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# Digital Health in Low- and Middle-Income Countries

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**CHAPTER MENU**



*Revolutionizing Tropical Medicine: Point-of-Care Tests, New Imaging Technologies and Digital Health*,
First Edition. Edited by Kerry Atkinson and David Mabey.

## 32.1 Introduction – The Digital Health Revolution

Arguably one of the greatest drivers of economic participation and prosperity in low- and middle-income countries (LMICs) over the last generation has been the advent of mobile banking. A decade since its founding in 2007, the Kenyan service M-PESA now enables over 20 million people in Africa to transfer money and receive micro-credit using their mobile phones (Harford 2017). (M-Pesa [M for mobile, pesa is Swahili for money] is a mobile phone-based money transfer, financing and microfinancing service, launched in 2007 by Vodafone for Safaricom and Vodacom, the largest mobile network operators in Kenya and Tanzania. It has since expanded to Afghanistan, South Africa, and India.) M-Pesa allows users to deposit, withdraw, transfer money and pay for goods and services easily with a mobile device. The downstream effects are clear – digital banking has made it possible for millions of people to receive a stable income, has reduced the risk of corruption, and opened new channels of commerce. The BBC has called it the "M-PESA Revolution." Mobile banking was revolutionary not because the technology was advanced, but because it was simple. This was a way to leverage existing mobile network infrastructure to solve the burning economic need for simple, secure payments.

The same trend is playing out in healthcare, where simple technologies are being co-opted to deliver critical health services in low resource environments in Africa and other areas. The need is even more pressing than for financial transactions, with 400 million people still lacking access to essential health services based on a 2015 World Health Organization (WHO) and World Bank Group report (Joint WHO/World Bank Group Report 2015). Meanwhile, the burden of chronic disease in low- and middle-income countries continues to rise precipitously. Over 85% of the premature deaths attributed to chronic diseases, including cardiovascular disease, diabetes, cancers and chronic obstructive pulmonary disease, occur in low- and middle-income countries (WHO 2013). The economic burden of this unchecked rise of non-communicable diseases (NCDs) in the LMICs has been estimated at US$7 trillion over a 15-year timespan. The United Nations Sustainable Development Goals (SDGs) have set a 2030 target to reduce premature deaths from NCDs by one third; to curb the infectious epidemics of HIV/AIDS, malaria, tuberculosis (TB) and other tropical diseases; and to reduce maternal mortality by providing universal access to reproductive health services. However, the global medical workforce looks to be overwhelmed by these looming public health trends, with the WHO estimating a shortage of almost 13 million healthcare workers internationally by 2035 (Global Health Workforce Alliance and World Health Organization 2013). The bold vision of the SDGs will only be achieved by rapidly upscaling the capacity of an already overburdened healthcare infrastructure using digital technologies.

Accompanying the rising burden of chronic disease is the increasing digital literacy of the LMICs. According to the most recent estimates from the International Telecommunication Union, mobile phone penetration in LMICs is approximately 85% in the 15–74 age group, with a rising rate of mobile broadband subscriptions, at 44 per 100 persons in 2017 (International Telecommunication Union 2017). Meanwhile, plummeting costs of computers, tablets, and wearable devices are creating a rich digital infrastructure even in low resource settings.

The last decade has seen tremendous innovation in the use of mobile technologies for healthcare delivery (mHealth) and the development of clinical software and data platforms (eHealth). From Nicaragua to Zimbabwe, there has been a wide array of digital health interventions, from large-scale public health efforts based around short message services (SMS) and smartphone apps, through to grassroots initiatives built by community health workers to streamline their own workflows. Some of the most successful examples have come from maternal health – delivering ante- and postnatal care via SMS and telemedicine services. However, the applications are far reaching, from point-of-care TB screening, to gamified platforms for self-management of chronic diseases, to inventory management and capacity planning services for health administrators. (Gamification software is any tool or platform used for applying game mechanics to non-game contexts in order to boost engagement and successful end-results. Common use cases include customer loyalty, e-learning, employee engagement, and performance management.) The value proposition is clear: digital technologies stand to increase healthcare access, improve clinical outcomes and reduce cost.

Traditionally, mHealth has involved SMS reminders and telemedicine consults; however, the proliferation of smartphones presents a range of new possibilities. Smartphone penetration in the LMICs rose from 21% to 37% between 2013 and 2015 (Poushter 2016), although East Africa and South Asia continue to lag behind global averages, with 25 and 30% penetration in 2017 respectively (GSMA Intelligence 2017a). Nevertheless, an increasing proportion of the world's population stands to carry with them a computer thousands of times more powerful than NASA's Apollo navigation systems, with a suite of sensors such as a gyroscope, camera and global positioning system (GPS) poised to collect new streams of physiological and behavioral data. Illiteracy and language barriers continue to be challenges. However, in the words of one MobileMedic user: "Even though I am not able to read and write, I am able to work with this mobile phone" (MedicMobile 2018). Capitalizing on this ambient technology in an engaged user base will open the door to a new mHealth revolution far beyond the traditional SMS reminder services.

This Chapter presents a high level overview of mHealth and eHealth technologies in the LMICs, highlighting key emerging trends, critical challenges and presenting a vision for the future. While we refer to these technologies collectively as "digital health," we recognize that the "broad church" of digital health contains further diversity still, including technologies such as wearables, virtual reality, and predictive analytics. While these technologies certainly have potential in low resource settings, the majority of case studies to date have related to mHealth and eHealth.

For this Chapter we have cataloged 120 such applications that were developed for, and typically in, low-income countries. This is by no means a comprehensive list. However, it is broadly representative of the digital health solutions identified by searching PubMed, the WHO Digital Health Atlas, the GSMA 2017 review of digital health trends in developing markets and a range of local and international mobile health news outlets. Sixty-eight per cent had significant operations in Africa, 28% in Asia and 13% in Latin America, with several solutions having inter-continental footprints and counted in each region. Although many solutions have multiple functionalities, 17% were categorized as being predominantly focused on patient education and awareness campaigns, 23% on self-management and remote monitoring, 35% on empowering frontline healthcare workers and managing electronic medical records, 4% on powering remote diagnostic devices, 13% on disease-tracking and epidemiology, 5% on financing and insurance and 3% on inventory management and supply chain.

## 32.2 The Current Landscape

To set the scene I begin by reviewing three clinical use-cases where digital health has been applied across the continuum of care. Specifically, I focus on one communicable disease (HIV), one non-communicable disease (diabetes mellitus) and maternal health.

## 32.3 HIV/AIDS

According to WHO estimates there were almost 37 million people living with HIV in 2016, of which over 25 million lived in Africa (World Health Organization 2017). Despite the development of effective anti-retroviral therapies (ART), an estimated one million people die each year from AIDS-related causes. The ongoing AIDS epidemic is multifactorial, related to awareness, cultural stigma and treatment access and adherence.

One problem space where digital health is making a particular impact is ensuring adherence to ART regimens for HIV-positive subjects. WelTel is an international platform specializing in SMS support programs for HIV. In a landmark randomized study in Kenya WelTel sent patients in the treatment group a weekly text message starting with a simple “mambo?” (“how are you?”) (Lester et al. 2010). This weekly check-in was associated with improved adherence to ART (relative risk [RR] of non-adherence 0.81) and reduced viral load (RR 0.84). Other solutions are attempting to assist care providers. iDART (intelligent Dispensing of Anti-Retroviral Treatment) is an open-source software platform developed by the South African non-governmental organization (NGO) Cell-Life, which helps pharmacies in the distribution of ART by offering inventory management, patient tracking and efficient barcoding so that medication packages can be reliably sent to remote distribution sites.

While medication adherence is an issue for those on treatment, there is also the upstream issue that many subjects are not screened for HIV. An estimated 24% of HIV-positive individuals in South Africa remained undiagnosed as of 2012, although this number is declining (Johnson et al. 2015). In order to reach the UNAIDS target of 90% diagnosis rate by 2020, various mobile health solutions have attempted to increase awareness of testing services. An early example was Project Masiluleke, which used the clever strategy of inserting screening advice into the blank space of “Please call me” SMS messages indicating that HIV screening were being offered for free in South Africa. In their first year of deployment in 2008/2009, they saw a tripling in the number of calls made to South Africa’s AIDS Helpline (Project Masiluleke 2009).

More recent initiatives are even more comprehensive. The Moyo project in Lesotho also aims to improve the access of remote communities to HIV screening and ART. Mobile clinics visit these communities offering free HIV testing and simultaneously register patients into a surveillance database via a smartphone application (app). If a patient needs medical attention or is unable to access ART, they are sent money for transportation to the nearest health facility using third-party mobile banking tools. In a country where 40% of pregnancy-related mortality is attributed to HIV, this holistic solution for remote communities is extremely promising.

## 32.4 Diabetes Mellitus

The prevailing pattern of morbidity in the LMICs has shifted from infectious diseases to non-communicable diseases, of which diabetes represents a significant burden. Eight and one half per cent of the adult population has diabetes internationally, with prevalence rising fastest in low- and middle-income countries (WHO 2016). The penetration of mobile phones into the population, and into the daily life of the individual, makes them a natural tool to effect behavioral change in chronic diseases. mHealth solutions have been deployed throughout the continuum of care for diabetes, from preventative medicine through to screening, diagnosis and longitudinal support for both patient and clinician.

With the International Diabetes Federation estimating that two thirds of diabetics in Africa remain undiagnosed (International Diabetes Federation 2017), screening is a particular priority. A variety of simple risk scoring tools exist, which have been packaged into mobile apps for use by patients and community health workers. The Diabetes Online Risk Assessment (DORA) initiative was launched across 12 African nations to provide an accessible web-based tool for diabetes risk stratification. Moderate and high-risk patients were given an electronic voucher for a blood sugar level (BSL) test which could be performed at local pharmacies, and those found to have high sugar readings received a diabetes management app with educational resources and symptom tracking, as well as a home BSL monitor.

Mobile technologies have also been used to screen for specific diabetic complications such as diabetic retinopathy. "Fundus on the Phone" is one example of a smartphone-enabled device for capturing high-quality retinal scans, currently deployed in Bangalore, India. Additionally, the PEEK Retina is a portable ophthalmoscope that connects to a smartphone, allowing remote ophthalmologists to make a diagnosis and suggest treatment strategies (see Chapter 25).

A new class of self-management platforms for diabetes has recently emerged throughout the LMICs. The Indian company JanaCare is one of the leaders in this space, having developed a suite of tools including a smartphone test-strip able to perform blood glucose levels, HBA1c levels, a lipid profile and hemoglobin levels, as well as behavioral coaching through an app called Habits with personalized advice and goal-setting, and a physician dashboard that allows patients to be monitored remotely. In Senegal an app is helping diabetic patients better manage their sugar levels during the Ramadan fast. mRamadan is an SMS reminder service that provides advice for patients and care-providers around diet and medication titration in the context of fasting.

Evidence is emerging to suggest that engagement with diabetes management apps is associated with improved clinical outcomes. A systematic review of mHealth diabetes interventions in mostly high-resource settings found a significant reduction in HbA1c in patients "treated" with a mobile app (Kitsiou et al. 2017). This has led to an emerging view of diabetes management apps known as "digital therapeutics."

## 32.5 Maternal Health

Each day approximately 830 women die during pregnancy or childbirth from preventable causes. Ninety-nine per cent of these women live in LMICs (WHO 2016). The Sustainable Development Goals call for a reduction in maternal mortality to less than

70 per 100 000 live births by 2030 with universal access to reproductive health services. This is a particular challenge in low-income countries because of significant resource shortages, especially in the maternal health workforce. In 2010, the UN launched the *Every Woman Every Child* initiative – a global movement advocating for major maternal health reform – which pioneered mHealth initiatives through a targeted grant program and support resources. Digital health is seen as an opportunity to upscale the capacity of overburdened health services by empowering mothers, training community health workers and better distributing specialized resources.

The Wired Mothers initiative in Zanzibar is a classical mHealth intervention involving SMS-based reminders during the antenatal and postnatal periods, as well as teleconsults with a midwife. It was an early example of rigorous evaluation with a cluster randomized trial – a trial which ultimately demonstrated an increase in the number of prenatal visits and a reduction in overall maternal mortality (from 3.6 to 1.9%) (GSMA Intelligence 2017; Sondaal et al. 2016). There are many similar solutions: the Mobile Alliance for Maternal Action (MAMA) has developed SMS-based pregnancy quizzes and an interactive question-and-answer service. The *MayMay* app from Myanmar provides regular antenatal reminders, educational tips and a listing of local doctors that women can access directly.

Alongside the wealth of patient-facing pregnancy apps is a growing class of tools designed for healthcare workers, which attempt to address the severe workforce shortage by upskilling existing staff. MedicMobile is a San Francisco based not-for-profit organization that has implemented a number of open-source solutions for health workers in low-resource settings across Africa, Asia, and Latin America. Their maternal health package enables community health workers to register pregnancies, track antenatal care visits and screen for high-risk pregnancies and red flags. A systematic review of mobile solutions for maternal health workers found widespread applications of mobile technologies for providing education, tracking patients, collecting epidemiological data, and communicating between care providers. However, more evidence around the impact on maternal and neonatal outcomes must be gathered (Sondaal et al. 2016).

## 32.6 Core Functionalities

The previous section reviewed the breadth of digital health solutions within three clinical verticals. We now draw out the common functionalities that appear across clinical domains. Figure 32.1 shows a breakdown of these core functionalities, categorized into patient-facing and clinician-facing functions.

These functions may be viewed as the building blocks of digital health tools – a useful frame-of-reference in an ecosystem that is increasingly modular, with open-source packages for various functions that may be stitched together into a custom app. The sections below briefly review each of these functions and provide relevant examples.

## 32.7 Patient-facing Functions

### 32.7.1 Patient Education

Patient education is among the most fundamental functions of digital health tools in low-resource settings. A number of systematic reviews in the maternal and child health

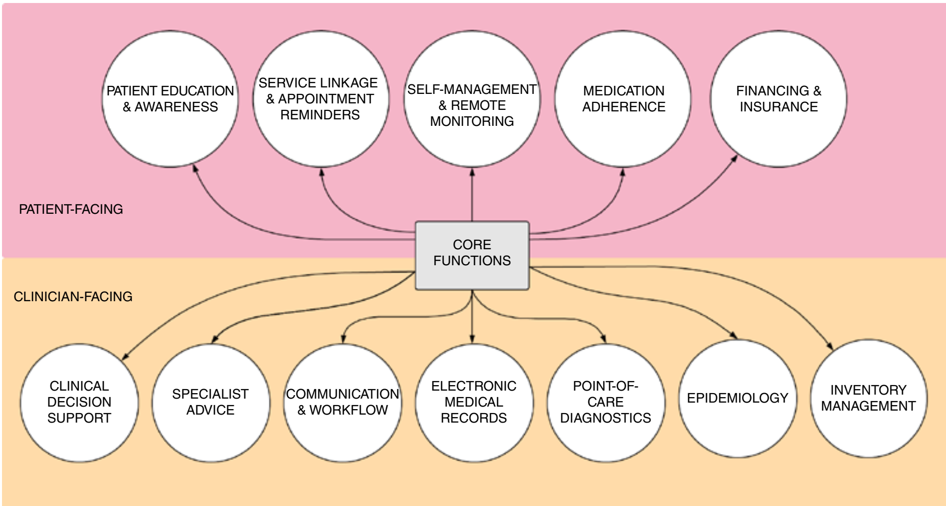


**Figure 32.1** Core functions of digital health applications categorized into patient-facing and clinician-facing functionalities.

space found that the provision of educational resources was the most common function (Chen et al. 2018; Sondaal et al. 2016). Patient education can be provided either passively or actively. The former refers to automated content delivered via mobile or web; the latter refers to interactive dialog with the patient via telemedicine or chatbots. Key challenges across the spectrum include

1) Ensuring content is accurate and up-to-date,
2) Making content engaging to users. A range of engagement strategies have proved effective, from simple SMS-based quizzes for HIV education (for example, using *Text to Change* in Uganda) to more sophisticated gamification such as the *Fooya* app, which aims to promote healthy eating habits and targets childhood metabolic syndrome in India and beyond.

### 32.7.2 Service Linkage and Reminders

mHealth tools can assist patients both in finding relevant health programs and in reminding patients of their appointment schedule. Numerous examples of SMS- and app-based reminders exist in the management of HIV, TB, antenatal care, diabetes, asthma and mental health. One systematic review across low- and high-resource settings showed improved follow-up adherence in 77% of studies using text reminders (Kannisto et al. 2014). Reminder services have been particularly effective in vaccination uptake, with one study in Zimbabwe showing a significant increase in childhood immunizations with simple SMS reminders (Bangure et al. 2015).

### 32.7.3 Self-management and Remote Monitoring

Self-management refers to solutions that empower patients to be in control of their own care, from assisted diagnosis through to longitudinal disease management. The related concept of remote monitoring refers to any two-way communication between patients and care providers that enables remote care delivery. I have discussed some of the applications in diabetes and antenatal care above, largely based around interactive mobile software and telemedicine consults with remote healthcare workers. However, the rise of sophisticated home sensors is creating a new dimension to self-management. One example is *UChek*, a low-cost urine dipstick reader powered by a smartphone. The associated app gives readings directly to patients about the presence of urinary leukocytes or high glucose, enabling assisted triage for conditions such as urinary tract infections as well as better home management of diabetes.

### 32.7.4 Medication Adherence

Medication non-adherence is known to be a significant contributor to morbidity in both communicable diseases such as HIV and TB, and in NCDs such as congestive heart failure. mHealth approaches to medication adherence range from simple SMS reminder services, video messages, regular phone calls by healthcare workers, and gamified medication journals powered by smartphone apps. In TB, where directly observed therapy (DOT) is recommended, medication adherence tools have needed to become more rigorous, with creative techniques such as video observation of therapy (VOT), embedded sensors in tablets, smart pill bottles, and low-cost urine tests which detect relevant drug metabolites (DiStefano and Schmidt 2016).

### 32.7.5 Financing and Insurance

mHealth is helping to streamline the finances of healthcare in the same way as mobile banking has streamlined general commerce. With over 75% of Kenyans uninsured, the Grameen Foundation pioneered the Uzima Project – a low-cost health insurance product interlinked with a smartphone app that provides patient education and reminders (Grameen Foundation 2018). Meanwhile, another Kenyan innovation, Changamka Microhealth, is allowing patients to set aside money for medical treatments with predefined costings for procedures. mHealth platforms have also begun to offer financial incentives for positive behavioral change. A systematic review of 10 such programs offering conditional cash transfers for healthy behaviors in low-resource environments showed increased utilization of preventative health services and, in some cases, improved clinical outcomes (Lagarde et al. 2007).

## 32.8 Clinician-facing Functions

### 32.8.1 Clinical Decision Support

Clinical decision support (CDS) systems are being used to upskill community health workers with minimal training to deliver high-quality evidence-based care. This decision support can be in the form of clinician education about consensus guidelines. An example is the sending of regular text messages with guidance about malaria management (which improved adherence when trialed in Kenya) (Zurovac et al. 2011). CDS may also involve point-of-care advice, personalized to the patient at hand. The George Institute for Global Health developed the SMARTHealth India system – a plainlanguage mobile CDS tool to conduct cardiovascular screening and basic management in rural India (Praveen et al. 2014). This enabled task-shifting from physicians to community health workers and allowed more intelligent triage of patients requiring specialist review. One CDS system in Pakistan even empowered laypeople from the community to screen others for TB, with financial incentives for case reporting (Khan et al. 2012). A review of CDS platforms deployed in sub-Saharan Africa for conditions including pneumonia, antenatal care, pediatric triage and hypertension, found significant potential in the use of such mHealth tools by health workers, although evidence around outcome improvement was still lacking (Adepoju et al. 2017). More work is needed on translating high level treatment guidelines into practical advice at the point-of-care. This ecosystem would likely benefit from a library of clinically-validated decision support tools accessible via application programming interfaces (APIs).

### 32.8.2 Specialist Advice

Myanmar was ranked last in a WHO ranking of 190 international health systems in 2000, and has faced ongoing challenges since. The first Myanmar-based telemedicine solution was implemented in 2014 for the purpose of providing specialist advice to remote clinicians (Leroux et al. 2016). Rural health workers were able to send x-rays, ECGs and ultrasound images to specialists in Yangon, as well as requesting support via video consultation. The service had promising uptake, with over 4500 specialist consults provided in the 16 month trial period. In Tanzania *First Derm* is being used by local physicians for dermatology support, with images being sent via the app to consultants in Dar es Salaam to select which patients should be referred for specialist investigation (Chung and Hyunsoo 2017). In Botswana similar technology is being used to transmit cervical photographs for review by specialist gynecologists, providing effective cervical cancer screening to women in remote communities (Quinley et al. 2011).

### 32.8.3 Communication and Workflow

mHealth technologies are helping clinicians to communicate with one another in order to streamline various components of their daily workflows. In Ghana and Liberia, the *MDNet* Program allows free physician-to-physician communication nationwide to promote education and collaboration. mHealth also accelerates feedback loops so that test results are communicated rapidly and not overlooked. An example is in Zambia where SMS is used for delivering infant HIV screening results back to the referring clinician more rapidly (Seidenberg et al. 2012).

## 32.9 Electronic Medical Record Management

Even in the highest resource settings electronic medical records (EMRs) are challenging to implement and configure, with significant shortcomings around user interface and interoperability. A number of simple modular EMR architectures have been developed for low resource settings, notably *OpenMRS* – an open-source EMR suite built and supported by a distributed community of developers. Even basic EMRs can help streamline patient care, capacity planning and observational research, especially if data starts to be collected longitudinally and shared between care providers (Williams and Boren 2008).

## 32.10 Point-of-Care Diagnostic Tests

mHealth solutions provide the backbone for the emerging sector of point-of-care diagnostics. *Swasthya Slate* is a mobile platform paired with a number of low-cost sensors, which allows a healthcare worker to perform over 30 diagnostic tests from vital signs through to rapid tests for HIV and syphilis (Wunker 2014). The platform, which also offers patient record management and decision support for the clinician, has now been deployed widely across India. A number of tools are leveraging the higher-performing cameras in smartphones to analyze blood samples for malaria (for example, *Lifelens*) and screen for anemia based on the color of the sclera (for example, *Eyenaemia*).

## 32.11 Epidemiology

During the recent Ebola outbreak in West Africa, mHealth apps such as the Ebola Care App were used to provide real-time information from the field about new exposures. This allowed health authorities and NGOs to track the epidemic, better allocate resources and facilitate contact-tracing. The open-source tool *GeoChat* is being used to track disease outbreaks such as cholera and avian influenza in Cambodia via crowd-sourced updates (http://instedd.org/technologies/geochat). Similar systems have been deployed for malnutrition, vaccine coverage and dengue fever. The same principle of mobile-powered data collection can be extended beyond the acute setting of outbreak tracking to epidemiological surveys and academic research.

## 32.12 Inventory Management and Supply Chain

A survey of 12 national AIDS programs in 2011 found that 67% of countries experienced episodes of insufficient antiretroviral stock lasting an average of 40 days, largely due to maldistribution and forecasting problems (Sued et al. 2011). mHealth can be used to build supply chain resilience by allowing frontline healthcare workers to monitor inventory and by enabling citizens to report counterfeit medications that can arise in times of undersupply (Agarwal et al. 1996). In Malawi, for example, *cStock* was developed to track medication inventory, providing dashboards for monitoring stock levels across the community and sending text messages to health workers when new stock became available.

## 32.13 Challenges to Scale

Despite the volume of new mHealth initiatives, few projects manage to achieve scale beyond the pilot stage. The WHO has recently published their MAPS (mHealth Assessment and Planning for Scale) toolkit as a framework for digital health solutions to cross that bridge from pilot to established initiative (WHO 2015). MAPS outline six "axes of scale": groundwork, partnerships, financial sustainability, technology architecture, operations, and monitoring/evaluation. The toolkit provides self-assessment tools to strengthen an mHealth program along each axis. In the following section, I will zoom out one level and present four common challenges that the digital health ecosystem at large is facing as it matures and scales.

### 32.13.1 Evidence-based Practice

Evidence-based clinical content is critical for scalability, but is often overlooked in digital health designs. A review of apps for TB prevention found numerous examples with poorly-substantiated and, in some cases, incorrect information, with only 2 of 24 apps citing peer-reviewed publications (Iribarren et al. 2016). Although the US Food and Drug Administration (FDA) is bolstering oversight around digital health (US Food and Drug Administration 2017), mHealth solutions in the LMICs continue to operate without any clinical vetting process. *Txt2MEDLINE* in Botswana aims to tackle this problem by allowing physicians to question MEDLINE literature via SMS. The ecosystem would benefit from more open-source documents, specifically clinically approved educational resources with multi-language support that could be readily customized and integrated into new tools. Ideally this would include multimedia options such as educational graphics and videos. Furthermore, it is becoming increasingly important to gather evidence around clinical outcomes following mHealth interventions. Although many of the systematic reviews in this space lament the shortage of high-quality evidence beyond feasibility studies (Chib et al. 2015; Oliver-Williams et al. 2017), others argue that the rigor of mHealth studies is increasing rapidly (Labrique et al. 2013). Digital health innovators are realizing that they must improve clinical endpoints or reduce costs in order to gain widespread adoption.

### 32.13.2 Integration into Clinical Workflows

A common pitfall of digital health interventions is a lack of integration with the surrounding health infrastructure, resulting in multiple, fragmented point solutions. Successful initiatives, such as the deployment of the *CommCare* app by the *m4Change2* project in Nigeria, have been deeply embedded within existing care pathways. This was a simple case-management and decision support tool for Nokia and Android devices, deployed across 10 rural primary health centers. However, the healthcare workers received good quality training and were able to use the app alongside their pre-existing workflows. Additionally, the system tied into a cash-transfer scheme supported by the federal health authorities to provide a small incentive payment to women accessing antenatal care. The same integration mantra applies for patient-facing tools – they are most valuable if they are interlinked with the health ecosystem, for example by connecting patients to relevant facilities or providing telemedicine support from local physicians.

### 32.13.3 Financial Sustainability

It can be difficult for digital health solutions to draw revenue from the end user, hence creative funding models must be considered. Many of the most successful initiatives to date have been funded by governments or NGOs. However, large technology companies such as Philips and GE, along with many of the cellular networks such as Telefonica and Telenor are contributing significantly to the ecosystem. There are also several recent examples of public–private partnerships being used as a successful model for building digital health infrastructure in the LMICs. An example is the one between Philips and Telkom Indonesia for mobile obstetric monitoring (GMSA Intelligence 2017; Latif et al. 2017). A recent set of recommendations from the United States National Academies of Sciences, Engineering, and Medicine called for USAID to provide seed funding to local governments in order to facilitate public–private collaborations (Dzau et al. 2017).

As health systems internationally move toward bundled or capitated payment schemes, there may also be more scope for digital health programs to provide preventative medicine in return for a share of cost savings. *AxisMed* is a chronic disease management platform in Brazil that has created a business case around reducing overall expenditure through decreased emergency room visits and hospitalizations. In Bangladesh Telenor and Grameenphone have developed *Tonic* – a health management platform offering education, service linkage, telemedicine consults and emergency insurance packages to over two million users – based around a low-cost subscription model where users pay a monthly access fee (US$1–4). Digital health innovators must consider creative reimbursement models to support their initiatives.

### 32.13.4 Technical Scalability

There are inherent limitations associated with mobile phone technologies in extremely low-resource environments. Mobile Internet continues to be lacking in some regions, and up to 10% of the world's population (predominantly in sub-Saharan Africa and rural Asia) still live without any cellular connectivity (GSMA Intelligence 2015). There can be issues around electricity coverage, phone battery life and the cost of mobile devices, making access to the most vulnerable populations an ongoing challenge (Latif et al. 2017).

Another aspect of achieving technical scale is data interoperability. It is important for digital health tools to be able to push and pull information from other health IT systems; however, to date there has been poor adherence to standards such as HL7 and FHIR. (Health Level-7 or HL7 refers to a set of international standards for transfer of clinical and administrative data between software applications used by various healthcare providers. These standards focus on the application layer, which is "layer 7" in the OSI model. The OSI model is The Open Systems Interconnection model, a conceptual model that characterizes and standardizes the communication functions of a telecommunication or computing system without regard to its underlying internal structure and technology. Its goal is the interoperability of diverse communication systems with standard protocols. The HL7 standards are produced by the Health Level Seven International, an international standards organization, and are adopted by other standards issuing bodies such as American National Standards Institute and International Organization for Standardization. Fast Healthcare Interoperability Resources (FHIR, pronounced "fire") is a draft standard describing data formats and elements (known as "resources") and an application programming interface (API) for exchanging electronic health records).

Digital health tools that support interoperability will help to power the emerging paradigm of data sharing and large-scale analytics, which stands to improve efficiency at a systems level (Latif et al. 2017). In Malaysia, the 2016–2020 eHealth strategy emphasizes interoperability as a key priority, aiming toward a "one person, one record" health system with an associated data warehouse (World Health Organisation, Malaysian Ministry of Health 2016).

Finally, data security and privacy must be a priority for technical scale, especially when dealing with vulnerable populations and highly sensitive information such as HIV status. The ecosystem would benefit from a simplified version of HIPAA (Health Insurance Portability and Accountability Act, US) and GDPR (General Data Protection Regulation, EU), the prevailing health data privacy guidelines for the western world, tailored to low-resource settings with practical guidance around identity management and encryption.

## 32.14 Emerging Trends and Future Vision

As the digital health ecosystem overcomes the challenges listed above, it can be predicted that a number of trends will emerge in moving from the "SMS era" into one of interactive, personalized digital health. Some of these trends have been pioneered in high-resource settings, fueled by the massive injections of talent and capital into digital health in recent years. However, others germinated in low-resource settings and are rapidly gaining momentum. I briefly highlight some of the most promising trends.

### 32.14.1 Modularity and Application Programming Interfaces (APIs)

The OpenMRS example is an open source, community-supported suite of EMR modules that can be analogized across digital health. The *Be He@lthy Be Mobile* campaign from the WHO aims to scale up national digital health initiatives by providing reusable mHealth toolkits, streamlined service models and collaboration platforms for digital health globally (WHO 2014). Imagine if local health organizations could drag and drop functionalities into templated software products with easy-to-use software development kits (SDKs), plug into the latest diagnostic and treatment guidelines using application programming interfaces (APIs), and connect with third-party services such as telemedicine consults. Technical modularity is helping to power the revolution toward human-centered design, where solutions are created in close consultation with end-users, and thus reshaping digital health more broadly (Pym 2015).

### 32.14.2 Personal Health Clouds

As mobile internet access expands, we can expect digital health tools to increasingly move into the cloud, allowing patients to store and manage their personal health data. (Cloud computing is an information technology paradigm that enables ubiquitous access to shared pools of configurable system resources and higher-level services that can be rapidly provisioned with minimal management effort, often over the Internet. Cloud computing relies on sharing of resources to achieve coherence and economies of scale, similar to a public utility.) The vision of an electronic "health passport" that travels with a patient over time (regardless of how fragmented health facilities may be on the ground) would empower patients, streamline diagnosis and treatment and enable better population health tracking.

### 32.14.3 Social Care Models

Platforms such as *Omada* and *WealLife* (both San Francisco-based) have recognized that strong social networks, between similar patients or even within a patient's own circle of family and friends, can assist in managing chronic disease. This principle is already in action organically in communities across the LMICs. However, technology can support this process by explicitly forming patients into "care teams," potentially built around different stages of chronic disease management.

### 32.14.4 Home-based Care

In the words of the UK's National Health Service director Sir Bruce Keogh, "the hospital of the future is in the home." Digital health will likely be an enabler of home-based care, providing tailored advice to patients and their carers, and allowing remote health workers to manage dozens of cases remotely.

### 32.14.5 Crowdsourced Medical Advice

The applications shown in Figure 32.1 summarize the mission to democratize medical knowledge by allowing physicians to upload clinical photographs and discuss cases with a network of specialists from around the globe. This technology is being used by Médecins Sans Frontières and a number of other healthcare NGOs to crowdsource medical advice. Given the impending workforce shortages and maldistribution of specialist talent between rural and urban areas, we anticipate that crowdsourcing for clinical education and decision support will be a growing trend. (Crowdsourcing is a sourcing model in which individuals or organizations obtain goods and services, including ideas and finances, from a large, relatively open and often rapidly-evolving group of Internet users. It divides work between participants to achieve a cumulative result.)

### 32.14.6 Artificial Intelligence (AI)

AI can assist with diagnosis, management, and population health predictions. One startup in Nigeria has applied AI to analyze the acoustic patterns of the cry of newborn babies in order to screen for neonatal asphyxia (*freelanceqz* 2017). Another project is using automated image analysis to screen for otitis media in tympanic membrane photographs with a view to deploying low-cost otoscopes and automating the diagnostic step (Myburgh et al 2016). The Artificial Intelligence and Medical Epidemiology (AIME) platform in Malaysia aims to predict disease outbreaks by aggregating public health and climate data, with promising results already demonstrated in tracking dengue epidemics.

### 32.14.7 Blockchain Technologies

A flurry of organizations are currently trying to adapt blockchain technology to store and manage health data securely. (Blockchain is a continuously growing list of records, called blocks, which are linked and secured using cryptography.) The advantages of this decentralized digital ledger includes an auditable ground-truth for important health data, identity management with custom access levels and smart contracts.

Blockchain-based solutions have helped to decrease corruption and improve transparency in the LMICs, such as in managing property rights in Ghana, and there are likely some transferable lessons for health systems, especially in settings where unauthorized practitioners or corrupt payment systems reduce access for the most vulnerable.

## 32.15 Conclusions

Digital health has a bright future in helping to improve access, quality, and cost for health systems around the globe. The benefits will arguably be felt most strongly in the LMICs, in the face of severe workforce shortages and the rising burden of chronic disease. The digital health ecosystem faces challenges such as a shortage of clinical evidence, technical limitations, a lack of sustainable financial models, and interfacing barriers with the broader health system. A number of upstream factors can accelerate the maturity of digital health in the LMICs: a supportive policy environment, more flexible funding (from governments, aid organizations and industry), and better educational resources for digital health innovators. Bidirectional knowledge and talent transfer between low- and high-resource settings is particularly valuable. The future will likely see a combination of tried-and-tested technologies such as SMS better embedded into care pathways, as well as some of the emerging technologies such as artificial intelligence powering new solutions altogether. We have already seen the "M-PESA" revolution for mobile banking – the next chapter will be the digital health revolution where these technologies blend into the fabric of healthcare and society.

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