliefs and practices impact the context of mHealth in different ways. From [20], we learned that neglecting to understand fundamental belief systems, such as witchcraft, may impact success in unintended ways. In another study [25] catholic teachings conflicted with public discourse on safe sexual practices to prevent the spread of HIV. Other investigators report that in Nigeria, where nearly half the population is Muslim, involvement of spouses in mHealth services was helpful because "the husband makes all decisions for the spouse about health care" [17]. Investigators report on ways that we can leverage mHealth services to meet the needs of individuals with varied belief systems, such as tailoring content to specific user groups [25] and collaborative service use [17].

Even more basically, advocates from schools, churches, and opinion leaders have existed throughout societies as sources of trusted information long before mobile phones. As these social supports continue to exist, as visible in [25, 33, 39], they should be our allies and solicited to actively contribute. When strong societal leadership opposes emerging new services, the services may be doomed before they can catch momentum.

4 Discussion

We have described the growing evidence of mHealth services, especially mobile phone technology, in LMIC. We showcased demonstrator services across clinical care, prevention, infectious diseases and population health settings. Those services applied to a diverse range of interventions, from mobile education, reminders, reporting, and peer support, to epidemiologic case reporting, and mobile care management supported by phone communication and messages. We also drew out contextual factors that shape the success of these services from instincts and emotions to skills, knowledge, cultural beliefs, and societal influences. We discuss how these findings expand our understanding of the value of mobile health interventions beyond high-income countries where prior research is largely focused [4].

4.1 Achievements

A number of demonstrator services resulted in the improvement of attitudes, knowledge, and often behaviors through mHealth interventions. Clinical care services improved timely adherence to treatment and appointments for a number of conditions that might lower staffing cost and be feasibly convenient [16-19]. Preventive interventions increased vaccination coverage through SMS appointment reminders [23] and promoted HIV testing uptake through SMS education [24]. However SMS education that only improves knowledge and attitudes may not result in improved behaviors or measurable clinical or public health effects [22]. In domains of infectious diseases, high quality evidence of clinical effectiveness [29, 30] has already been achieved, as well as for the technically high end cloud-based diabetes care [19]. Services for population health, such as monitoring the spread of communicable diseases [32, 13], where citizens are passive suppliers of geo-positioning data, demonstrate potential for surveillance, but require further follow up on privacy and confidentiality considerations. These findings help to fill evidence gaps surrounding mHealth in LMIC [4, 5, 11].

4.2 Service Design and Delivery

Although simple reminders for agreed upon behaviors, such as medication adherence, were often found sufficient, in other services that communicate more sophisticated knowledge, we uncovered evidence that the design and appearance of content matters [24, 28]. Automated messages must be well-considered and fine-tuned in terms of communication style (e.g., command, instruction, information, quiz, invitation to reply), length, and frequency. Insights we uncovered about tailoring messages with motivating content expanded evidence on parameters under which SMS work [5]. Consideration should also be made for the capabilities required of users to process the content received, such as language and literacy requirements. For example, requests for local languages were explicitly reported in [17, 25, 29], but are presumably present in many LMIC. Furthermore, designing content for persons with low literacy and other disabilities that limit mobile phone use is an important area for future work.

Infrastructure factors that support service delivery greatly shape success and, if neglected, can contribute to adverse effects. As a basic prerequisite, the mobile phone is widely welcomed [25] as a mediator of information, as an empowering factor, and as a proven source of big data to improve health care delivery. Concurrently, mobile services present logistical challenges. Cell phones and SIM cards can be shared by a number of different people, and ownership can change frequently [24]. Thus a phone number does not guarantee secure and confidential communication [17, 34, 35]. We also observed logistical flaws on the part of providers, such as failure to send SMS or incentives not credited [23, 12]. Few complaints were reported about insufficient cell coverage, even in remote areas. Conversely, some investigators reported that patients who lived far from their caregivers appreciated the opportunity of remote communication, and in one case, adherence increased with distance from health care center [19]. In settings that lack technical infrastructure to support wide mHealth dissemination, the use of shared models, such as cloud-computing resources, show promise for scalability [19]. Beyond technical infrastructure, high staff requirements for some mHealth services, such as making manual phone calls, may not scale to broader dissemination [17, 23]. However, this human contact of traditional phone calls is an important component of mHealth services reported by some authors [18, 26]. Interactive approaches, such as IVR might point toward middle ground [19]. Thus, future work is needed to further examine trade-offs in scalability that come with automation versus preferences for human intervention.

4.3 Social and Environmental Forces

The wider societal environment and the immediate social fabric serve as strong modifiers, and even pivotal elements, in the service success of several investigations. These forces range from influential organizations whose collaborative cooperation was encouraged [25] to family members whose support was a strong success factor [19, 31]. We frequently found mobile phones shared in communities and hence the community necessarily moderating [37] and the role of community-based partnerships important [33]. More research should be directed toward addressing challenges that emerge when health interventions come into conflict with societal belief systems [20, 21].

4.4 Methodological Considerations

There is a clear need for high quality trials to evaluate clinical and economic performance to scale up mHealth in LMIC [4, 5, 10]. Care must be taken when comparing results from evaluations of mHealth on higher- and lower-income countries because usual care conditions may differ considerably [4]. Our survey identified several controlled trials in which a number of demonstrator servicesshowed significant improvement in behavioral and clinical outcomes. In contrast, a number of demonstrator services have been reported at earlier stages of development in which feasibility studies [15] helped to establish the technical capacity, logistical operation, and user acceptance of the interventions required for full-scale controlled trials. Nonetheless, there are a number of methodological considerations for the evaluation of mHealth in LMIC.

Only three demonstrator services significantly showed clinical improvement [19, 29, 30], while various services were associated with improvements in patient attitudes, knowledge, or behavior. Three investigations that complemented subjective data with objective data on clinical impact pointed out the problem that self-reports can overestimate the objective clinical effect [21, 22, 29]. Because to only rely on self-reports may impact results with known biases, such as subject expectancy and social desirability effect, investigators are encouraged to include objective measures to help bolster evidence. For wide-spread conditions such as depression, much effort has been invested to address such biases through standardized instruments, many of which are available in multiple languages. Knowing the importance of local languages on the one hand and the effort to calibrate a standardized questionnaire on the other hand, it is prohibitive to strive for standardized self-reporting for numerous languages.

Another important consideration is potential confounders. A number of demonstrator services applied in multiple interventions. For example, [21] and [29] combine phone communication with SMS reminders. Mixed interventions make it difficult to discern individual effects of service components. New study designs are needed that can separate the effects of different interventions that make mHealth services effective [5]. While providing research participants with cell phones ensures access, it can also lead to novel, e.g. therapeutic effects, by providing additional opportunities for social support or emergency assistance. Some investigators provided control groups with cell phones to help address this potential bias [21].

Incentives are another important consideration for mHealth in LMIC. Low turnout may be owed to the reason found in LMIC– people change SIM cards frequently and SMS may be sent to unattended numbers. Some investigators offered cell phones and/or airtime for participation alone [20, 21], or for favorable behaviors [23]. Subject expectancy and social desirability can be enhanced by such incentives. Since few services among those we surveyed compared effects with and without incentives, it is difficult to know whether the service or the incentive was the more effective agent. Other investigators offered a "PCM" (free 'please call me' line) that bears no cost to the recipient and thus promotes adoption in resource-limited regions, but turnout was not reported when recipients had to face costs [24]. Therefore, funding the cost or having recipients paying should be investigated to support implementation.

Although our survey helps to open the "black box' on evidence [5], more research is needed to further examine the impact and opportunities for mHealth in LMIC. For example, evidence of negative impact [20] is just as important for understanding the value of mHealth as evidence of positive outcomes. Further, collecting data only on patient-reported problems [29] can leave one not knowing what happened to those that chose not to report, as observing few reports of problems does not necessarily reflect a "healthy" problem-free population. Big data analytics [32, 13] offer opportunities to investigate mHealth at large scale. Future research should also investigate opportunities such as mHealth-mediated peer support, meeting the need of limited literacy patients, and how specific service components contribute to outcomes.

4.5 Opportunities for IMIA

In this analysis of the literature, we revealed a number of future opportunities for research and practice of mHealth, and especially in the use of mobile phones to improve health care. We found many opportunities for methodological advancement. Capacity building and sufficient funding for larger scale, more rigorous trials should be supported where smaller-scale investigations show promise. Transition paths for translating research-based services to broader dissemination in practice should be pioneered for the most promising approaches. Mobile broadband coverage has improved widely and provides a backbone for national deployment and beyond. As mobile broadband penetration rises, mHealth opportunities in LMIC will continue to flourish. Barriers to scaling up services in terms of human resource requirements or local language coverage, must be identified upfront. Given the demonstrated success and promise of mobile phone use even in the poorest countries, we are encouraged about a future in which IMIA takes a lead role in leveraging mobile tools in the hands of citizens for empowerment through Consumer Health Informatics that consolidates scattered evidence by promoting new MeSH keywords for fast evolving technologies, and by leveraging sensor technology.

International sponsors have made it possible that the poorest of the five tiers fares equally well as the richest in terms of numbers of projects, and the three clinical farthest reaching services (significant clinical improvement in [19, 29, 30]) are from tiers 2 through 4. There is, however, a trough in terms of projects published in the middle tier, and no European LMIC was present. It appears that there is a forgotten middle: too poor to help themselves but too rich or too badly networked to get access to funding. IMIA may play a moderator role to make this better known.

The spread of the 55 articles we reviewed across 42 scientific journals poses a serious threat to knowledge sharing among researchers in resource poor countries. Few may have access to all these journals. IMIA can assume a communicator role by allocating space in its endorsed journals, in sponsoring affordable workshops, or in sponsoring regular digests about health informatics progress in LMIC.

Whereas many mHealth interventions are currently limited to traditional cell phones, emerging wireless and sensor technology should provide new significant opportunities for mHealth in LMIC. With the continued expansion of wireless broadband, we anticipate opportunities to diversify the range of potential interventions that use mobile and wireless technology in LMIC. Because self-reported outcomes can add bias and the effort to have standardized forms in all required languages is prohibitive, leveraging inexpensive robust sensor technology, such as the MEMS, could be further expanded. Significant opportunities surround interdisciplinary research that leverages low-cost, real-time devices to assess disease, social, behavioral, and biometric data, and promote health and healthcare [39].

5 Conclusion

Our survey of demonstrator services shows a breadth of achievements and future opportunities for harnessing mobile technology to promote consumer health in LMIC. We have not found universal success, but a range of diverse and well-considered examples that the evidence base for mHealthoutcomes in LMIC. We also identified a "forgotten middle" where a trough remains for research and practice to fight poverty and disease. Demonstrated improvements and promise of mHealth in the poorest countries encourages a future in which IMIA takes a lead role in leveraging mobile phones in the hands of citizens for empowerment through Consumer Health Informatics.

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