Digital Health in LLMICs:

Current and future technological developments with the potential to improve health outcomes in low- and lower-middle-income countries

Background Paper

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Pathways for Prosperity Commission
Technology & Inclusive Development

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This paper is part of a series of background papers on technological change and inclusive development, bringing together evidence, ideas and research to feed into the commission's thinking. The views and positions expressed in this paper are those of the author and do not represent the commission.

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Executive Summary

Background

Technology will shape the future of healthcare over the coming decades across the world. In low- and lower-middle-income countries (both the focus of this report and referred to henceforth as LLMICs), digital health has a great potential to strengthen healthcare provision for the most vulnerable. There are, however, a number of hurdles to overcome. This report, commissioned by the Pathways for Prosperity Commission, explores current and future technological developments with the potential to improve health outcomes, particularly those that could alleviate high disease burden conditions in LLMICs. The report builds on 18 expert interviews undertaken for this study and makes a number of recommendations for local, national and international actors.

Chapter 2 explores current applications of digital health technologies across five categories: i) process optimisation; ii) preclinical research; iii) clinical pathways; iv) patient-facing applications; and v) population-level applications. Chapter 3 identifies some overarching barriers faced by those designing and implementing programmes, and the risks that arise from them. Chapter 4, on future developments, takes a forward scan, examining the first and second order effects of three trends: i) universal internet access; ii) proliferation of data; and iii) ubiquitous and powerful artificial intelligence (AI).

Acknowledgements

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Key findings

A key finding of this research is that, while there is a plethora of applications with great potential, there is a need for essential infrastructure so that citizens can experience the full promise of digital health. To benefit from the current and future advances in digital health, the most vulnerable people in LLMICs need to have access to reliable electricity, internet access and digital literacy skills.

Our interviews highlighted two consistent challenges: the difficulties of measuring the impact of digital health initiatives; and scaling them up to a national level. We also found that some of the biggest obstacles to scaling are not technical, but relate to governance, regulation and competing incentives for donors and developers.

Overcoming these barriers in order to lay the foundations of digital health depends on leadership and, crucially, effective coordination at national and international levels. Sustained efforts will be required to ensure that the benefits reach those people who are worst off, and that existing health inequalities – for instance between rural and urban areas – are not exacerbated.

Overall, if the risks are managed effectively, we envisage a future where digital health applications play a significant role in helping healthcare systems in LLMICs respond to the complex and evolving challenges they face.

Recommendations

Our recommendations are aimed at policymakers, donors, international bodies, development agencies, researchers and other stakeholders engaged in digital health – including in the private sector. Please see Chapter 5 for a further explanation of all 12 recommendations.

At a national level:

i. Aim to create digital health architectures and adopt standards that encourage interoperability and effectively manage health information exchanges.
ii. Consider the health benefits of investing in robust national infrastructure related to electricity, broadband and mobile access.
iii. Consider the health benefits of investing in nationwide digital literacy initiatives.
iv. Design national action plans for implementing electronic medical records.
v. Develop and implement clear, national frameworks and regulations for data protection.
vi. Test AI tools on relevant and appropriate data sets to avoid data bias.
vii. Establish clear governing bodies to oversee implementation of the national digital health strategy and invest in leadership and capacity building.

At a global level:

viii. Coordinate on digital health projects according to the Principles of Donor Alignment for Digital Health, in order to share resources, learning, and avoid duplication.
ix. Adhere to the Principles for Digital Development, including assessing user needs prior to the development or implementation of a digital health platform and adopting a problem-based approach.
x. Engage actively with international benchmarking processes for algorithmic validation, explainability and accountability.
xi. Establish a globally accessible online health information hub, akin to the UK's National Health Service (NHS) website.
xii. Consider the ethical challenges of AI in healthcare as set out in Future Advocacy's 2018 report, *Ethical, Social and Political Challenges of Artificial Intelligence in Health.*

1. Introduction

The global health landscape is rapidly evolving. Partly this is due to shifts in the types of health conditions faced. While low- and lower-middle income countries (LLMICs) still suffer greatly from infectious diseases, with increasing global wealth, sanitation standards, and scientific advances in healthcare and drug discovery, the global disease burden is shifting from communicable to non-communicable diseases. While life expectancy is increasing, more people live with chronic diseases, mental health disorders and injuries. As one commentator put it, most people will be faced with a 'devastating irony: avoid premature death but live longer and sicker'.[1]

Healthcare systems will need to adapt to this new set of challenges. The global shortfall of doctors, nurses and other health workers is set to grow to 12.9 million by 2035, and huge inequities in the distribution of health workers still exist between and within countries.[2] Climate change, disruption to supplies of food and water, mass migration, changes in diet and lifestyle, and many other trends, will create serious and novel challenges for health systems at every level.

Digital technology will undoubtedly play a key role in helping health providers to respond to some of these developments over the coming decades. Digital health is an expansive and rapidly growing field. A range of technologies – such as mobile health apps, electronic health records, and remote consultations – are already widely deployed in some countries. Many more are being researched and used at a smaller scale, in diverse areas including diagnostics, robot-assisted surgery, decision support for clinicians, and outbreak prediction.

While many interventions show enormous promise, attempts to assess their impact and effectiveness have been hindered by evidence gaps, particularly in poorer settings. Most initiatives have not been implemented at scale, and those that are often lack systematic data and evaluation. The difficulty of establishing a causal relationship between a digital health initiative and a particular health outcome is exacerbated by a large number of intervening variables, contextual variation, and the need for extensive studies to monitor long-term effects.

This report looks at the potential of digital health to address the specific challenges faced by LLMICs.[3] By drawing on the latest research and interviews with experts in the field, it maps current applications that show promise across a range of use cases and contexts, and the obstacles to effective implementation. It then takes a forward scan, suggesting strategies that policymakers and developers could use to maximise the benefits and minimise the risks of future developments

[1] Murray, C. (2012). *Global Burden of Disease: Massive shifts reshape the health landscape worldwide.* Available at: www.healthdata.org/news-release/global-burden-disease-massive-shifts-reshape-health-landscape-worldwide, (accessed 19 July 2019).

[2] WHO. (2013) 'Global health workforce shortage to reach 12.9 million in coming decades'. Available at: https://www.who.int/mediacentre/news/releases/2013/health-workforce-shortage/en/, (accessed 19 July 2019).

[3] For the current 2020 fiscal year, the World Bank defines low-income economies as those with a GNI per capita of $1,025 or less in 2018; lower-middle-income economies are those with a GNI per capita between $1,026 and $3,995; upper-middle-income economies are those with a GNI per capita between $3,996 and $12,375; high-income economies are those with a GNI per capita of $12,376 or more. More information is available at: https://datahelpdesk.worldbank.org/knowledgebase/articles/906519-world-bank-country-and-lending-groups

in digital health. As Nina Schwalbe, former Principal Health Advisor at UNICEF, summarised, 'there are tools with fantastic potential to be game changers in this system. We need to develop the regulatory and evaluation frameworks to be able to deploy them'.[4]

Digital health

Digital health refers to the use of digital technology in healthcare. Once rooted in eHealth, or the use of information and communication technology (ICT) to address health problems, the term now also encompasses emerging fields such as genomics, artificial intelligence (AI), advanced computing and 'big data'.[5] Digital health in this broader sense draws on numerous technologies, including mobile phones and applications, wearable devices, image scanning, remote monitoring sensors, robotics, virtual reality and telemedicine.[6] These are increasingly being used for diagnosis, treatment and risk management, but also for disease prevention and promotion of good health and wellbeing.[7]

The digital divide

Digital health interventions intended for use by patients and clinicians (as opposed to drug discovery, for instance) depend on the availability of devices and access to the internet. Rapid improvements in broadband and satellite technologies, together with the miniaturisation of fast, powerful and portable computing devices, has greatly increased global access to digital technology since the 1980s.[8] The International Telecommunication Union (ITU) estimates that, at the end of 2018, 51.2% of the global population, or 3.9 billion people, were using the internet, up from 30% in 2010.[9] Over 7 billion people (95% of the global population) live in an area that is covered by a mobile-cellular network, with almost 4 billion of them (53% of the global population) having access to a 4G Long Term Evolution (LTE) network.[10] By 2020, there will be more than 6.1 billion smartphone users globally.[11]

[4] Interview with Nina Schwalbe, 29 June 2019.

[5] WHO. (2019). *Recommendations on Digital Interventions for Health Systems Strengthening*. Available at: https://apps.who.int/iris/bitstream/handle/10665/311941/9789241550505-eng.pdf, (accessed 19 July 2019).

[6] WHO. (2019). What you need to know about digital health systems. Available at: www.euro.who.int/en/health-topics/Health-systems/pages/news/news/2019/2/what-you-need-to-know-about-digital-health-systems, (accessed 19 July 2019).

[7] Bhavnani et al. (2016). 'Mobile technology and the digitization of healthcare', *European Heart Journal, 2016 May 7; 37(18): 1428–1438*. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4914890/, (accessed 19 July 2019).

[8] Strukelj et al. (2018). *Technology Forward Scan: Future applications for digital technology in low and middle income countries*. Available at: https://futureadvocacy.com/wp-content/uploads/2019/01/nic-futureadvocacy-28nov18_final_to_go_on_website.pdf, (accessed 19 July 2019).

[9] ITU. (2019). Global ICT developments, 2001-2018. Available at: https://www.itu.int/en/ITU-D/Statistics/Pages/stat/default.aspx, (accessed 19 July 2019).

[10] ITU. (2017). *ICT Facts and Figures 2016*. Available at: https://www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFacts-Figures2016.pdf, (accessed 19 July 2019).

[11] Marr, B. (2015). Big Data: 20 Mind-Boggling Facts Everyone Must Read. Available at: https://www.forbes.com/sites/bernardmarr/2015/09/30/big-data-20-mind-boggling-facts-everyone-must-read/#2f9d70b117b1, (accessed 19 July 2019).

The proportion of the population that uses the internet is much greater in high-income countries (80.9% in Europe compared to 24.4% in Africa). However, access in LLMICs is rising rapidly. The ITU reports that, in 'developing' countries, the proportion of internet users increased from 7.7% in 2005 to 45.3% at the end of 2018. Of all ITU regions, the fastest growth was documented in Africa, where the proportion grew from 2.1% in 2005 to 24.4% in 2018.[12] There is also a significant connectivity gap between rural and urban areas: 3G coverage increased from 75% to 87% globally between 2014 and 2017, reaching an additional 1.1 billion people. However, only around a third of rural populations in low-income countries are covered by 3G networks.[13]

> 'Digital tools are ultimately accelerants… the biggest risk of digital health is that, rather than accelerating movement towards equity, it instead accelerates movement toward disparity.'
> *Skye Gilbert, Executive Director of Digital Square*

The number of mobile phone users in low- and middle- income countries rose from 2.8 billion in 2012 to 3.6 billion in 2016, according to the 2017 GSMA survey.[14] This surge is driven largely by young people. In the least developed countries (as per the United Nations definition) up to 35% of individuals using the internet are aged 15–24, compared with 13% in developed countries and 23% globally. In China and India alone, up to 320 million young people use the internet.[15,16]

Unequal access to connectivity and devices across gender, region, language, income level and age, have serious consequences for digital health programmes. While, in many cases, digital initiatives can be an equalising force – targeting remote and hard-to-reach locations – they can also exacerbate health inequalities. As Skye Gilbert, Executive Director of Digital Square, told us: 'digital tools are ultimately accelerants… the biggest risk of digital health is that, rather than accelerating movement towards equity, it instead accelerates movement toward disparity.'

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12 ITU. (2018). ITU releases 2018 global and regional ICT estimates. Available at: https://www.itu.int/en/mediacentre/Pages/2018-PR40.aspx, (accessed 19 July 2019).

13 GSMA. (2019). The Mobile Economy 2019. Available at: https://www.gsma.com/r/mobileeconomy/ (accessed 19 July 2019).

14 GSMA. (2015). *Bridging the Gender Gap: Mobile access and usage in low and middle-income countries*. Available at: https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2016/02/Connected-Women-Gender-Gap.pdf, (accessed 19 July 2019).

15 UN Economic Analysis and Policy Division. (2019). LDC identification criteria and indicators. Available at: https://www.un.org/development/desa/dpad/least-developed-country-category/ldc-criteria.html (accessed 19 July 2019).

16 ITU. (2017). ICT Facts and Figures 2017. Available at: https://www.itu.int/en/ITU-D/Statistics/Documents/facts/ICTFacts-Figures2017.pdf, (accessed 19 July 2019).

Shifting disease burden

The proportion of a country's disease burden caused by communicable diseases shrinks as income increases. As shown in Figure 1, in low-income countries, communicable diseases cause around 59% of Disability-Adjusted Life Years (DALY is an indicator of disease burden – see below).[17] For lower-middle-income countries, this figure drops to 29%, and is overtaken by non-communicable diseases, which make up 60% of DALYs. Injuries cause around 11% of DALYs worldwide, and this figure is fairly consistent across income groups.[18]

Figure 1: Percentage of DALYs caused by communicable diseases, non-communicable diseases, and injuries in 2016 (WHO)

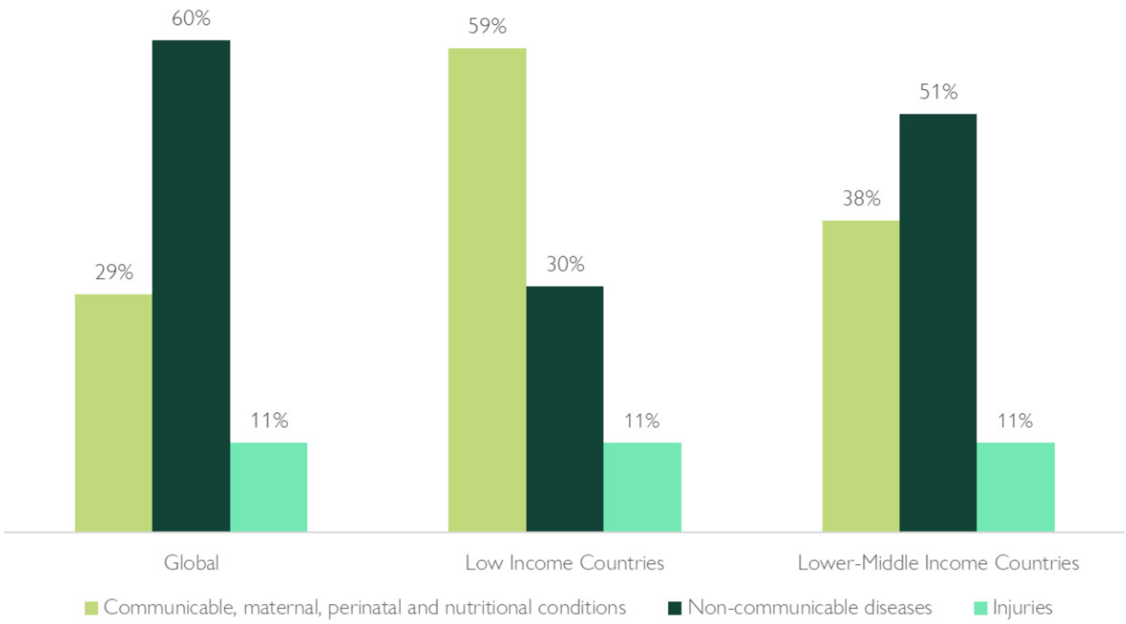
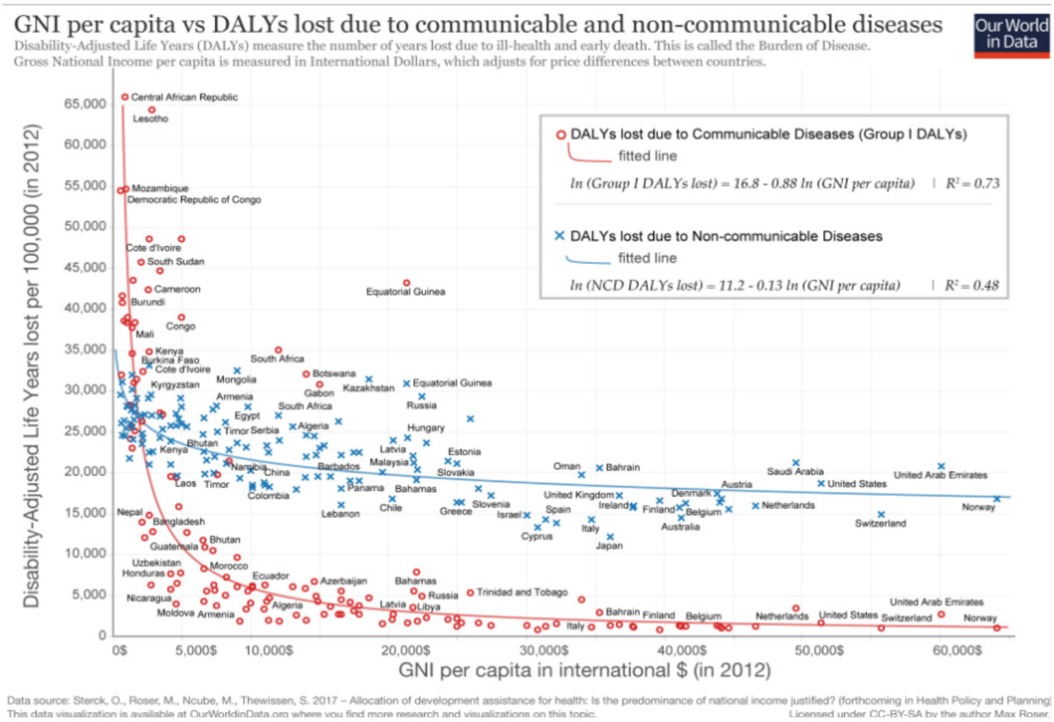


Figure 2 (2012 data) shows a clear correlation between GNI per capita and total DALYs. Only in the very poorest countries do communicable diseases cause more DALYs than non-communicable diseases.

[17] Developed in the 1990s by the Harvard School of Public Health, the World Bank and the World Health Organization (WHO), burden of disease describes 'death and loss of health due to diseases, injuries and risk factors for all regions of the world.' The burden of a particular disease or condition is calculated by adding together Years of Life Lost (YLL), and Years of Life lived with Disability (YLD). This gives a single estimate, called the Disability Adjusted Life Year (DALY), which represents the loss of one year of life lived in full health. More information can be found at: WHO, Metrics: Disability-Adjusted Life Year (DALY), available at: https://www.who.int/healthinfo/global_burden_disease/metrics_daly/en/ (accessed 20 August 2019).

[18] WHO. (2019). Disease burden and mortality estimates. Available at: https://www.who.int/healthinfo/global_burden_disease/estimates/en/index1.html, (accessed 19 July 2019).

Figure 2: GNI per capita vs DALYs lost due to communicable and non-communicable diseases[19]



In 2016, the top 10 causes of death and ill-health (as measured by DALYs) in LLMICs are shown in Figure 3 below. Conditions relating directly to maternal health and childbirth feature prominently in both lists. The growing burden of non-communicable diseases as income increases is shown by the shift from malnutrition and malaria in low-income countries, to strokes, pulmonary disease and heart disease in lower-middle-income countries.[20]

Figure 3: Top 10 most DALY-causing diseases and conditions in low-income and lower-middle-income countries

Low-income countries	Lower-middle-income countries
Lower respiratory infections	Ischaemic heart disease
Diarrhoeal diseases	Lower respiratory infections
Malaria	Pre-term birth complications
Pre-term birth complications	Diarrhoeal diseases
Birth asphyxia and birth trauma	Stroke
HIV/AIDs	Birth asphyxia and birth trauma
Congenital anomalies	Tuberculosis
Neonatal sepsis and infections	Chronic obstructive pulmonary disease
Protein-energy malnutrition	Congenital anomalies
Tuberculosis	HIV/AIDs

19 Roser, M. and Ritchie, H. (2018) Burden of disease. Available at: https://ourworldindata.org/burden-of-disease, accessed 12 September 2019.

20 WHO. (2019). Disease burden and mortality estimates. Available at: https://www.who.int/healthinfo/global_burden_disease/estimates/en/index1.html, (accessed 19 July 2019).

Health inequalities

While numerous digital health initiatives target a specific disease, this report aims to also look more broadly at health systems and gaps in essential care and resources, as well as prevention and wellness programmes. Globally, the average national percentage of total government expenditure devoted to health was 11.7% in 2014.[21] However, the distribution of resources is extremely unequal, and it is widely agreed that funding aligns poorly with global health needs.

The World Health Organization (WHO) estimates that, based on population need, there is a shortage of about 7.2 million healthcare workers. This is expected to rise to about 12.9 million globally by 2035.[22] LICs and LMICs face a huge shortage of trained, accessible and equitably distributed health workers. From data reported by governments between 2007 and 2016, 76 countries have less than one physician per 1,000 population, and 87 countries have less than three nurses or midwives per 1,000 population. In many countries, nurses and midwives constitute more than half of the national health workforce and therefore take on a range of highly specialised tasks without sufficient training.[23]

The rural-urban divide in terms of both health workforce and life expectancy is stark. In India, there are 1.71 physicians per 10,000 population in urban areas, dropping to 0.45 in rural areas. In Nigeria, the figure is 0.14 in urban areas, and only 0.01 in rural areas.[24] In addition, many people do not have regular access to essential medicines: only 64% of public-sector facilities in low-income countries and 58% of those in lower-middle income countries stock medicines for pain management and palliative care.[25] The next section explores how digital technologies can help health systems to meet some of these pressing challenges.

[21] WHO. (2018). *World health statistics 2018: Monitoring health for the SDGs.* Available at: https://apps.who.int/iris/bitstream/handle/10665/272596/9789241565585-eng.pdf, (accessed 19 July 2019).

[22] WHO. (2018). *WHO Global Health Workforce Statistics*. Available at: https://www.who.int/hrh/statistics/hwfstats/en/ (accessed 19 July 2019).

[23] Ibid.

[24] Guo, J. and Li, B. (2018). *The Application of Medical Artificial Intelligence Technology in Rural Areas of Developing Countries.* Available at: https://www.liebertpub.com/doi/pdf/10.1089/heq.2018.0037 (accessed 19 July 2019).

[25] WHO. (2018). *World health statistics 2018: Monitoring health for the SDGs.* Available at: https://apps.who.int/iris/bitstream/handle/10665/272596/9789241565585-eng.pdf, (accessed 19 July 2019).

Scope of this report - potential in five areas

To maintain an overview of the range of possibilities, we will classify technologies according to five key areas:[26]

1. **Process optimisation** – e.g. procurement, logistics and staff scheduling
2. **Preclinical research** – e.g. drug discovery and genomic science
3. **Clinical pathways** – e.g. diagnostics and prognostication
4. **Patient-facing applications** - e.g. delivery of therapies or the provision of information
5. **Population-level applications** – e.g. identifying epidemics and understanding non-communicable chronic diseases

Various digital technologies, including those involving AI, have already seen widespread deployment in a number of areas. Some are being piloted at a smaller scale. Others still are in the early stages of research. Some examples of applications at all three stages are shown in Figure 4.

Figure 4: Current and future digital health applications (scaled, pilot and research stages)

Theme	Widespread/scaled	Pilot/small-scale	Research/ speculative
Process optimisation	• Electronic medical records (OpenMRS and DHIS) · Rota/schedule optimisation, eg Hong Kong Health Authority • Medical supplies management, eg eLMIS in Bangladesh · Supply chain management for medicines	· Data-driven optimisation of logistics, procurement · Client registration and identification, biometric systems · Counterfeit drug testing	•Automated analysis or completion of medical notes and other documentation · Patient experience analysis · Management decision and human resource support
Preclinical research	· Candidate molecule screening (BenevolentAI, AtomNet) · Repurposing drugs (Teva) · Predicting potential side effects (Cloud Pharmaceuticals)	· Analysis of large -omics datasets to gain insights.	· Determining targets for gene editing, eg CRISPR

[26] Fenech et al. (2018). *Ethical, Social and Political Challenges of Artificial Intelligence in Health*. Available at: https://futureadvocacy.com/wp-content/uploads/2018/04/1804_26_FA_ETHICS_08-DIGITAL.pdf, (accessed 19 July 2019).

Clinical pathways	· Telemedicine (remote consultation) · Risk assessment and triaging tools (eg Emergency Triage Assessment and Treatment (ETAT)) · Healthcare worker supervision and communication systems (eg mHero)	· Image scanning (DeepMind – Moorfields) · Analysis of clinical conversations (Corti) · Prognostication (prediction of all-cause mortality, Stanford, KenSci) · Healthcare worker training (eg iDEA) · Drones – delivery of essential materials	· Automated transcription of clinical interactions · Automated completion and submission of investigation requests/referrals · Personalised and precision medicine
Patient-facing applications	· Personal health apps (Babylon, Ada) · Prescription and medication management	· Smart homes and wearables · Personalised health advice and interventions, (CareSkore, Viome, DayTwo) · Robot carers · Autonomous (closed-loop) insulin pumps	· Robot surgeons
Population-level applications	· Prediction of infectious disease outbreaks (Dengue fever app in Malaysia) · Platforms for reporting public health incidents (eg Ebola TxT)	· Better understanding of risk-factors for non-communicable diseases · Data-driven resource allocation	· Natural language processing in multiple languages to analyse new sources and predict outbreaks

The next chapter sets out the opportunities and challenges of current applications in each of these five categories, with a range of context-specific case studies.

2. Current applications

Process optimisation

Optimising the use of limited healthcare resources through digital technology could bring important benefits to LLMICs. Process optimisation measures include the digitisation of medical records, staff scheduling, supply chain and logistics. Greater cost-efficiency could free up resources to train physicians, increase the quality of care, and widen the reach of essential services.

Digitalising back-end operations can provide crucial data to help make better public health decisions. Precisely analysing infectious disease spread, identifying patient risk factors, and distributing resources effectively, all depend on reliable and good-quality data. Electronic medical records, particularly when interoperable (able to be shared and combined with data produced across organisational boundaries) can open the door to more evidence-based decisions at a system level.

The development of open source software has been an essential development for LLMICs. Governments can choose to host open source platforms locally, without becoming dependent on big tech companies. Optimisation software can also be used by development actors, including foreign aid ministries, international organisations, and non-governmental organisations (NGOs), to make evidence-based decisions about where to send medicines, health workers and other resources. The rich data produced by digitising medical records can also be used by researchers and developers to create new tools and treatments.

Case study 1: Electronic medical records and Ebola

As a response to the global challenge of pandemics, the Open Medical Record System (OpenMRS) was founded in 2004 as an open source, electronic medical records platform for lower-income countries.[27] OpenMRS is currently operating in many countries around the world, including South Africa, Kenya, Rwanda, Lesotho, Zimbabwe, Mozambique, Uganda, Tanzania, Haiti, India, Pakistan and the Philippines. In Uganda, it is used in more than 500 facilities.

OpenMRS provides a repository that health workers, supervisors and managers can use to store patient data, clinical observations and treatment programmes. The platform supports multiple languages, can be customised for different uses and stores information in a way that allows it to be easily summarised and analysed. During the Ebola epidemic of 2014–2016, OpenMRS was deployed in a treatment centre in Sierra Leone.[28] Due to health and safety concerns, paper-based record-keeping was not an option. Instead, the staff at the centre wore gloves and accessed the OpenMRS system on waterproof, sterilisable Android tablets. The system was used for hundreds of patient registrations, prescription orders and medical administrations before the treatment centre was closed following a drop in Ebola cases.

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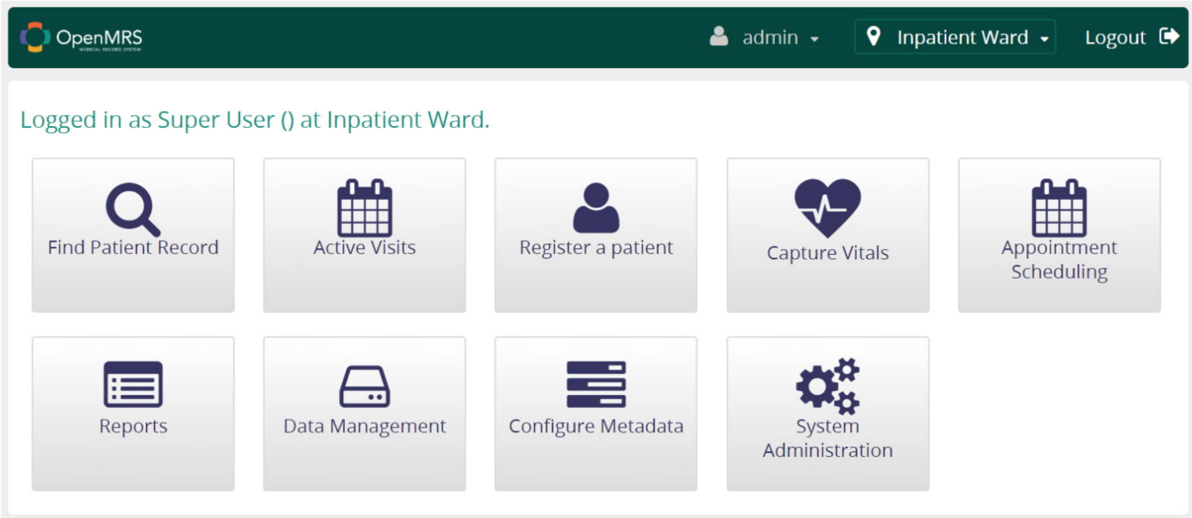
[27] OpenMRS. (2019). About OpenMRS. Available at: https://openmrs.org/about/, (accessed 19 July 2019).

[28] Oza et al. (2017). *Development and Deployment of the OpenMRS-Ebola Electronic Health Record System for an Ebola Treatment Center in Sierra Leone*. Available at: https://www.jmir.org/2017/8/e294/, (accessed 19 July 2019).

Figure 5: Image of the OpenMRS electronic medical records system[29]



Case study 2: Birth registration in Uganda

Mobile Vital Records System (Mobile VRS) in Uganda aims to 'address the bottlenecks in a paper-based system' and 'play a vital role in streamlining, simplifying, and decentralising delivery of births and deaths registration services'.[30] The system enables health workers to use a web-based application or SMS messages on their mobile phones to register births and deaths in local communities. This information is then accessed by the relevant registration officers for a given area, who verify it for completeness and accuracy before a certificate is printed and issued. At hospitals, a web-based system is used and certificates are issued immediately. At the same time, the information is uploaded to the central Mobile VRS server.

According to UNICEF, Mobile VRS is now used in 135 government and missionary hospitals and in 73 district local governments to notify communities of births and print standardised birth notifications.[31] The technology has contributed to an increase in the national birth registration rates for children under 5 years old from 30% in 2011 to 69% in 2016. It is expected that at least 90% of children aged under 5 years will have their birth registered by 2020. According to figures published by Mobile VRS, a total of 5.8 million birth notifications were recorded from 2011 to 2019, as well as 5.2 million birth registrations.

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29 OpenMRS Demo, OpenMRS. Available at: https://openmrs.org/demo/, accessed 12 September 2019.

30 Uganda Mobile VRS. (2019). About Mobile Vital Records System. Available at: www.mobilevrs.co.ug/home.php (accessed 19 July 2019).

31 Unicef. (2019). MobileVRS: Supporting birth registration of Ugandan children. Available at: https://www.unicef.org/uganda/what-we-do/mobilevrs, (accessed 19 July 2019).

Figure 6: Birth notifications and registrations made using Mobile VRS

Case study 3: Commcare and frontline health workers

CommCare, a mobile and cloud-based platform developed by Dimagi, is a further example of a system-wide efficiency intervention. It is open source and specifically designed for frontline health workers, including those with low literacy rates, and runs offline. With CommCare, health organisations can design customised mobile applications that help their frontline health workers deliver better healthcare to patients. The health worker is able to track their work and manage patients using customisable mobile forms. All data collected by health workers is submitted to secure cloud servers where it is made available to approved supervisors, researchers and managers in web-based reports. More than 350,000 frontline health workers in 80 countries use CommCare, many through government-supported health projects. As Jonathan Jackson, Co-founder and CEO of Dimagi, told us, 'each of CommCare's 2,000 active projects has built different content on top of the CommCare platform – we view this as a critical factor for adoption and impact.' Process-mapping what the worker does is key. He added: 'There typically is a huge disconnect between their theoretical job function and their actual job function. It is important to bridge this gap in order not to build things into the system that they're not actually doing'.[32]

> 'Giving a smartphone to a community health worker just to address HIV is crazy; it's like buying a laptop just to use Microsoft Word.'
> *Jonathan Jackson, Co-founder and CEO of Dimagi*

Featured in the *Global Goods Guidebook*, CommCare has addressed many health verticals, from maternal and child health to Ebola response and HIV prevention. The platform also provides useful data for decision-making at the public health level. However, Jonathan Jackson was keen

[32] Interview with Skye Gilbert, 13 June 2019

to emphasise that it is essential not to think of an intervention in a narrow sense as 'a means to get data back', but as a platform with a real return on investment in terms of health outcomes. In Jackson's words 'giving a smartphone to a community health worker just to address HIV is crazy. It's like buying a laptop just to use Microsoft Word'. Jackson argues that developers often assume they will be able to pivot from an application that addresses one health vertical into a 'horizontal, holistic use case'. In reality, this rarely happens.

Case study 4: AI for rostering in Hong Kong

One area where AI is being applied in healthcare systems is rostering. The Hong Kong Health Authority, for example, is using an AI-based tool developed at the local City University of Hong Kong to produce monthly or weekly staff rosters that satisfy a set of constraints, such as staff availability, staff preferences, allowed working hours, ward operational requirements and hospital regulations.[33] This tool has been deployed across 40 public hospitals, and is responsible for the rostering of more than 40,000 staff. Since being introduced, the Hospital Authority reports increased productivity, improved staff morale, and improved quality of service, as the system is seen to be fair, frees up managers' time, and can provide management with insights into working patterns and resource utilisation.[34]

Challenges

While adoption of basic digitisation measures such as electronic medical records is growing, significant challenges remain. Critical to these tools is a workforce that can design, implement and maintain the system. One key issue is whether they can be managed effectively in the context of limited human resources. An analysis of Mobile VRS by UNICEF found that introduction of the technology led to an increase in demand for birth registration services and that staff shortages at local government levels affected the programme's success.[35] If the technology replaces an existing system, such as a paper-based records system, this may be less of an issue as the application may actually be reducing the amount of time spent on data input. However, if the technology is delivering an entirely new service, this may add extra strain to health workers and require additional training and recruitment.

Data training and expertise is another hurdle for process optimisation tools. Just as good data can lead to good outcomes, bad data can lead to bad ones. It is therefore critical that new systems come with sufficient training about what good data looks like. For example, if the data on malaria infections is inaccurate due to transcription errors, this can lead to a misallocation of resources by health ministries and NGOs. As such, the digital and non-digital literacy of users is key to the

[33] Chun et al. (2000). Nurse Rostering at the Hospital Authority of Hong Kong. Available at: https://www.cs.cityu.edu.hk/~hwchun/research/PDF/IAAI2000HA.pdf, (accessed 19 July 2019).

[34] Chun, A. (2019). AI Success Stories. HA: Nurse rostering. Available at: www.cs.cityu.edu.hk/~hwchun/AIProjects/stories/hrrostering/harostering/, (accessed 19 July 2019).

[35] Shanker, A. (2012). Equity Case Study: Uganda – Using mobile technologies to improve delivery of, and access to, birth registration services for all children. Available at: https://www.unicef.org/equity/archive/index_66507.html, (accessed 19 July 2019).

success of these applications. Producing platforms that are user friendly is also essential: inputting data for electronic medical records is widely reported as one of the most time-consuming tasks in healthcare facilities.[36] Furthermore, in order for the data to help identify social and environmental risk factors for a particular disease, it must be interoperable.

More broadly, the trend towards increased use of 'people analytics' – the comprehensive collection of data about employees' behaviour, which is then used to inform managerial decisions – has been criticised as having a dehumanising effect on work, and may not even be effective in increasing productivity or optimising working practices.[37]

Compared to other emerging technologies, tools that support process optimisation do not provide immediate relief or diagnosis. Instead, they help alter the systems used by healthcare workers, improving back-end processes and freeing up time and resources. In the medium to long term, these tools are likely to create greater capacity for health workers and support quality research through enhanced data collection.

Preclinical research

One of the great promises of AI is its potential to revolutionise drug discovery. Advances in machine learning, combined with good-quality data, could significantly speed up the process of identifying and testing new drugs. Preclinical research involves undertaking feasibility studies and iterative testing to help determine the risk of testing a product or drug on a human in clinical trials. Currently, it can take up to 15 years for a new drug to reach the market, following the testing of thousands of chemical compounds.[38]

The design of cheaper and more effective medicines could have a huge impact globally, particularly on high disease burden conditions. AI could expand the number of drugs available, but also decrease the cost of development, and shorten the time it takes for new drugs to reach patients. Additionally, the research need not take place in the LLMICs; research anywhere in the world can benefit those most at risk of high disease burden conditions. AI could also make possible more tailored kinds of medicine, which would take into account an individual's genetics, environment and lifestyle in order to prescribe the best drug.[39]

[36] Guo, J. and Li, B. (2018). *The Application of Medical Artificial Intelligence Technology in Rural Areas of Developing Countries*. Available at: https://www.liebertpub.com/doi/pdf/10.1089/heq.2018.0037, (accessed 19 July 2019).

[37] Gal, U. (2017). Why algorithms won't necessarily lead to utopian workplaces. Available at: https://theconversation.com/why-algorithms-wont-necessarily-lead-to-utopian-workplaces-73132, (accessed 19 July 2019).

[38] Carlson, E. (2012). Computation Aids Drug Discovery. Available at: https://www.nigms.nih.gov/education/Inside-Life-Science/Pages/computation-aids-drug-discovery.aspx, (accessed 19 July 2019).

[39] Precision medicine is defined as 'an emerging approach for disease treatment and prevention that takes into account individual variability in genes, environment, and lifestyle for each person.' See: https://ghr.nlm.nih.gov/primer/precisionmedicine/definition, (accessed 20 August 2019).

Ethically, a greater use of technology in preclinical research may also reduce the need for controversial techniques such as animal testing. A study by the Center for Alternatives to Animal Testing at Johns Hopkins University found that their software (which used machine learning) correctly predicted the outcome of toxicity studies 87% of the time, compared to 70% with animal testing.[40]

Case study 5: Benevolent AI

A growing number of companies are using AI to advance drug discovery and repurposing. For instance, BenevolentAI, a company valued at more than £1 billion, mines and analyses data from clinical trials, academic papers and elsewhere to predict the effectiveness of different compounds.[41] Based in the UK and founded in 2013, the company developed the Benevolent Platform, combining its analysis of structured and unstructured data with deep learning to create automated hypothesis generation and validation. The company also acquired its own drug development facility in Cambridge, enabling them to take their drugs from discovery to clinic.[42]

Benevolent AI's early results from a research collaboration with four UK sight-loss charities identified seven existing drugs that have the potential to be repurposed to treat macular degeneration and identified new gene targets for investigation.[43] Age-related macular degeneration ranks third among the global causes of vision impairment and can result in the total loss of vision.[44] The projected number of people globally with age-related macular degeneration is 196 million in 2020, increasing to 288 million in 2040.[45]

Case study 6: Deep Genomics

Another company, Deep Genomics, founded by a professor at the University of Toronto, uses deep learning to analyse genomic data to help develop drugs that address the behaviour of faulty genes.[46] The focus of the company is on genetic medicines. Using their platform to identify drug candidates with desirable properties, they develop medicines that target the genetic determinants

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[40] Hartung, T. (2019). Opinion: AI Beats Animal Testing at Finding Toxic Chemicals. Available at: https://www.the-scientist.com/critic-at-large/opinion--ai-beats-animal-testing-at-finding-toxic-chemicals-65795, (accessed 19 July 2019).

[41] Medeiros, J. (2019). This AI unicorn is disrupting the pharma industry in a big way. Available at: https://www.wired.co.uk/article/benevolent-ai-london-unicorn-pharma-startup, (accessed 19 July 2019).

[42] Shields, J. (2018). Why we need to use AI for life not just lifestyle. Available at: https://benevolent.ai/blog/why-we-need-to-use-ai-for-life-not-just-lifestyle1, (accessed 19 July 2019).

[43] Benevolent AI. (2019). Artificial intelligence identifies existing drugs that may reduce sight loss from macular degeneration. Available at: https://benevolent.ai/news/artificial-intelligence-identifies-existing-drugs-that-may-reduce-sight-loss-from-macular-degeneration, (accessed 19 July 2019).

[44] WHO. (2019). Priority eye diseases. Available at: https://www.who.int/blindness/causes/priority/en/index7.html, (accessed 19 July 2019).

[45] Wong et al. (2014). 'Global prevalence of age-related macular degeneration and disease burden projection for 2020 and 2040: a systematic review and meta-analysis', The Lancet. Available at: https://doi.org/10.1016/S2214-109X(13)70145-1, (accessed 19 July 2019).

[46] Knight, W. (2017). 'An AI-Driven Genomics Company Is Turning to Drugs', MIT Technology Review. Available at: https://www.technologyreview.com/s/604305/an-ai-driven-genomics-company-is-turning-to-drugs/, (accessed 19 July 2019).

of disease at the level of the RNA or DNA. They are currently using their platform to evaluate more than 69 billion molecules against 1 million targets to generate a library of 1,000 compounds that are verified to manipulate cell biology as intended.[47] They aim to begin testing their compounds in clinical trials from 2020.[48]

Case study 7: Cambridge malaria research

A further example is the work undertaken by researchers at the University of Cambridge who used machine learning to discover that triclosan, an ingredient commonly found in toothpaste, could be employed as a drug to combat strains of malaria that are particularly resistant to current medicines.[49]

Challenges

These forms of preclinical research are fairly new, and it is difficult to tell when the impact will be felt in any country. Many of the existing challenges will remain, including production costs, distribution and counterfeit medicines. The identification of new drugs will not necessarily solve the problem of cost and accessibility for those who need them most.

Another factor here is data bias, a perennial issue in machine learning. Training data that do not accurately reflect an entire population, across gender, race and other demographic identifiers, result in skewed outcomes for any health tech application, but particularly for preclinical research, as any treatment generated may be effective only for certain subsets of the population. This risks widening health inequalities. A 2016 analysis of diversity in genomics found that 81% of participants in genome-mapping studies were of European descent[50] despite their proportion of the world's population being estimated at 10%.[51] While this was an improvement from the 96% in a previous study undertaken in 2009, the majority of non-European ancestry participants were from Asian ancestry with other ethnicities still trailing behind. One of our interviewees, Edmond Ng (Senior Statistical Analyst at the London School of Hygiene & Tropical Medicine) remarked that, while precision medicine has shown huge promise in specific cases, it has so far done very little on a population level.[52]

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47 Deep Genomics. (2019). Project Saturn. Available at: https://www.deepgenomics.com/project-saturn/, (accessed 19 July 2019).

48 Lohr, S. (2018). From agriculture to art – the AI wave sweeps in. Available at: https://www.nytimes.com/2018/10/21/business/from-agriculture-to-art-the-ai-wave-sweeps-in.html, (accessed 19 July 2019).

49 University of Cambridge. (2018). AI 'scientist' finds that toothpaste ingredient may help fight drug-resistant malaria. Available at: https://www.cam.ac.uk/research/news/ai-scientist-finds-that-toothpaste-ingredient-may-help-fight-drug-resistant-malaria, (accessed 19 July 2019).

50 Popejoy, A. and Fullerton, S. (2016). 'Genomics is failing on diversity', *Nature*. Available at: https://www.nature.com/news/genomics-is-failing-on-diversity-1.20759, (accessed 19 July 2019).

51 UN Population Division. (2019). World Population Prospects 2019. Available at: https://population.un.org/wpp/, (accessed 19 July 2019).

52 Interview with Edmond Ng, 17 May 2019.

Clinical pathways

Digital technologies have made essential improvements to a wide range of existing clinical pathways. This section is divided into four sub-applications: remote consultation and decision support; the Internet of Things (IoT); virtual and augmented reality; and drones.

Remote consultation and decision support

Due to the stark inequalities in healthcare worker distribution, interventions that improve the working conditions and augment the capacities of health workers in remote and underserved areas are a high priority – for instance, cutting out unnecessary or bureaucratic tasks, providing additional training opportunities and improving access to healthcare information, or maintaining more consistent support and supervision. As our interviewee, Dr Raymond Sarmiento, Director of the University of the Philippines Manila National Telehealth Center, told us, applications dependent on SMS and mobile health applications work well for reaching far flung regions in Southeast Asia as well as the Pacific Islands, Indonesia, Fiji and Samoa, 'even in the face of unstable internet connections and power grids'.[53]

Traditional telemedicine (providing consultations remotely) and mHealth (providing platforms and services through mobile devices) can have clear benefits for reducing the healthcare divide between urban and remote areas. In regions with few highly trained doctors, support through mobile apps can help community health workers to take on more specialised tasks, which also improves their reputation and social standing. The portability of devices such as mobile phones is an added advantage for health workers who must travel long distances to their patients. A connection to a professional community in the form of remote supervision is also considered by many to be an important source of advice and morale.

> 'Younger generations want everything now, on demand. Amongst the older generations, some people are sceptical.'
> *Fazilah Allaudin, Senior Deputy Director, Malaysian Ministry of Health*

Some countries already have a huge uptake of remote consultation as a standard way to see a doctor. The 2017 Ipsos Digital Doctor study of 18 countries across three regions found that China is leading, with 73% of doctors currently using telemedicine.[54] Opinions are divided over what has been termed the 'uberisation' of healthcare – the provision of services remotely and on demand. Fazilah Allaudin commented that, in Malaysia (an upper-middle-income country) 'younger generations want everything now, on demand. Amongst the older generations, some people are sceptical'. Virtual services have been in the consumer market since 2015 and more and more players have appeared since then. The Malaysian Ministry of Health is currently looking into a regulatory framework for this new service model.[55]

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[53] Interview with Raymond Sarmiento, 24 June 2019.

[54] Ipsos Healthcare. (2017). Digital Doctor. Available at: https://connectedhealth.ipsos.com/digital-doctor.html, (accessed 19 July 2019).

[55] Interview with Fazilah Allaudin, 4 July 2019.

Given that the amount of information in medical literature doubles every three years, digital tools that combine patient history with clinical protocols to assist with diagnosis and treatment also have huge potential.[56] Misdiagnosis is fairly common: data from EU member states suggests that medical errors and healthcare-related adverse events occur in 8% to 12% of hospitalisations.[57] Advances in AI will further improve the efficiency, accuracy and consistency of diagnostics. A number of breakthroughs have already been made, such as Google's convolutional neural network framework to help diagnosis of breast cancer, which it is reported would predict a quarter of the number of false negatives of human pathologists.[58,59] Another example of this is provided by the ongoing work at Moorfields Eye Hospital, London. Pearse Keane, Consultant Ophthalmologist at Moorfields Eye Hospital and NIHR Clinician Scientist at University College London, spoke to us about the increasing use of optical coherence tomography (OCT), a safe and relatively straightforward way of imaging the retina to pick up retinal diseases.[60] Several case studies from LLMIC contexts are described below.

Case study 8: RapidSMS in Rwanda

Communication tools have been critical in remote areas. As Akaliza Keza Ntwari, Founder of Girls in ICT Rwanda and member of the UN Secretary General's High Level Panel on Digital Cooperation, suggested, pregnant women can particularly benefit from accurate information, as well as any population with a low patient-to-health worker ratio, such as rural and overpopulated areas. Rwanda has made significant improvements in maternal and child health through an mHealth system, RapidSMS, a text-messaging tool that allows workers to report health events and receive automated, actionable responses and appointment reminders throughout a woman's pregnancy and into the first year of her child's life. Health facilities are also notified in advance of a delivery. As WHO reports, Rwanda has made significant improvements: the under-5 mortality rate halved between 2005 and 2010 when the programme was rolled out, and at least 45,000 community health workers received training.[61]

Case study 9: mPowering Frontline Health Worker

mPowering Frontline Health Workers is a public–private partnership launched by USAID and the mHealth Alliance. This initiative has 18 partners and a close network of more than 40 other organisations. It is designed to contribute to the elimination of preventable child and maternal

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[56] Guo, J. and Li, B. (2018). 'The Application of Medical Artificial Intelligence Technology in Rural Areas of Developing Countries', *Health Equity*. Available at: https://www.liebertpub.com/doi/pdf/10.1089/heq.2018.0037, (accessed 19 July 2019).

[57] WHO. (2019). Data and statistics. Available at: www.euro.who.int/en/health-topics/Health-systems/patient-safety/data-and-statistics, (accessed 19 July 2019).

[58] Guo, J. and Li, B. (2018). 'The Application of Medical Artificial Intelligence Technology in Rural Areas of Developing Countries', *Health Equity*. Available at: https://www.liebertpub.com/doi/pdf/10.1089/heq.2018.0037, (accessed 19 July 2019).

[59] Liu et al. (2017). 'Detecting cancer metastases on gigapixel pathology images'. Available at: https://arxiv.org/pdf/1703.02442.pdf, (accessed 19 July 2019).

[60] Fenech et al. (2018). *Ethical, Social and Political Challenges of Artificial Intelligence in Health*. Available at: https://futureadvocacy.com/wp-content/uploads/2018/04/1804_26_FA_ETHICS_08-DIGITAL.pdf, (accessed 19 July 2019).

[61] WHO. (2013). *Assisting Community Health Workers in Rwanda*. Available at: https://apps.who.int/iris/bitstream/handle/10665/92814/WHO_RHR_13.15_eng.pdf, (accessed 19 July 2019).

deaths by accelerating the use of mobile technology to help improve the performance of thousands of health workers around the world (mostly in Sub-Saharan Africa and South Asia). It is active in countries such as Cambodia, India and Uganda. The use of SMS to address demand-side barriers to vaccination and improve immunisation coverage has been tested through randomised control trials in settings such as Kenya and the US.[62]

Case study 10: d-Tree International in Zanzibar

d-Tree International provides community health workers in Zanzibar, Tanzania, with a digital antenatal and postnatal assistant. The app helps the health worker schedule regular visits to the patient during pregnancy and after the birth. It provides information about how to screen for signs of serious complications and make any necessary referrals. It also helps women and their families pool money into community savings groups, which can be drawn on as loans to assist with transportation costs to the relevant health facility. Pregnant women are connected to community drivers who have agreed to pre-negotiated rates. The programme is currently being implemented in 10 out of 11 districts in Zanzibar, supporting approximately 30,000 women per year, or 80% of all pregnant women in these areas. Since the programme was introduced in 2011, d-Tree found that infant deliveries within a facility (rather than at home) increased by around 50% compared to baseline estimates. The data generated 'innumerable insights' for programme managers to make improvements at a system-level.[63]

Challenges

Telemedicine and decision support programmes face a number of challenges. A central concern is how the technology fits into the wider ecosystem of health services. Diagnosis or identification of a condition, for example, may induce anxiety and distress patients who have no access to treatment.[64] Problems with the design of digital platforms have also been widely documented. For instance, programmes are sometimes not available in minority languages, and SMS character limitations may limit the length of messages. In these cases, digital interventions may *decrease* efficiency and *increase* workload – for instance, where two systems (paper and digital) must be maintained in tandem for different tasks.

As for all interventions that digitalise patient data, a number of ethical concerns remain around privacy and security. Gaining informed consent from individuals is particularly difficult in areas with low literacy or digital literacy rates. Health workers may experience stress if they feel that they cannot guarantee data security. This is particularly true of information about sensitive or stigmatised health conditions. Additionally, while enhanced supervision is beneficial for some, health workers who are used to working with little oversight may feel patronised or overly scrutinised.

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[62] Wahl et al. (2018). 'Artificial intelligence (AI) and global health: how can AI contribute to health in resource-poor settings?' *BMJ Global Health*. Available at: https://gh.bmj.com/content/bmjgh/3/4/e000798.full.pdf, (accessed 19 July 2019).

[63] d-tree. (2019). Sexual and reproductive health. Available at: https://www.d-tree.org/srh, (accessed 19 July 2019).

[64] Wahl et al. (2018). 'Artificial intelligence (AI) and global health: how can AI contribute to health in resource-poor settings?' *BMJ Global Health*. Available at: https://gh.bmj.com/content/bmjgh/3/4/e000798.full.pdf, (accessed 19 July 2019).

Internet of Things (IoT)

IoT refers to a single device or network of devices that can be monitored and/or controlled from a remote location, and which can transfer data without requiring human-to-human or human-to-computer interaction. IoT has many promising applications in healthcare. Sensors capture data remotely, allowing healthcare practitioners to monitor patients returning home. Diabetes apps and wearables can improve self-management, for example, by prompting patients to take their insulin dose. IoT can also help hospital management determine whether specialist doctors are over- or under-utilising equipment. This could be particularly useful in poorer settings, for example, to establish whether expensive Magnetic Resonance Imaging (MRI) equipment, could be moved around a hospital based on need, making more efficient use of limited resources.[65] An LLMIC example is described in Case study 11.

Case study 11: ColdTrace

One of the reasons that many children in low- and middle-income countries go unvaccinated each year is that vaccines get spoiled in transit, due to insufficiently low temperatures. Many of the 200,000 vaccine fridges being used in these countries are located in remote places, where it is hard to ensure that vaccines are stored between 2°C and 8°C to avoid damaging vaccines and putting children at risk. The non-profit technology company Nexleaf Analytics builds cloud-based sensors that upload data in near real time. One of their practical applications of this technology is ColdTrace, a 'wireless remote temperature monitoring (RTM) solution designed for vaccine refrigerators in rural clinics and health facilities'. This came in response to a WHO and UNICEF joint statement that 56% of cold chain equipment in low- and middle-income countries is poorly functional or non-functional.[66]

ColdTrace's sensors, analytics and report-generating tools, provide crucial information for health workers and ministries for strengthening vaccine storage and cold chain equipment. The nurse can respond by checking the latch or turning on the generator. As the system collects the fridge data, patterns can help with diagnosing issues. In the case of a malfunction, repairs can be carried out remotely, by a mechanic guiding a nurse through the steps over the phone.[67] As of June 2018, 1,247 community health workers had been trained to use ColdTrace, and 15,804 devices had been rolled out to monitor vaccine refrigerators. Nexleaf reports that this amounts to protecting a total of 12.6 million babies born each year across more than 10 countries.[68]

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[65] Daughtery et al. (2015). *Driving Unconventional Growth Through the Industrial Internet of Things*. Available at: https://www.accenture.com/us-en/_acnmedia/Accenture/next-gen/reassembling-industry/pdf/Accenture-Driving-Unconventional-Growth-through-IIoT.pdf, (accessed 19 July 2019).

[66] WHO. (2016). *Achieving immunization targets with the comprehensive effective vaccine management (EVM) framework*. Available at: https://www.who.int/immunization/programmes_systems/supply_chain/EVM-JS_final.pdf, (accessed 19 July 2019).

[67] Nexleaf Analytics. (2017). IoT for development: Coldtrace. Available at: https://nexleaf.org/impact/coldtrace-real-time-data/, (accessed 19 July 2019).

[68] Nexleaf Analytics. (2019). *Vaccines*. Available at: https://nexleaf.org/vaccines/, (accessed 19 July 2019).

Virtual and augmented reality

Virtual reality refers to the simulation of an environment by generating realistic sensory inputs such as sound and imagery. Augmented reality describes an environment onto which digital information has been overlaid in real time.

Seeing a problem virtually can aid understanding and retention, as well as enable people across the globe to address it together, at the same time. A highly promising application for augmented reality and virtual reality is therefore education and training.[69] Virtual reality is already being used to teach students about human anatomy and to research infection prevention behaviours. Performing a computer simulation of an operation gives students access to a very realistic environment with unobstructed views, where they can receive instant feedback.[70,71,72]

Case study 12: Holograms

In 2017, surgeons from Mumbai and London appeared 'live' as avatars in a single operating room. Three-dimensional holograms of a patient's tumour allowed them to 'draw' on the image and discuss the best course of action. Professor Ahmed, a surgeon at Barts Health NHS Trust, said that 'by bringing together specialists in real time from across the world and different time zones, we have demonstrated that we can make surgery safer and ensure the best patient outcomes.'[73] This could eventually bring benefits to LLMICs lacking in highly trained doctors, as specialists could advise on complex procedures at a distance. In 2014, Professor Ahmed also used Google glasses to allow 13,000 people from 115 countries, including many surgical students, to witness him performing an operation.

Challenges

Virtual reality is currently at a more mature stage than augmented reality. Augmented reality tools have many technical challenges, including the problem of registration. This refers to a problem with misalignment between the virtual avatars and images created by the augmented reality tool, and the 'real world' on which they are superimposed. Aside from vision fatigue, this can also have

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[69] IT News Africa. (2016). Africa's first interactive digital learning centre launches in South Africa. Available at: https://www.itnewsafrica.com/2016/06/africas-first-interactive-digital-learning-centre-launches-in-south-africa/ (accessed 19 July 2019).

[70] Lung, N. (2019). NUS Medicine School uses virtual reality to enhance learning of human anatomy. Available at: https://www.opengovasia.com/nus-medicine-school-uses-virtual-reality-to-enhance-learning-of-human-anatomy/, (accessed 19 July 2019).

[71] Clack et al. (2017). 'Virtual reality enhanced behaviour-change training for healthcare-associated infection prevention', *Frontiers*. Available at: https://www.frontiersin.org/10.3389/conf.FPUBH.2017.03.00045/4089/3rd_UCL_Centre_for_Behaviour_Change_Digital_Health_Conference_2017_Harnessing_digital_technology_fo/all_events/event_abstract (accessed 19 July 2019).

[72] Ahmed, S. (2018). Think virtual reality surgery is a thing of the future? Think again… Available at: https://www.jisc.ac.uk/blog/think-virtual-reality-surgery-is-a-thing-of-the-future-think-again-28-feb-2018, (accessed 19 July 2019).

[73] Crouch, C. (2017). Virtual reality connects surgeons from across the globe. Available at: https://www.digitalhealth.net/2017/10/surgeons-from-across-the-globe-work-together-virtual-reality/, (accessed 19 July 2019).

serious implications for contexts that demand total accuracy, such as surgery. Augmented reality systems are also unable to satisfy all levels of eyesight, meaning that some people with poor vision are excluded from using them.

A further barrier that makes these technologies particularly prohibitive in LLMIC contexts is cost. Hardware cost remains a significant constraining factor to scaling up of both technologies. For example, Microsoft's HoloLens is priced at $3,000. Furthermore, augmented and virtual reality both require a lot of bandwidth; 5G connectivity is perceived as critical to ensuring their mainstream deployment. These technical and financial barriers mean that they are unlikely to benefit LLMICs in the short term.

Drones

An unmanned aerial vehicle (UAV), or drone, is an aircraft that can fly autonomously or be piloted remotely. The most obvious and common application for drones in countries with poor roads and disconnected communities is to provide a delivery service. Although cargo drones will not replace conventional transport methods, they do allow essential goods to be delivered to remote places where roads are unlikely to be constructed in the near future.

Drone technology is yet to be regulated by most countries around the world. This year, Kenya's civil aviation authority released regulations for the commercial use of drones that are over 2kg in weight, fly over 50 feet above the ground and are not fitted with a camera. The rules include obtaining and renewing a drone and pilot licence.[74] Since 2017, the Civil Aviation Administration of China has been giving the go-ahead for delivery companies to start sending packages to certain rural areas.[75]

Case study 13: Drones in Rwanda

Drones have been delivering blood transfusions in eastern Rwanda since October 2016. The packages are parachuted down, and the shortened delivery time – which can be down from 4 hours to 45 minutes – keeps the supplies fresh and regular. This 'Uber for blood' is the result of a partnership between Zipline, a Silicon Valley robotics company, and the country's health ministry.[76] Similarly, drones are transporting blood samples for HIV tests in remote areas of Malawi, and medical cargo drone flights have been tested in Peru.[77,78]

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74 Wamathal, J. (2018). You need a license to import & operate a drone in Kenya. Available at: https://hapakenya.com/2018/03/05/you-need-a-license-to-import-operate-a-drone-in-kenya/, (accessed 19 July 2019).

75 Bloomberg Hyperdrive. (2018). China Is on the Fast Track to Drone Deliveries. Available at: https://www.bloomberg.com/news/features/2018-07-03/china-s-on-the-fast-track-to-making-uav-drone-deliveries, (accessed 19 July 2019).

76 McVeigh, K. (2018). 'Uber for blood': how Rwandan delivery robots are saving lives', *The Guardian*. Available at: https://www.theguardian.com/global-development/2018/jan/02/rwanda-scheme-saving-blood-drone, (accessed 19 July 2019).

77 Mbah, F. (2017). UNICEF uses drones in Malawi to speed up HIV diagnosis. Available at: https://www.trtworld.com/mea/unicef-uses-drones-in-malawi-to-speed-up-hiv-diagnosis-389506, (accessed 19 July 2019).

78 Meier, P. (2017). Cargo drones deliver in the Amazon rainforest. Available at: https://robohub.org/cargo-drones-deliver-in-the-amazon-rainforest/, (accessed 19 July 2019).

Patient-facing applications

There are a variety of digital tools that patients directly interact with. Currently, most applications are limited by cost and availability, and tend to be found in higher-income settings. Examples include chatbots, closed-loop autonomous insulin pumps for diabetes sufferers, 'smart home' assistants and robot carers for the elderly.[79] Countries that are resistant to migration, such as Japan, will be more likely to turn to technology as a means to support ageing populations.

As life expectancy in LLMICs increases, and the disease burden shifts towards non-communicable diseases, there will be a growing emphasis on prevention and wellness. Digital applications that encourage health-seeking behaviours and nudge people away from social and environmental causes of non-communicable diseases are likely to have a bigger role in the future. Apps like Ada Health (see Case study 15) and Babylon, which has over 2 million users in Rwanda, are becoming more popular.[80]

While AI technologies are currently high-cost, they also have significant cost-saving potential. For instance, the Chicago-based CareSkore uses AI to analyse historic patient data and identifies risks of readmission, falls and sepsis, for individual patients. By suggesting different methods of reminding patients about upcoming appointments (for example, calling versus texting), readmission rates at the Methodist Hospital of Chicago dropped from 12% to 4%.[81]

Case study 14: Eye checks in Kenya

There are some prominent patient-facing apps already being rolled out in lower-income countries. In response to growing visual impairment among children in these countries, Peek Solutions build apps and hardware to enable eye checks to be conducted in homes, communities and schools.[82] Smartphones can generate an image, either to be processed mechanically, or to send to an ophthalmologist remotely, who can they diagnose eye conditions at a distance. An independent study tested the effects of their screening tool in primary schools in Trans-Nzoia County, Kenya. The project included a smartphone-based sight test and referral system, as well as SMS reminders to parents. Teachers performed vision screening, and there was a significant uptake of referral to hospital for a full assessment. However, the authors did note that a high number of false positives 'risks overburdening already overstretched eye-care services'.[83]

[79] Fenech et al. (2018). *Ethical, Social and Political Challenges of Artificial Intelligence in Health.* Available at: https://futureadvocacy.com/wp-content/uploads/2018/04/1804_26_FA_ETHICS_08-DIGITAL.pdf, (accessed 19 July 2019).

[80] Strick, K. (2018). 'The Rwandan project: how Babylon helped rebuild healthcare in a war-shattered country', *The Evening Standard.* Available at: https://www.standard.co.uk/futurelondon/health/the-rwandan-project-how-babylon-helped-rebuild-healthcare-in-a-warshattered-country-a3885946.html, (accessed 19 July 2019).

[81] Lee, K. (2017). Population health management platform uses AI, machine learning. Available at: https://searchhealthit.techtarget.com/feature/Population-health-management-platform-uses-AI-machine-learning, (accessed 19 July 2019).

[82] Peel. (2019). What is Peek? Available at: https://www.peekvision.org/en_GB/about-peek/what-is-peek-vision/, (accessed 19 July 2019).

[83] Ramke, J. and Kyari, F. (2018). 'Strengthening eye health evidence for children in low-income and middle-income countries', *The Lancet*. Available at: https://www.thelancet.com/action/showPdf?pii=S2214-109X%2818%2930269-9 (accessed 19 July 2019).

Case study 15: Ada Health

Ada Health offers an AI-powered health platform to support clinical decision-making and provide information to individuals through a personalised assessment tool. The app has 7 million users globally, has been ranked the number 1 medical app in more than 130 countries and has carried out in excess of 10 million health assessments to date. Health data, which is anonymised, aggregated and separated from users' personal data, could in the future be used to provide real-time public health insights.

Hila Azadzoy, Managing Director of Ada's Global Health Initiative, explains that Ada's ambition is to bring the future of personalised health to everyone by helping people to understand their health and navigate to the appropriate care, while also supporting clinicians and healthcare providers to deliver care more effectively. While the app can benefit anyone with a smartphone, Azadzoy sees particular potential for adolescents – who are 'creating habits and behaviour that will carry on throughout their lifetimes and within their families' – as well as those on the frontline, such as drug dispensers and community health workers who lack critical support.[84]

Ada is building up a knowledge base that works horizontally across all disease verticals, including rare diseases. A recent peer-reviewed study co-authored by researchers from the Hannover Medical School and Ada demonstrated that AI has the potential to support doctors' identification of rare diseases faster and after fewer consultations.[85] Ada's recently launched Global Health Initiative aims to improve access to healthcare for underserved populations around the world using AI. Azadzoy emphasised that finding the right strategic partners for this initiative is a key focus, since it is vital to address cultural specificities in each location. For instance, 'the description of pain is different in every language'. Ada also aims to integrate with local services to help connect users with the right care: 'by linking with the health ecosystem, our value can be significantly extended'. Azadzoy acknowledged that a bigger milestone would achieve this integration in very low-income areas, where local services are severely limited.[86]

Challenges

Chatbots and AI-powered apps can already answer basic medical questions, and the potential for more sophisticated AI to support decision-making is huge. A white paper produced by the ITU-WHO Focus Group on AI for Health states that 'medical decision support systems have shown promising results'.[87]

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[84] Interview with Hila Azadzoy, 24 May 2019.

[85] One in 17 people will be affected by a rare disease in their lifetime, and patients wait an average of four years and 10 months from the onset of symptoms for an accurate diagnosis. The report, published in the *Orphanet Journal of Rare Diseases*, concluded that more than half of the 113 rare disease patients in the test could have been diagnosed earlier using Ada's technology, and one-third of patients could have been correctly diagnosed in the first clinical visit, saving years of unnecessary tests and waiting. More information available at: Ronicke et al, 'Can a decision support system accelerate rare disease diagnosis? Evaluating the potential impact of Ada DX in a retrospective study', *Orphanet Journal of Rare Diseases*. 2019, 14(69). Available at: https://ojrd.biomedcentral.com/articles/10.1186/s13023-019-1040-6, (accessed 20 August 2019).

[86] Interview with Hila Azadzoy, 24 May 2019.

[87] Salathé et al. (2019). *White paper of the Focus Group on Artificial Intelligence for Health (FG-AI4H)*. Available at: https://www.itu.int/en/ITU-T/focusgroups/ai4h/Documents/FG-AI4H_Whitepaper.pdf, (accessed 19 July 2019).

However, significant challenges remain. As Edmond Ng told us, increasing diagnosis rates in contexts where there is no treatment available may be counterproductive: 'you don't want to generate false hope'.[88] Nina Schwalbe concurred, saying, 'we don't have the data to evaluate whether [AI health intervention tools] are bettering the standard of care' in a cost-effective way. A range of issues would need to be better understood to prove efficacy and effectiveness, she added, including the 'potentially disturbing consequences' of either a false negative or false positive diagnosis. The former might result in death due to lack of treatment, and the latter might overwhelm the health system by rushing people unnecessarily to hospital. For now, according to Schwalbe, AI health tools 'are designed as a cool tool and do not start from the user needs we are trying to solve or the healthcare implementation challenges'.[89]

Population-level applications

Predicting outbreaks

AI-based tools could be useful for various population-level applications, given their ability to derive insights from large volumes of data, discover patterns, and uncover predictive trends. One application is the identification of groups likely to require interventions to prevent the onset of disease, which can be particularly effective for managing chronic illness.[90,91] For instance, a machine-learning model has been developed that predicts and suggests non-standard risk factors for childhood obesity.[92]

Natural language processing, 'a branch of AI that helps computers understand, interpret and manipulate human language' has been used to analyse electronic health records and online social media sources to monitor disease spread.[93,94] In combination with AI's powerful analytical ability at scale, tools are being developed to use non-traditional data sources such as mobile phone activity to forecast the progression of epidemics, and thus divert the necessary resources to where they are most needed at the correct time. Mobile phone data has already been used to

88 Interview with Edmond Ng, 17 May 2019.

89 Interview with Nina Schwalbe, 29 June 2019.

90 Hibbard et al. (2017). 'Improving population health management strategies: Identifying patients who are more likely to be users of avoidable costly care and those more likely to develop a new chronic disease', *Health Services Research*. Available at: https://www.ncbi.nlm.nih.gov/pubmed/27546032, (accessed 19 July 2019).

91 Kini, P. (2017). Why population health is an AI problem. Available at: https://www.beckershospitalreview.com/population-health/why-population-health-is-an-ai-problem.html, (accessed 19 July 2019).

92 Dugan et al. (2015). 'Machine learning techniques for prediction of early childhood obesity', *Applied Clinical Informatics*. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4586339/pdf/ACI-06-0506.pdf (accessed 19 July 2019).

93 SAS. (2019). Natural language processing: What it is and why it matters. Available at: https://www.sas.com/en_gb/insights/analytics/what-is-natural-language-processing-nlp.html, (accessed 19 July 2019)

94 Wahl et al. (2018). 'Artificial intelligence (AI) and global health: how can AI contribute to health in resource-poor settings?' *BMJ Global Health*. Available at: https://gh.bmj.com/content/bmjgh/3/4/e000798.full.pdf, (accessed 19 July 2019).

model the spread of cholera in Haiti in 2010, and of dengue fever in Pakistan in 2013.[95'96] Global Health Monitor is a further example: it locates and analyses English-language news stories to help experts monitor infectious disease outbreaks.[97]

Case study 16: Malaysia dengue outbreak prediction

In 2016, Malaysia became the first country in the world to use an app to predict dengue outbreak – the Dengue Outbreak Prediction Platform. AI is used to analyse parameters including geography, weather and symptoms of dengue cases to predict hotspots, where preventative actions such as the elimination of mosquito larvae are then performed.[98] The platform is able to predict outbreaks three months ahead with an accuracy of 86%.[99]

Case study 17: Crowdbreaks

Marcel Salathé, who we interviewed for this report, leads the Digital Epidemiology Lab at EPFL, Switzerland. Among his team's projects is Crowdbreaks, an open platform that facilitates health trend tracking. The system uses natural language processing and machine-learning techniques to filter relevant information through real-time, crowdsourced labelling of social media content.[100] Salathé emphasised that public health institutions need to be equipped with flexible tools and real-time information to monitor and respond to public opinion in the context of online misinformation campaigns. His lab's mission is to provide the tools to, in his words, 'get better data more quickly'.[101]

So far, Crowdbreaks has been used to indicate public opinion towards vaccination, on the basis that a decline in vaccine confidence could be linked to disease outbreaks, for instance of polio or measles.[102] The researchers hope for 'the eventual incorporation of similar models into the public health decision-making process', but acknowledge that this would require 'proper validation and benchmarking of machine-learning models'.[103]

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[95] Bengtsson et al. (2015). 'Using mobile phone data to predict the spatial spread of cholera', *Scientific Reports*. Available at: https://www.nature.com/articles/srep08923.pdf, (accessed 19 July 2019).

[96] Wesolowski at al. (2015). 'Impact of human mobility on the emergence of dengue epidemics in Pakistan', *PNAS*. Available at: https://www.pnas.org/content/pnas/112/38/11887.full.pdf, (accessed 19 July 2019).

[97] Doan et al. (2008). *Global Health Monitor - A Web-based System for Detecting and Mapping Infectious Diseases*. Available at: https://pdfs.semanticscholar.org/8819/496a9505b7a2ed41e6eaba257d0a4b456d90.pdf, (accessed 19 July 2019).

[98] Yee San, M. (2016). Malaysia is first in the world to use a mobile app to predict dengue outbreak. Available at: http://annx.asianews.network/content/malaysia-first-world-use-mobile-app-predict-dengue-outbreak-33938, (accessed 19 July 2019).

[99] Saifi et al (2018). AI and big data joins effort to predict deadly disease outbreaks. Available at: https://edition.cnn.com/2018/03/06/health/rainier-mallol-tomorrows-hero/index.html, (accessed 19 July 2019).

[100] Crowdbreaks. (2019). About Crowdbreaks. Available at: https://www.crowdbreaks.org/en/about, (accessed 19 July 2019).

[101] Interview with Marcel Salathé, 4 June 2019.

[102] Yahya, M. (2007). 'Polio vaccines—"no thank you!" barriers to polio eradication in Northern Nigeria', *African Affairs*. Available at: https://academic.oup.com/afraf/article/106/423/185/50647, (accessed 19 July 2019).

[103] Müller, M. and Salathé, M. (2019). 'Crowdbreaks: Tracking health trends using public social media data and crowdsourcing', *Digital Public Health*. Available at: https://www.frontiersin.org/articles/10.3389/fpubh.2019.00081/full, (accessed 19 July 2019).

3. Overarching challenges and risks

The previous chapter showed the breadth and variety of digital health initiatives. However, there are some serious barriers to effective implementation. Table 1 below gives an overview of the overarching barriers and risks that affect all (or most) of the examples so far, which are also discussed in more detail below.

Table 1: Barriers to implementation of digital health initiatives, associated risks, and mitigation strategies

Barriers to effective implementation	Associated risks	Mitigation strategies
Infrastructure		
Lack of quality data	• For efficiency measures, poor data can lead to ineffective public health decisions, leading some to lose out. • For AI-powered tools, poor data can lead to algorithmic bias, leading to poor health outcomes for those not reflected in training data.	· Improve means of data collection and intuitive user-interfaces to allow for easy input from health workers; connectivity; integrate patient data into electronic medical records
Lack of access to electricity and connectivity	· Exacerbation of health inequality according to electricity and connectivity access (likely to be rural–urban)	· Connect people (particularly those in rural areas)
Lack of access to mobile devices	· Exacerbation of health inequality according to device access (likely to be gender-based)[104]	· Increase access to cheap devices (particularly for women and other underserved groups)

[104] GSMA. (2015). *Bridging the Gender Gap: Mobile access and usage in low and middle-income countries*. Available at: https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2016/02/Connected-Women-Gender-Gap.pdf, (accessed 19 July 2019)

Technical and design challenges		
Lack of user-friendly apps and platforms	· Poor retention of intervention due to patient/ health worker frustration, poor-quality data, and health worker inefficiency	· Involve patients and health workers in all stages of the design process for user interfaces; adhere to the Principles for Digital Development[105]
Language and cultural barriers	· Patient and health worker use limited by language; potentially harmful social effects of not understanding cultural norms around health and care	· Work with local partners on the ground to develop linguistic and cultural sensitivity · Understand existing health infrastructure and how intervention will affect relationships and ability of health workers to deliver care
Skills, behaviour and organisations		
Organisational challenges of public health institutions and facilities	· Institutions struggle to react quickly enough to with 21st century challenges, including unhealthy lifestyles, misinformation and distrust, drug refusal, etc.	· Adjust organisational structures of public health institutions; develop 'living' principles that can be easily adjusted to deal with new challenges
Skills shortage (both medical and digital) due to emigration and lack of education and training	· Lack of training and support speeds up emigration of skilled workforce; proliferation of devices without proper training leads to resource waste and poor retention	· Effective and sustained programmes, health worker supervision and support
Lack of digital literacy among citizen population	· Poor health outcomes resulting from vulnerability to misinformation; strain on health services; distrust of digital platforms	· Education schemes to help citizens identify misinformation; keeping the 'human touch' by designing tools to enhance, not replace, health workers

[105] Principles for Digital Development. (2019). Available at: https://digitalprinciples.org/about/, (accessed 19 July 2019).

Governance and regulation		
Lack of standards and interoperability	· Siloed data prevents compatibility between platforms, and analysis and comparison across data sets. It also disrupts the continuity of care across different services.	· Develop digital health architectures and interoperable data standards to manage health information exchanges
Lack of regulation around data ownership, privacy, security and accountability	· Violations of privacy, data breaches and cyberattacks	· Develop clear national and international guidelines around data security, informed consent and data ownership and implement at the national level
Lack of standards to ensure trustworthiness and robustness of algorithms	· AI-driven misdiagnosis or other poor decision-making with no accountability mechanism; declining trust in AI	· Engage with open benchmarking processes (see ITU-WHO Focus Group on AI for Health)
Lack of digital health governing bodies and insufficient public resourcing, particularly for scalable, interoperable solutions	· Slow advancement of technology, fragmented approach to digital governance	· National governments identify central body responsible for digital health policy; invest in leadership and training
Investment and incentives		
Lack of comprehensive national strategies and donor alignment	· Proliferation of interventions without cohesive strategy leads to inefficiency, duplication and strain on health workforce	· Better mechanisms for donor coordination and cohesive national strategies to mobilise resources effectively, using a problem-based approach
Funding concentrated along health verticals	· Lack of systems analysis results in distortion of funding away from certain high disease burden conditions	· Problem-based approach, addressing horizontal as well as verticals, led by national strategies, not just donor priorities; interdisciplinary research

Data quality

AI relies on high volumes of quality data, but often the sectors in most need of advancement lack the required quantity and quality of data. Healthcare is a prime example of a sector where most data is stored in formats that are not machine-readable. Latin American countries provide an exception in terms of data management in healthcare: for instance, 73% of hospitals across Chile have implemented national electronic medical record systems.[106] Also of concern is the interoperability of data to enable drawing conclusions across a range of contexts and socio-economic indicators. As Edmond Ng pointed out, 'we have always had data; we just didn't have the technology to record it'.[107] A confluence of improvements in these tools – cheap storage, computing power and analytics – will make a real difference to the quality of health data, and therefore the conclusions that can be drawn from it. Skye Gilbert emphasised that, in contexts that lack the foundational capacity and infrastructure, a priority is to 'solve the fundamentals', like data cleaning and collection.[108]

As previously discussed, incomplete training data for AI that does not accurately reflect an entire population, across gender, race and other demographic identifiers, can result in skewed outcomes for any health application. An example is preclinical research where any treatment generated may be effective only for certain subsets of the population; this risks widening health inequalities. In the UK for instance, GP data excludes homeless people and travelling communities, as you must have a fixed address to register with a GP practice. As Nina Schwalbe stated, 'tools are only as good as their test data sets'. Sharing data is essential, she added: 'countries with small populations will never compete – their data sets are too small – so they need to share data sets and benefit from data sharing.'[109]

Access to internet and electricity

Patient and clinician-facing digital tools are usually dependent on access to internet and electricity, both of which vary by geography, gender, socio-economic status, and other determinants. One of the reasons for these variations is cost, which remains high in many LLMICs. Often, people have devices but not the money to pay for data contracts. In Zimbabwe, for example, mobile internet is provided predominantly through $1 daily data bundles for around 250MB. According to the Alliance for Affordable Internet, 1GB of mobile data 'costs nearly 45% of a citizen's average income'.[110] Efforts to expand access are crucial to avoiding a scenario where only wealthy citizens who own smartphones can benefit. According to an Oxford Martin School and Citi report, the divergence in penetration rates of technology adoption can account for 82% of the increase in

106 Global Health Intelligence. (2017).The Healthcare Data Revolution in Latin America. Available at: https://globalhealthintelligence.com/ghi-analysis/the-healthcare-data-revolution-in-latin-america/, (accessed 19 July 2019).

107 Interview with Edmond Ng, 17 May 2019.

108 Interview with Skye Gilbert, 13 June 2019.

109 Interview with Nina Schwalbe, 29 June 2019.

110 Karombo, T. (2018). Zimbabwe is trying to transform itself into a leading tech hub with China's help. Available at: https://qz.com/africa/1306520/zimbabwe-needs-china-for-its-tech-and-ict-ambitions/, (accessed 19 July 2019).

the global income gap since 1820.[111] Despite growth in internet access, the bandwidth of internet connection may not be sufficient for AI applications in LLMICs, although some mHealth tools work offline and sync when there is sufficient bandwidth.[112]

Delmiro Fernandez-Reyes (Reader in Digital Health and Intelligent Systems, University College London) argued that one of the biggest obstacles relates to infrastructure, logistics and education. In his work in Sub-Saharan Africa, 'a lack of reliable electrical power is one of the biggest problems we faced', particularly in conflict zones.[113] The World Bank's *2017 State of Electricity Access Report* estimated that, due to population growth, half a billion people still won't have access to electricity by 2040.[114] New models of electrical generation will be required to power the sheer volume of devices, and countries are introducing low-cost alternatives and off-grid solutions. Thanks to cheapening costs of renewable energy sources, solar panels and hydropower may allow countries to 'leapfrog' over coal as a major energy source.

The starkest inequality in terms of internet and electricity access is between rural and urban areas. Only 26% of the rural populations of low-income countries had access to electricity in 2017, compared with 70% of the urban population. This jumps to 79% for rural populations in lower-middle-income countries, compared with 97% in urban areas, still a stark divide.[115] A failure to address this in the digital health space is likely to result in ever-higher inequities in health outcomes between those residing in cities and remote areas. On the positive side, once this basic infrastructure reaches rural areas, digital health has the potential to lessen health inequalities, by providing higher-quality care to underserved groups and allowing community health workers to reach more patients. Antoine Geissbuhler (Professor and Director of Digital Transition, eHealth and Innovation, Geneva University) emphasised that connectivity in remote areas would be a 'game changer' for digital health, particularly in parts of Western and Sub-Saharan Africa, in which small towns but not villages are connected.[116]

On the other hand, Merrick Schaefer, Digital Health Lead at USAID's Global Development Lab, argued that internet or mobile connectivity is not essential *at the facility itself*. This can be worked around – for instance, by designing mobile tools for health workers to use when they are in the marketplace and have alternative connectivity.[117] Fazilah Allaudin also noted that lower-income countries sometimes have an advantage of being able to leapfrog to new technologies. In Malaysia, 'we have legacy systems which makes change difficult'.[118]

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[111] Oxford Martin School. (2016). *Technology at work v2.0*. Available at: https://www.oxfordmartin.ox.ac.uk/downloads/reports/Citi_GPS_Technology_Work_2.pdf, (accessed 19 July 2019).

[112] Wahl, B., Cossy-Gantner, A., Germann, S., and Schwalbe, N. 'Artificial intelligence and global health: How can AI contribute to health in resource-poor settings?' *BMJ Global Health 2018*; 3. doi:10.1136/ bmjgh-2018-000798. Available at: https://gh.bmj.com/content/bmjgh/3/4/e000798.full.pdf, (accessed 20 August 2019).

[113] Interview with Delmiro Fernandez-Reyes, 3 June 2019.

[114] World Bank (2017) *State of Electricity Access Report 2017*. Available at: http://documents.worldbank.org/curated/en/364571494517675149/pdf/114841-REVISED-JUNE12-FINAL-SEAR-web-REV-optimized.pdf, (accessed 20 August 2019).

[115] World Bank, Access to electricity, rural (% of rural population). Available at: https://data.worldbank.org/indicator/EG.ELC.ACCS.RU.ZS, (accessed 20 August 2019).

[116] Interview with Antoine Geissbuhler, 29 May 2019.

[117] Interview with Merrick Shaefer, 30 May 2019.

[118] Interview with Fazilah Allaudin, 4 July 2019.

Access to mobile devices

The number of mobile phone users in low- and middle-income countries rose from 2.8 billion in 2012 to 3.6 billion in 2016, according to the 2017 GSMA survey.[119] Runbin Dong (Digital Transformation, Prudential Corporation Asia) argued that the most important trend for LLMICs, particularly in Asia, is going to be the infrastructure that will support the adoption of reliable, mass-used technology', adding that, 'in Asia, people need things that work reliably'. Fazilah Allaudin agreed that one of the big risks of digital tools is service interruption. 'It is very daunting when a system goes down and you lose the trust of the user.'[120]

> 'In Asia, people need things that work reliably.'
> *Runbin Dong, Digital Transformation, Prudential Corporation Asia*

Jonathan Jackson noted that, 'as smartphones penetrate to clients there is a huge opportunity to revolutionize how digital coaches and systems will change the ways that individuals in LLMICs access care'. In areas with few frontline workers, putting tools in the hands of patients can be a powerful step.

Technical and design challenges

Platform and app design

In response to what was perceived as a fragmented, siloed and short-term approach to digital development in general, a set of development agencies and international organisations created the Principles for Digital Development. These are nine 'living guidelines' that outline best practices in technology-enabled programmes. One of these is 'user-centred' or 'human-centred' design, which emphasises the need to build tools *with* the people who will use them, to ensure that they address actual needs. The principle states that, 'by designing with the users, and not for them, you can build digital tools to better address the specific context, culture, behaviours and expectations of the people who will directly interact with the technology. Designing together means partnering with users throughout the project lifecycle, co-creating solutions, and continuously gathering and incorporating users' feedback'.[121]

Following this principle is essential, as the user interface makes a huge difference to the retention of interventions involving patient or clinician-facing tools. To alleviate the time-consuming task of data collection, user interfaces should be easily readable and allow for intuitive navigation by health workers. Sufficient initial and ongoing training should be provided. In developing digital workflows, the extra burden of digital data entry should be weighed against the benefits and time savings of automated data aggregation and report generation.

[119] GSMA. (2015). *Bridging the Gender Gap: Mobile access and usage in low and middle-income countries*. Available at: https://www.gsma.com/mobilefordevelopment/wp-content/uploads/2016/02/Connected-Women-Gender-Gap.pdf, (accessed 19 July 2019)

[120] Interview with Fazilah Allaudin, 4 July 2019.

[121] Principles for Digital Development. (2019). Design with the user. Available at: https://digitalprinciples.org/principle/design-with-the-user/, (accessed 19 July 2019).

Merrick Schaefer told us that, although the evidence shows that, 'adoption rates go way up where you address problems that workers face on a day-to-day basis', most implementers still don't take a user-centred approach. The funders' requirements are often at odds with the requirements of health workers on the ground, he explains, because, 'the upstream [public health] data needs are not the downstream [local] data needs. Things that help the centre, can hurt the edge, and things that help the edge aren't seen by the centre as useful necessarily'. In other words, an overemphasis on data reporting, to help with resource management and efficiency at a system level, often overburdens the health worker. Tools that create data as a *byproduct* of other processes, but do not create strain at the facility level, will be immensely useful and unlock the power of machine learning through high-quality data, Schaefer argues.[122]

Language and cultural barriers

The language landscape in many low-resource regions of the world is very diverse. Tools for natural language processing as well as language translation tools will be of key importance to support the work of clinicians and allow wider use of digital interventions across large sectors of the population. Interviewee Delmiro Fernandez-Reyes stressed that, 'digital health applications interact with the user through spoken and written language as well as visual human–computer interaction relevant to the clinical pathway. It is critical to improve automatic translation tools to increase adoption of these applications in language diverse regions".[123]

In LLMICs, data is often recorded in a multiplicity of different languages, if it is recorded electronically at all. WHO has also advocated for the adoption of standardised medical terminologies that would allow for easier comparison of health indicators across time and space.[124] At the same time, platform designers should be sensitive to cultural ideas about health and wellbeing in the areas they are working in. Interdisciplinary teams and genuine user engagement in the process can help with this. The issue of trust in new technologies may be less important to younger generations, who tend to be more amenable and less suspicious of new tools. Apps may also have an advantage over face-to-face care for culturally sensitive issues such as sexual health and gynaecology.

Through a partnership with Fondation Botnar, Ada Health (see Chapter 2's section on patient-facing applications) has been addressing some of these challenges by offering its app in Swahili and Romanian. Beyond simply translating the app into these languages, the team is also adapting Ada's AI to take into account disease prevalence and other nuances of healthcare in each region. In Tanzania, this work is being done with Dar Es Salaam's Muhimbili University Hospital to tailor Ada to the specific challenges facing Tanzania.

[122] Interview with Merrick Shaefer, 30 May 2019.

[123] Interview with Delmiro Fernandez-Reyes, 3 June 2019.

[124] Wahl et al. (2018). 'Artificial intelligence (AI) and global health: how can AI contribute to health in resource-poor settings?', *BMJ Global Health*. Available at: https://gh.bmj.com/content/bmjgh/3/4/e000798.full.pdf, (accessed 19 July 2019).

Skills, behaviour and organisational challenges

Organisational challenges

Antoine Geissbuhler noted that, for telemedicine, some of the key issues are not technical or logistical but behavioural. Remote supervision of previously unsupervised health workers, for instance, can be met with resistance. Shifting tasks and workflows, particularly adding new skills (such as data inputting) to overstretched teams, can be highly challenging. In some cases, Geissbuhler added, a service gets off to a good start, but high quality and consistency is not maintained due to a failure to make systemic changes in organisations. Making sure the service is 'delivered by the right people, with the right incentives, and with the right response time, is crucial and difficult to achieve'.[125]

> 'There is almost a paralysis… people don't know what to do with such fast-moving technology.'
> *Marcel Salathé, Associate Professor at École Polytechnique Fédérale de Lausanne*

Fazilah Allaudin added that, in the future, the 'doctor-patient relationship will change. Patients are already ahead of doctors. It will be more of a partnership than the doctor being the sole decision-maker'.[126] Health workers need to be equipped with the necessary skills and support structures as their everyday roles and responsibilities shift. Marcel Salathé remarked that, as well as health workers on the ground, public health institutions will have to dramatically shift their organisational cultures if they are to adapt to the new realities of tech-driven healthcare. As he stated, 'there is almost a paralysis… people don't know what to do with such fast-moving technology'.[127]

Skills shortages

There is a critical shortage of health workers in LLMICs. Edmond Ng highlighted that the emigration of skilled health practitioners means that low-income countries essentially subsidise the workforce in richer countries: 'when higher-income countries are not investing in their own people, when they poach clinical staff from poorer countries, higher-income countries do not pay for their own training'. In this context, incentivising doctors to stay by improving working conditions and increasing the perceived value of remote locations, is crucial. To quote Antoine Geissbuhler, an essential task is to 'equip care workers with tools that enable them to do things that would otherwise require someone to be transferred to a higher level of care'. This could include improving primary and secondary facilities, giving more recognition for the work of community health workers, and increasing contact with those working in 'medical deserts'.[128]

125 Interview with Antoine Geissbuhler, 29 May 2019.

126 Interview with Fazilah Allaudin, 4 July 2019.

127 Interview with Marcel Salathé, 4 June 2019.

128 Interview with Antoine Geissbuhler, 29 May 2019.

The Future Health Index found that 47% of healthcare professionals claimed to be knowledgeable about connected care technology (telehealth, ehealth, etc).[129] However, less experienced and younger individuals seem to be more comfortable with digital tools: 54% of those with 0–10 years' experience claimed to be knowledgeable, compared to 42% of those with 20 or more years of experience.[130] This suggests that the future workforce will be more digitally literate. However, ongoing training is needed if the expertise is to keep up with the rate of change of health technologies.

There is not only a skills gap among health practitioners, but also with those who research, strategise, manage and evaluate digital health programmes. A 2018 seminar series convened by HealthEnabled and the Digital Frontiers Institute[131] identified the following key skills gaps in the digital health workforce globally:

- digital health leaders, managers, and policymakers
- digital health programme designers and implementers
- architects, programmers, engineers and data scientists
- digital health skills for health professionals: doctors, nurses, community health workers and administrators.

The Community Health Academy, a project run by Last Mile Earth, is trying to address this challenge. It aims to upskill at least 16,000 community health workers and train at least 15,000 current and next-generation health systems leaders over the next four years, using digital training tools developed in partnership with Ministries of Health. These tools allow for standardised content to be easily updated and adjusted for new contexts.[132]

Digital literacy and misinformation

In the era of 'fake news' and 'deepfakes' (AI-generated fake videos), the problem of online misinformation is of growing concern. The anti-vaccination movement, supported by high-level populists and celebrities, has had deeply worrying effects, and has been linked to the measles outbreak in New York City in early 2019.[133] As Skye Gilbert told us, social media was also an amplifier of misinformation during the Ebola outbreak, leading to the use of wrong treatments, anger, mistrust and even violence towards health workers. Use cases from the health field should inform wider debates about the extent to which information should be curated on online networks. In areas

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[129] Connected care or technology-enabled care (TEC) is the collective term for telecare, telehealth, telemedicine, mHealth, digital health and eHealth services. See: https://www2.deloitte.com/content/dam/Deloitte/uk/Documents/life-sciences-health-care/deloitte-uk-connected-health.pdf

[130] Philips. (2019). Future Health Index 2019. Available at: https://www.philips.com/a-w/about/news/future-health-index, (accessed 19 July 2019).

[131] Digital Health Index. (2019). State of Digital Health 2019. Available at: https://www.digitalhealthindex.org/stateofdigitalhealth19, (accessed 19 July 2019).

[132] Last Mile Health. (2019). Last Mile Health: Our model. Available at: https://lastmilehealth.org/our-model/, (accessed 19 July 2019).

[133] Kilgannon, C. (2019). 'What We Know About the Measles Outbreak in N.Y.', *The New York Times*. Available at: https://www.nytimes.com/2019/05/02/nyregion/newyorktoday/nyc-news-measles-outbreak.html, (accessed 19 July 2019).

with limited health infrastructure or trusted sources, the costs of misinformation are especially high. While it is theoretically possible to counteract misinformation by putting out competing viral content, Gilbert also stressed that platforms with end-to-end encryption and decentralised content generation, such as WhatsApp (which has high penetration in LLMICs) are even harder to monitor.[134]

Marcel Salathé concurred that the emergence of negative views about drugs and healthcare professionals is 'not a first world problem'. Rather, 'we are going full speed into a world in which public opinion is not shaped by decision-makers but by the public itself'.[135] Public health institutions established in the 20th century are not designed for a world in which people increasingly refuse drugs and are suspicious of doctors and 'experts' in general. Akaliza Keza Ntwari added that one of the most prominent threats is the 'spread of misinformation', and that digital literacy programmes could help prevent this.[136]

Governance and regulation

Standards and interoperability

Policymakers in LLMICs will need to create clear legal guidelines on data ownership, transfer and usage. Regional organisations will also play a key role in enabling international data sharing. Countries in trade blocs, such as ASEAN, are already well connected in terms of trade and migration; the challenge will be to ensure the same for cross-border data flows.

Akaliza Keza Ntwari told us that the most transformative innovation in this area has been 'open source technology which can be adapted to different contexts and localised'.[137] As Lesley-Anne Long (consultant and former Director of Digital Square) told us, 'devices which collect data but do not integrate with the district, regional or national databases are not going to be very useful beyond the programme in which the data is collected – the focus should be on interoperable systems'.[138]

> 'Devices which collect data but do not integrate with the district, regional or national databases are not going to be very useful beyond the programme in which the data is collected.'
> *Lesley-Anne Long, consultant, former Director of Digital Square and former Global Director of mPowering Frontline Health Workers*

One initiative working in this area is Digital Square, a partnership between PATH, USAID, the Gates Foundation and others, which aims to bring on new partners to align global investments for digital health systems. Digital Square promises to become a centre of gravity for digital

134 Interview with Skye Gilbert, 13 June 2019.

135 Interview with Marcel Salathé, 4 June 2019.

136 Interview with Akaliza Keza Ntwari, responses provided via email, June 2019.

137 Ibid.

138 Interview with Lesley-Anne Long, 29 May 2019.

health development, bringing private sector technology companies, national and international governments and NGOs together in scaling successful digital health innovations around the world. Early-stage innovations may apply for funding to solve issues to do with scaling up, including interoperability, user-interface design and language localisation.

The *Global Goods Guidebook* produced by Digital Square[139] documents 'global goods', which can be one of three things:

- Software: A software tool that is free, open source, and used to manage, analyse, or transmit health-related data, with proven utility in several settings.
- Services: A software as a service (SaaS) tool that is used to manage, transmit, or analyse health-related data. These tools can be freely accessed and adheres to open data principles.
- Content: A resource, toolkit or data standard that is available under an open licence and that is used to improve or analyse health data management processes.

To be listed in the guidebook, the tool has to have been approved for investment through Digital Square. The aim is to better coordinate the development of new technologies, reduce duplication, and 'ensure that platforms are not only more aligned with national priorities, but that they strengthen health systems'.[140]

Data ownership, privacy and security

The 2018 WHO resolution on digital health urges members states 'to develop, as appropriate, legislation and/or data protection policies around issues such as data access, sharing, consent, security, privacy, interoperability and inclusivity consistent with international human rights obligations'.[141] Individuals are both consumers and producers of data, and developing frameworks that address legitimate concerns about privacy, security, data ownership and consent should be an urgent priority.

This involves, to quote Raymond Sarmiento, finding the 'sweet spot in terms of the trade-off between protecting privacy and security, and providing a proportional amount of information so that the healthcare provider or system can provide the patient with the best care available, improve care delivery, and ensure patient safety'.[142] Runbin Dong made the point that 'we have to be very cognisant of what the technology does, and whether it has the capacity to go beyond the boundaries of what we set it up to do'.[143] USAID's new guide to responsible data use in development

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139 PATH. (2019). *Global Goods Guidebook: Version 1.0.* Available at: https://static1.squarespace.com/static/59bc3457ccc5c5890fe7cacd/t/5ced6f3c7817f7e261ddbc0a/1559064401781/Global-Goods-Guidebook_V1.pdf, (accessed 19 July 2019).

140 Ibid.

141 WHO. (2018). *Resolution A71/20 on Digital Health.* Available at: https://apps.who.int/gb/ebwha/pdf_files/WHA71/A71_ACONF1-en.pdf, (accessed 19 July 2019).

142 Interview with Raymond Sarmiento, 24 June 2019.

143 Interview with Runbin Dong, 14 June 2019.

is a useful starting point for understanding the risks associated with health data. It emphasises that 'this is not just an issue for IT security staff, privacy experts, or even data managers': anyone involved in a development programme should be aware of the risks related to data collection and management.[144]

'Data sovereignty, privacy, and security are hugely under-regulated in many of the ecosystems we work in.'
Jonathan Jackson, Co-founder and CEO of Dimagi

Providing an open and secure data environment involves building frameworks that enable the sharing of (sensitive) information with other organisations and sectors. Despite the large number of internet users, countries including Kenya and Nigeria still lack data protection and privacy laws.[145] As Skye Gilbert emphasised, there is no consensus on the best way to regulate for privacy and data ownership: for example, the US, EU and China all have different models, and are all 'influencing dynamics in Sub-Saharan Africa, and to some extent in Asia'. Merrick Schaefer added that there is often a disconnect between OECD models of privacy and safety, normally understood within an insurance-based harm framework, and low-income countries. Policymakers in LLMICs must be given the opportunity to make their own decisions on these crucial and contentious issues.

Jonathan Jackson, Co-founder and CEO of Dimagi, remarked that 'data sovereignty, privacy and security are under-regulated in many of the ecosystems we work in'. He added that there is often a trade-off between achieving data sovereignty goals (which often means that the government can host and run the software in-country) and security and reliability goals (which often favour hosting the platform outside of the country, increasing the potential for vendor or donor lock-in). Jackson explained that CommCare is Open Source and can be set up anywhere (CommCare has many users, both in its cloud environments and also hosted locally), but that big clouds like Microsoft Azure or Amazon Web Services come with economies of scale that lower costs, and also offer security, compliance and reliability features which would likely be prohibitively expensive to reproduce locally.[146] Carlos Otero (Head of Clinical Informatics at the Hospital Italiano de Buenos Aires) identified software regulation as a major issue in South America. In Argentina, the absence of domestic regulation means that hospitals rely on US Food and Drug Administration (FDA) or Europe-based offices that validate and certify software. 'We need the human resources and institutions to do this domestically', he said.[147]

Putting manufacturing plants, equipment, or remote facilities online can make them vulnerable to cyberattacks and data theft. Cybersecurity is therefore essential to building a reliable IoT networks in particular, which must be closely monitored – for example, by keeping an inventory of the sensors and devices online, building in failsafe mechanisms to prevent physical harm, and managing legacy systems. This all adds to the expense of this technology and requires highly

[144] USAID. (2019). *Considerations for Using Data Responsibly at USAID*. Available at: https://www.ictworks.org/usaid-guide-responsible-data/#.XTG8fOhKhPZ, (accessed 19 July 2019).

[145] Bizimungu, J. (2018). 'Is Africa ready to protect citizens' personal data?' *The New Times*. Available at: https://www.newtimes.co.rw/news/africa-ready-protect-citizens-personal-data, (accessed 19 July 2019).

[146] Interview with Jonathan Jackson, 9 July 2019.

[147] Interview with Carlos Otero, 3 July 2019.

skilled operators. Thus, the expenses associated with deploying IoT solutions may be prohibitive to many countries, which have access to various sources of financing, including venture capital firms, development banks, and machinery-related lending.[148,149] Five hospitals in Romania, for instance, were recently victims of a ransomware cyberattack and lost all digitised information on their hospitalised patients.[150]

Standards to ensure trustworthy and robust algorithms

AI medical applications will bring a whole host of new ethical and regulatory challenges. Certification for the plethora of medical apps, for instance, is a subject of much debate. A remaining issue is that traditional licensing cannot easily be replicated for constantly self-updating algorithms. Diagnostic errors are a serious threat to healthcare quality and safety. Moreover, for scenarios in which humans are removed from the decision-making process altogether, clear accountability mechanisms need to be put in place. Hila Azadzoy of Ada Health noted that 'to have governments adopt and promote any digital solution, you need a framework to assess medical quality', and that the lack of a globally recognised benchmarking framework to assess all AI-powered solutions on an ongoing basis for dynamic systems, is a serious concern.[151]

The more complex the algorithm, the harder it is to interpret. There are many views on what constitutes algorithmic trustworthiness and to what extent we need to be able to understand how an algorithm functions. A joint WHO-ITU Focus Group on AI for Health was set up to 'identify opportunities for international standardization of AI for Health-relevant data, information, algorithms, and processes, which will foster the application of AI to health issues on a global scale. In particular, it will establish a standardized assessment framework with open benchmarks for the evaluation of AI-based methods for health, such as AI-based diagnosis, triage or treatment decisions'.[152]

According to the Focus Group's proposal, models will be submitted to agreed benchmarking platforms (such as www.crowdAI.org). The benchmarking platform executes the model on the undisclosed test set. Subsidiary bodies of the Focus Group will manage the creation and governance of this undisclosed test set, which represents the gold standard data set for the benchmark. The benchmarking platform allows for the comparison of the models' performance on a central leaderboard, or using a pass/fail scoring. This process is depicted in Figure 7.

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[148] OECD. (2017). *Opportunities and Policy Challenges of Digitalisation in Southeast Asia*. Available at: https://www.oecd.org/southeast-asia/events/regional-forum/Forum_Note_Digital_Transformation_STI.pdf, (accessed 19 July 2019)

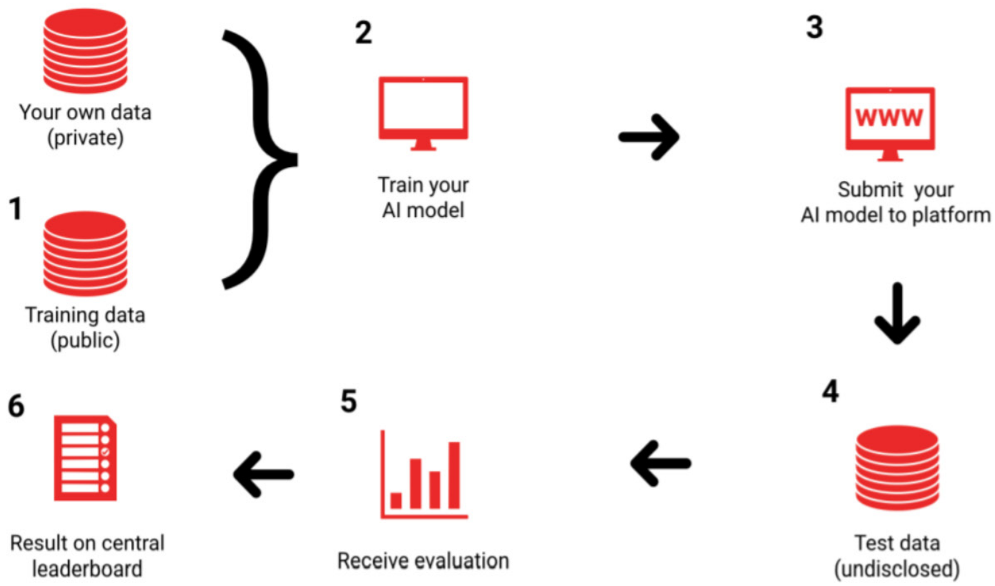
[149] Parmar, D. (2018). 4 obstacles to IoT adoption & how to fix them. Available at: https://jaxenter.com/4-obstacles-iot-adoption-fix-146939.html, (accessed 19 July 2019).

[150] Romanian Insider. (2019). Romanian hospitals, affected by ransomware attack. Available at: https://www.romania-insider.com/cyberattack-victor-babes-hospital-june-2019, (accessed 19 July 2019).

[151] Interview with Hila Azadzoy, 24 May 2019.

[152] Salathé et al. (2019). *White paper of the Focus Group on Artificial Intelligence for Health (FG-AI4H)*. Available at: https://www.itu.int/en/ITU-T/focusgroups/ai4h/Documents/FG-AI4H_Whitepaper.pdf, (accessed 19 July 2019).

Figure 7: ITU benchmarking pipeline[153]



NOTE: Private data: One's own data for training purposes; Undisclosed data: test data not available to algorithm developers.

Many believe that total algorithmic explainability will not be possible, because this would involve stripping algorithms of their monetary value. Marcel Salathé, Vice Chairman of the Focus Group, defends their benchmarking approach. He explains: 'we don't care exactly how they do it, it is just important that they do it right'. Salathé added that, 'we're quickly getting to a point where we will see AI having the potential to make public health decisions'. In this context, a benchmarking process that is able to keep up with the rate of change of algorithms is essential.[154]

Nina Schwalbe pointed out that the lack of regulation is a rate-limiting factor for the best technologies, as public scale-up requires regulatory review: 'the fact that the regulatory and systems and legal and human rights protections are so much weaker in many low-income countries means that these problems are just going to be exacerbated in those settings. Until we develop regulatory, legal and ethical guidelines, we won't be able to implement promising interventions at scale, as health is mostly publicly funded.'[155] Skye Gilbert added that, if you architect solutions for LMICs, it can be hard to enter into upper-income countries, as re-engineering for the stringently regulated markets can be very expensive.[156]

Leadership and governance structures

Our research suggests that digital health programmes work best when they are country-led and developed in partnership with the people who will use them to address a real problem or need. This requires a government that is able to identify national and local priorities and manage implementation.

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[153] Ibid.

[154] Interview with Marcel Salathé, 4 June 2019.

[155] Interview with Nina Schwalbe, 29 June 2019.

[156] Interview with Skye Gilbert, 13 June 2019.

As Raymond Sarmiento told us, effective governance of digital health requires strategic planning with multiple stakeholders and multi-sectoral coordination, with efforts embedded into the whole-of-government, and more widely a whole-of-society, strategy.[157] Merrick Schaefer suggested that effective governance is a more urgent issue than regulation in low-income countries. 'The compliance lens is dreadfully lacking, even in countries with good regulatory frameworks.'

Strong leadership is essential. Pratap Kumar (Founder and CEO of Health-E-Net Limited) said, 'I wouldn't say regulation is the biggest barrier, I'd say it's inertia. People at mid-management level don't take the risk. It needs leadership at a high level'. Lesley-Anne Long concurred that any new development 'comes down to political will, leadership, coordination, thoughtful investment'.[158]

Skye Gilbert, the Executive Director of Digital Square, thinks that the first priority at a country level is to determine a governing body with the authority to make decisions and implement the national strategy. This is particularly important as the responsibility for digital health policy is often distributed between multiple departments (health, ICT, e-government, and so on). This body can decide general principles to work towards (for instance, on privacy and security), and deliberate on which particular model to use. The role of international actors, she argues, should be to support this country-led process.[159]

Investment and incentives

National strategies and donor alignment

Several of our contributors commented that there is a notable lack of coordination among the many actors working in the digital health field in LLMICs, including donors, multilateral organisations, NGOs, developers and investors. Not only has this led international actors to behave in ways that run counter to national strategies and priorities, it is also a major cause of inefficiency and duplication. Various studies have cited cases where health workers are given multiple devices for recording different kinds of data, with new training required for each device, and no way of amalgamating the data collected. Antoine Geissbuhler emphasised that it is 'for governments to define their priorities and to make sure they are understood and followed' by donors. Donor alignment on digital strategy is 'something we need to achieve' and this is 'recognised at the policy level', he added.[160]

Important efforts have been made over the past year to improve the alignment and coordination of the various actors. In 2018, WHO passed a landmark resolution on digital health. Among other things, the document requests that the Director-General develop 'a global strategy on digital health identifying priority areas including where WHO should focus its efforts', and urges member

[157] Interview with Raymond Sarmiento, 24 June 2019.

[158] Interview with Pratap Kumar, 27 June 2019.

[159] Interview with Skye Gilbert, 13 June 2019.

[160] Interview with Antoine Geissbuhler, 29 May 2019.

states to consider ways of integrating digital health into existing systems, promote the use of 'international and open standards' for interoperability, and identify best practices and priority areas for further normative guidance.[161] The Principles of Donor Alignment for Digital Health (or 'Digital Investment Principles'), which 30 donors have already signed up to, advocates for pooling money to build digital platforms working across different diseases and financing tools like the Digital Square Initiative create the means for funders to do so.[162] More than 40 countries have now signed up to these principles, driven by the Gates Foundation and others. These are signs that there is growing political will to coordinate and avoid duplication.

Funding for health verticals vs horizontals

Related to the issue of donor coordination is the tension between vertical (disease-specific) and horizontal (system-wide) approaches to implementation. Lesley-Anne Long told us that 'there is time and money wasted on creating single-disease approaches'. Single-use interventions are easier to understand but investing in systems and interoperability generates huge returns.[163] Merrick Schaefer concurred, saying, 'there is an inverse correlation between focusing on a single disease area and creating a sustainable systemic approach'. There must be a shift from global targets for disease eradication to the overall health of the community. Schaefer describes this as a 'health systems approach from a disease perspective', addressing systemic barriers and multi-use platforms to achieve disease objectives. For instance, the same underlying tool can be used for multiple messaging needs (family planning services, disease outbreak surveillance, and so on).[164]

Jonathan Jackson adds that, while the Digital Investment Principles are a good step, 'whether those manifest on the ground remains to be seen'. There is a deeper problem, he explained, that 'project-based funding encourages organisations to focus on achieving only project goals regardless of whether the project is aligned to the countries' national health strategies.' He added that 'there is a need for an additive systemic solution that would encourage organisations and projects to go beyond their project-specific mandate'. This is a broad ecosystem problem: money for digital projects comes through vertical (disease-specific) programmes. 'If an efficient, transparent and objective mechanism existed, organisations would be incentivised to think critically about high-value, high-return activities to accelerate completion towards the national strategy'.[165]

Addressing health systems as well as hitting disease-reduction targets is complex, but adopting a problem-based approach is a good place to start. Many of our interviewees were keen to stress that digital solutions are only useful if developed in response to a real-world challenge. This requires collaboration between people working across different sectors and disciplines. Delmiro Fernandez-Reyes emphasised that digital health has been 'heavily hindered by knowledge silos' and that research must be interdisciplinary, involving not only computer scientists, but also social,

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161 WHO. (2018). *Resolution A71/20 on Digital Health*. Available at: https://apps.who.int/gb/ebwha/pdf_files/WHA71/A71_ACONF1-en.pdf, (accessed 19 July 2019).

162 Digital Investment Principles. (2019). The Principles of Donor Alignment for Digital Health. Available at: https://digitalinvestmentprinciples.org/, (accessed 19 July 2019).

163 Interview with Lesley-Anne Long, 29 May 2019.

164 Interview with Merrick Shaefer, 30 May 2019.

165 Interview with Jonathan Jackson, 9 July 2019.

data, clinical, life and population scientists. Additionally, links must be made to potential health benefits of 'non-medical' digital applications, such as accessibility to digital-banking and micro-credit platforms, data services and educational platforms.[166] Skye Gilbert added that it is useful to have a champion in government who is working across health programmes, or even across sectors.[167]

Edmond Ng agreed that 'all interventions should be problem-based'. Some developers have a tendency to 'back-fit' – inventing the technology first, fitting it to a problem second. The 'hyped factor' of technologies such as the possibility of gene therapy for the treatment of common diseases has so far not been realised for improving health outcomes at a population level, may be diverting resources from more 'traditional' interventions that might have a greater impact. In Ng's words, ',To overly invest in unproven advances can be a distraction to things that may seem more conventional but actually are doing good things for populations'.[168]

Public investment

Public investment is essential: as Merrick Schaefer argues, if the standardisation of tools is driven solely by private actors (like insurance companies), there is a risk that the tools will be used purely to 'optimise profit returns' and that 'we won't see big health outcomes'.[169] In Argentina, Carlos Otero told us around there is a big disparity in the use of health informatics between private and public health providers. Only around 20% of public institutions have some level of informatisation in their centres, compared to 70–80% private institutions. He added that the integration of public and private services is a problem across the region, an additional interoperability issue.[170]

Antoine Geissbuhler pointed out that research and evidence gathering often follow funding priorities. This leads to a short-term approach and an excess of pilots, where interest quickly moves on to the new 'shiny' solution. Digital health is being mainstreamed, but still lacks comprehensive long-term studies in many areas. Geissbuhler emphasised that making direct links between a digital health initiative and particular effects on mortality and morbidity is difficult. However, his team have worked on developing proxy indicators that are known to be linked to, for instance, maternal or neonatal outcomes. If a tool affects a proxy indicator, this provides fairly good evidence of its effectiveness. For example, micronutrient supplementation (iron and folic acid) is known to improve birth outcomes. If a digital tool is known to improve micronutrient uptake in mothers, it is reasonable to assume that it also results in healthier births.[171]

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166 Interview with Delmiro Fernandez-Reyes, 3 June 2019.

167 Interview with Skye Gilbert, 13 June 2019.

168 Interview with Edmond Ng, 17 May 2019.

169 Interview with Merrick Shaefer, 30 May 2019.

170 Interview with Carlos Otero, 3 July 2019.

171 Perrin et al. (2018). 'Systematic review to identify proxy indicators to quantify the impact of eHealth tools on maternal and neonatal health outcomes in low-income and middle-income countries including Delphi consensus', *BMJ Open*. Available at: https://www.ncbi.nlm.nih.gov/pubmed/30121608, (accessed 19 July 2019).

To be able to make more confident claims about the impact of digital health, initiatives need to be scaled up. Lesley-Anne Long noted that many systems rely on time-limited donor funding, and that there is little capacity building at a country level to run complex open source systems. While there is growing private sector involvement, Long emphasised that 'unless there is Ministry involvement it's quite hard to go to scale'.[172] Greater public investment for scalable and interoperable solutions is essential.

172 Interview with Lesley-Anne Long, 29 May 2019.

4. Future developments

The future for digital healthcare applications will present greater opportunities and more complex challenges. As more and more of the world's population gains internet access, the potential for digitally-enabled precision medicine will grow. The proliferation of electronic medical records may lead to better data and better management of resources. Tech-savvy community health workers may be able to take on more complex tasks. AI-enabled drug discoveries combined with 3D printing may wipe out entire diseases with cheap and readily available medicines.

Some of the future challenges for LLMICs are already being seen in high-income countries, where digital health is more widespread. Poor implementation of electronic medical records may lead to leaks of sensitive information. The question of who should benefit from the monetisation of private health data is already a topic of much debate in Europe and the US. Internet-connected masses may fall victim to conspiracy theories, 'fake news' and misinformation campaigns, as we have seen already in the US, through anti-vaccination campaigns. 3D printers owned by criminal gangs may lead to markets being flooded with cheap, counterfeit medicines.

But other challenges are likely to look unlike anything we have seen in higher-income settings. Low-income countries have unique health challenges, regulatory environments and developmental pathways. To help envision future scenarios in LLMICs specifically, our researchers undertook a 'futures wheel' exercise to map out the potential first order and second order consequences of three key trends:

1. universal internet access
2. proliferation of data
3. ubiquitous and powerful AI.

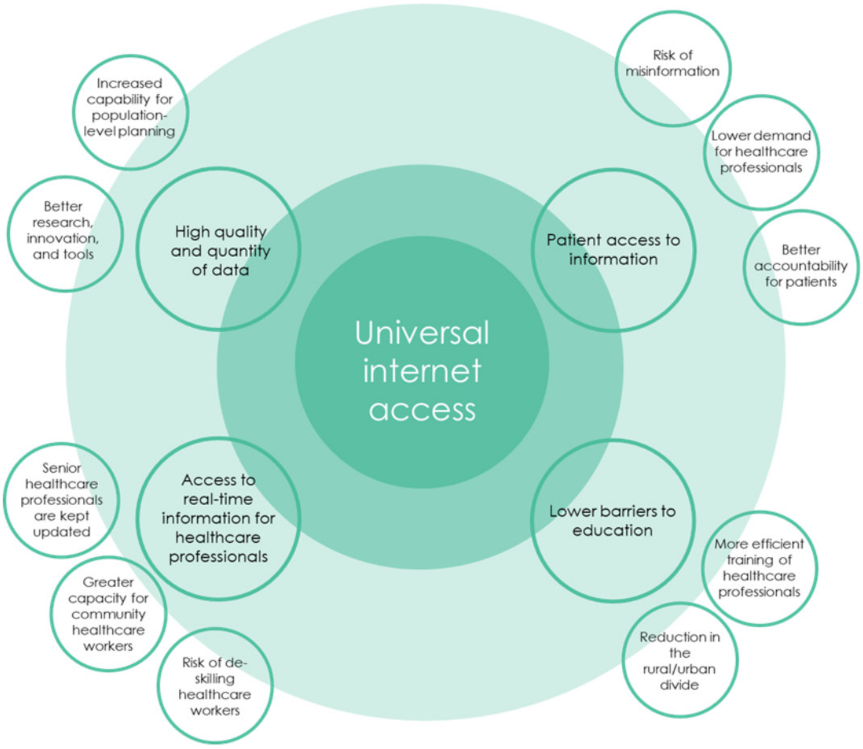
The exercise outlines important risks, challenges, and opportunities that may shape the future direction of digital health applications. The inner circles represent potential first order consequences. The outer circles represent second order consequences.

Universal internet access

The most transformative developments for digital health in LLMICs may not be high tech, but rather based on improvements to basic but vital infrastructure. More than diagnosis tools, data analytics, or drug discovery technologies, there is a great need for reliable digital infrastructure. This view was confirmed by many of our expert interviewees, who emphasised that universal and reliable access to the internet and mobile devices will underpin future advances in digital health.

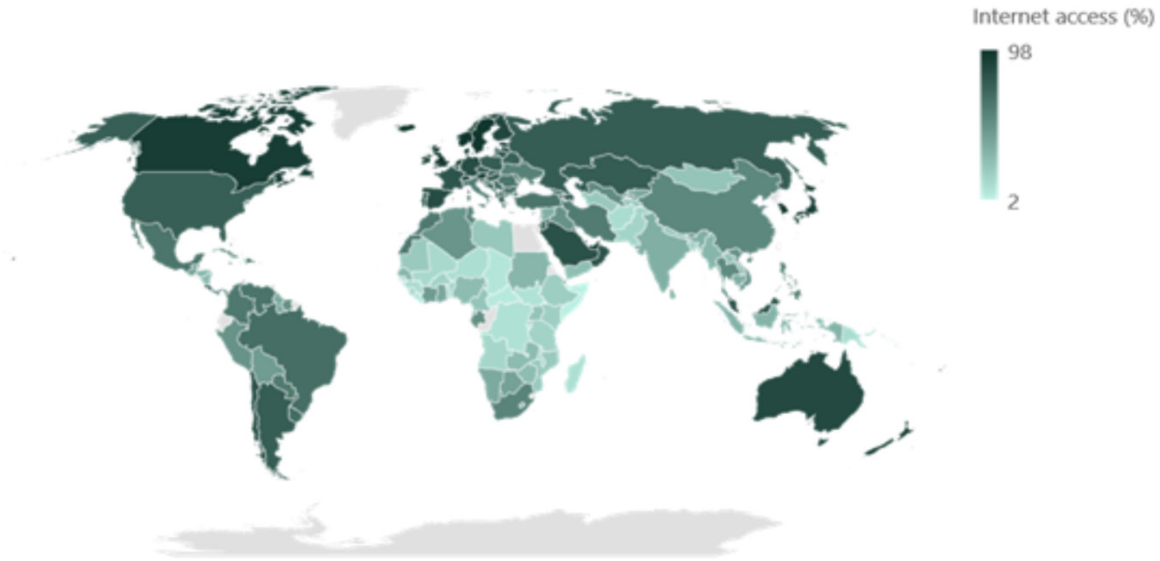
By lowering the barriers to education, the internet can lead to more efficient and effective training of doctors, nurses and community health workers. Given the low physician-to-patient ratios in many of our focus countries, the ability to train healthcare practitioners quickly and cheaply will be vital. Encouraging health workers to return to remote areas after training may also help close the rural–urban divide, ensuring that rural areas aren't left behind as countries become increasingly urbanised. Universal internet access may bring about innovative online medical training courses, virtual seminars and digital knowledge-sharing platforms.

Figure 8: Universal internet access, futures wheel



High-quality and reliable information will also generate better-educated citizens and patients. Affordable, accessible and reliable internet access will create an environment in which digital symptom-checkers can thrive. This may eliminate some unnecessary consultations and save individuals travelling time. Earlier diagnosis of symptoms can lead to earlier treatment and better health outcomes for the patient. Apps also provide patients with advice about prevention and wellness, and the tools to hold local health workers to account.

Figure 9: Internet access by country[173]



However, a reliance on information obtained from digital health apps and websites opens the door to the risk of misinformation, a phenomenon seen across the world in recent years. In an article on the 'global measles crisis', the Director-General of WHO wrote that uncertainty around vaccinations has been 'fuelled by the proliferation of confusing and contradictory information online' which has been 'amplified by algorithms that reward controversy and clicks'.[174] Some have theorised that the spread of misinformation on WhatsApp has been hindering attempts to alleviate cases of yellow fever in Brazil with 'sophisticated' anti-vaccination videos and audio files going viral.[175]

Figures 9 and 10 show an inverse correlation between internet access and the number of DALYs per 1,000 population.[176] Whether there is any causal link between these variables could be an interesting area of further research.

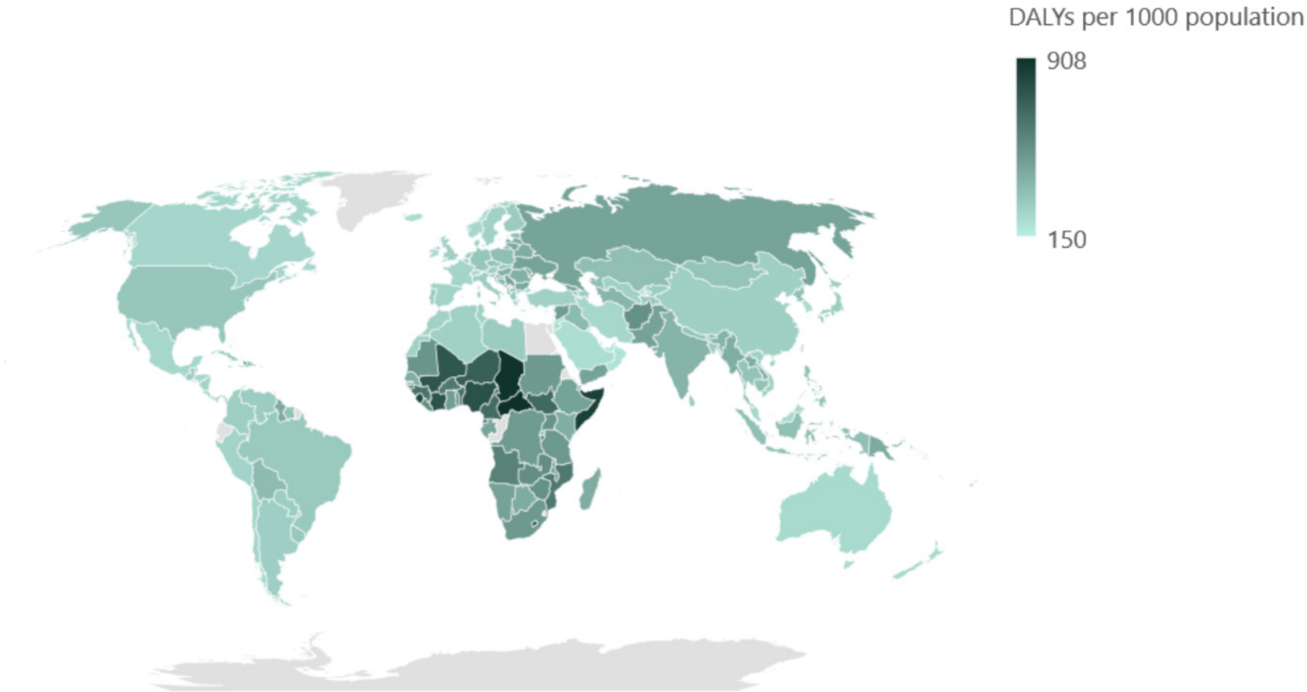
173 Murphy, J. and Roser, M. (2019). Internet access by country. Available at: https://ourworldindata.org/internet#broadband-access, (accessed 19 July 2019).

174 Fore, H and Ghebreyesus, T. (2019). Measles cases are up nearly 300% from last year. This is a global crisis. Available at: https://edition.cnn.com/2019/04/15/opinions/measles-cases-rise-global-crisis-fore-ghebreyesus/index.html, (accessed 19 July 2019).

175 Molteni, M. (2018). 'How WhatsApp could worsen Brazil's yellow fever outbreak', *Wired*. Available at: https://www.wired.com/story/when-whatsapps-fake-news-problem-threatens-public-health/, (accessed 19 July 2019).

176 WHO. (2019). Disability-adjusted life years (DALYs). Available at: https://www.who.int/gho/mortality_burden_disease/daly_rates/en/, (accessed 19 July 2019).

Figure 10: DALYs per 1,000 population

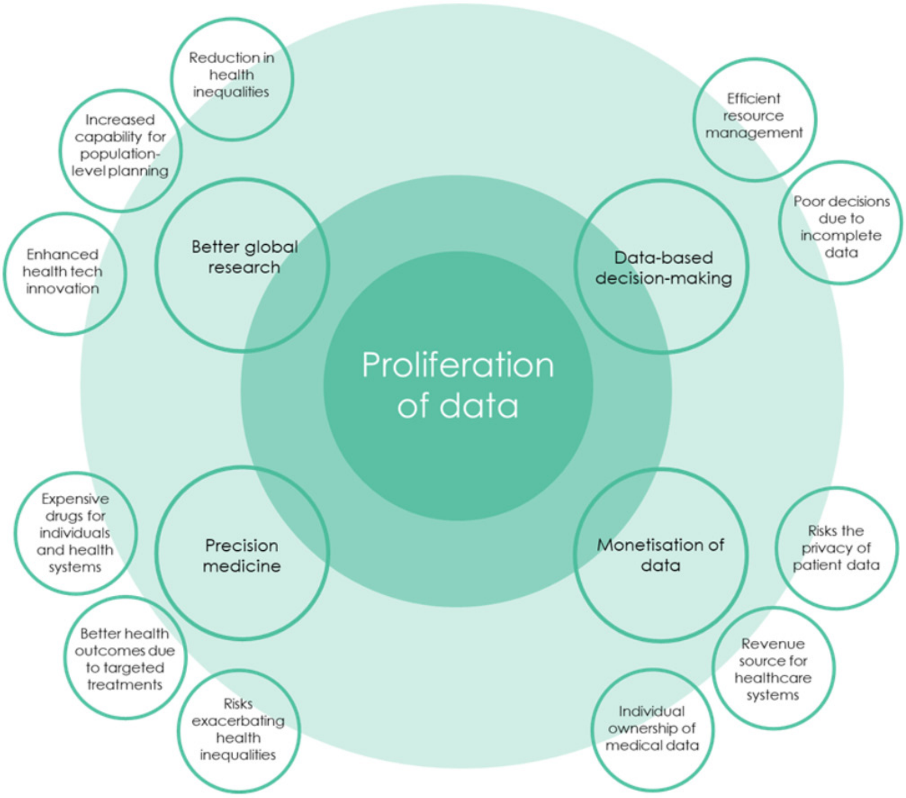


The spread of internet-connected devices creates an opportunity for higher quality and quantity of data from users. This could be individual-level health data that aids doctors in their diagnosis and treatment of patients, or it could be population-level data that helps academics, governments and NGOs map diseases and channel resources. The current, analogue data-collection system makes collation, distribution and analysis expensive and difficult to achieve. Good data collected using an internet-enabled system will deliver new insights to domestic and international researchers and can help foster new digital health innovations, as well as the development of new demographic-specific treatments. Beyond this, the proliferation of data will open a vast range of new opportunities. These are explored in greater detail in our futures wheel in Figure 11.

Proliferation of data

Most digital health interventions are heavily reliant on good-quality data, as we have already discussed. Rich data collected from LLMICs will enhance global research while leading to more effective decision-making, and possibly a growth in precision medicine. If the internet is the *infrastructure* that will shape the future, data is the *asset*. The proliferation of data was highlighted as the most important development in the coming decades by several interviewees. Improvements in data collection are fundamental to all five of our identified themes: process optimisation; preclinical research; clinical pathways; patient-facing applications; and population-level applications.

Figure 11: Proliferation of data, futures wheel



Data-driven research conducted by domestic and global institutions will increase the capability for governments and NGOs to undertake population-level planning. Diseases will be mapped and tracked in more sophisticated ways, including using machine-learning techniques, which will reduce response times. Better predictions will be made about population growth, changing demands for healthcare, and the effectiveness of initiatives at every level. Health inequalities that arise today from poor and incomplete data on certain demographics can be reduced with new information and insights on underrepresented groups in fields such as genomics.

> 'We need to unlock data at scale from large parts of the developing world where almost no health data exists, at least not in digital form.'
> *Pratap Kumar, Founder and CEO of Health-E-Net Limited*

The monetisation of these datasets presents both risks and opportunities. The sale of medical data to third-party developers and institutions can become an important, sustainable, source of revenue for public healthcare systems across the world. However, there is a risk that confidential patient data is sold on to third parties such as insurance companies, without informed consent. Given the weak regulatory frameworks in place in many LLMICs (as highlighted by a number of our interviewees), there is potential for this to become a serious concern.

With the growth of digital health tools, data-based decision-making may become the norm. Along with the clear benefits of more accurate diagnosis, more efficient channelling of resources, and more effective treatments, there are a number of associated risks. An over-reliance on data-based decision-making may paradoxically lead to the deskilling of healthcare workers, who may uncritically follow the outputs of algorithms, unable to explain the decisions underpinning them. Poor and inaccurate data input may exacerbate these problems further. Public health decisions are often ethically and politically charged; technology can never entirely replace human decision-making in this area.

Precision medicine may become realisable as a result of the proliferation of data. With rich data on individuals, diseases and drug effectiveness, we may see global growth in more personalised treatments. Patients may have drugs and treatment plans tailored specifically for them, leading to optimal health outcomes. There are two risks, however, which should be taken into consideration. The first is that precision medicine may become the most effective form of treatment, bolstering demand for tailored drugs, increasing costs for healthcare systems which could divert funds from elsewhere. The second is that precision medicine risks exacerbating health inequalities by creating a higher tier of healthcare for those who can afford it.

Ubiquitous and powerful AI

As AI systems become better at sorting data, finding patterns, and making predictions, algorithms are undertaking an ever-increasing range of tasks.[177] It is clear that these technologies will also take on an expanded role in medical diagnostics and treatment. This is because of the reliance of modern medicine on ever-increasing amounts of data derived from imaging, histopathological, biochemical and other investigations, as well as the fact that many modern management pathways follow strict, semi-algorithmic protocol. Investment in AI varies significantly between countries and regions. The US is currently the biggest investor, estimated at around $15 billion to $23 billion in 2016 alone.[178] Asia's AI investments were valued at $8 billion to $12 billion, and Europe at $3 billion to $4 billion for the same year.

In engaged and connected health markets, 50% of doctors agree, or strongly agree, that AI will transform primary care and advance the role doctors; however, a number of doctors remain sceptical. A higher proportion of doctors in Mexico (55%) and India (51%) agree or strongly agree with the statement than in the UK (35%) and Japan (41%).[179]

177 Fenech et al. (2018). *Ethical, Social and Political Challenges of Artificial Intelligence in Health*. Available at: https://futureadvocacy.com/wp-content/uploads/2018/04/1804_26_FA_ETHICS_08-DIGITAL.pdf, (accessed 19 July 2019).

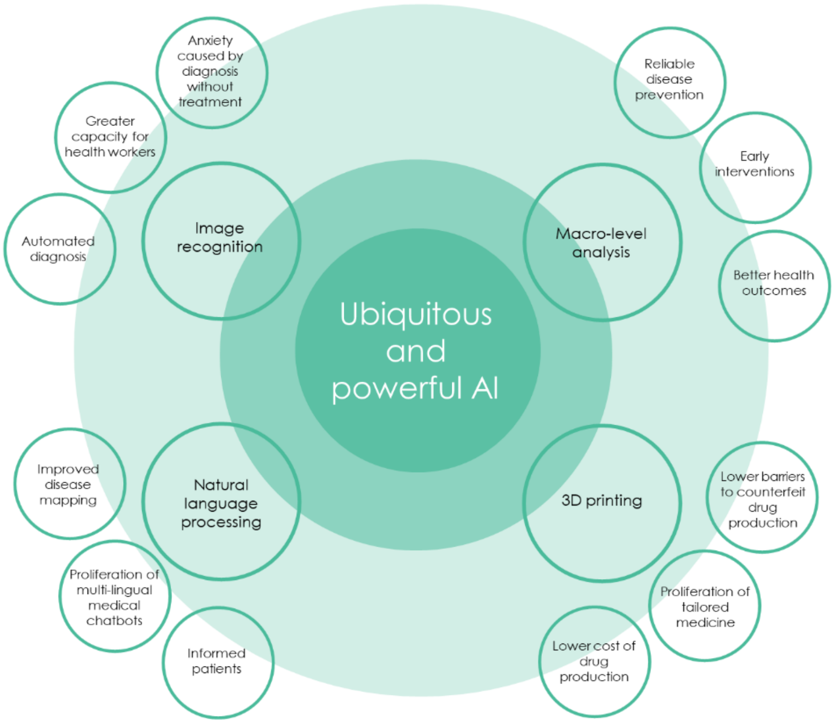
178 Manyika, J. and Sneader, K. (2018). *AI, automation, and the future of work: Ten things to solve for.* Available at: https://www.mckinsey.com/featured-insights/future-of-work/ai-automation-and-the-future-of-work-ten-things-to-solve-for, (accessed 19 July 2019).

179 Ipsos Healthcare. (2017). Digital Doctor. Available at: https://connectedhealth.ipsos.com/digital-doctor.html, (accessed 19 July 2019).

In the futures wheel in Figure 12, we highlight four areas where AI may have its greatest impact on digital health in LLMICs: macro-level analysis; 3D printing; image recognition; and natural language processing.

The potential of AI to make predictions about future population changes, the spread of disease, and the effectiveness of treatments may have a transformational impact on early intervention initiatives. By using AI to identify causal factors, practitioners and policymakers can equip themselves to intervene against high disease burden conditions at an early stage and prevent diseases from being contracted in the first place. Automated, real-time, macro-level analysis may become achievable once AI applications become ubiquitous. This would help ensure that diseases are identified early and encourage the optimal allocation of resources. To reach this stage, however, will require investment in reliable internet access and rich data.

Figure 12: Ubiquitous and powerful AI, futures wheel



The advancement of natural language processing also has the potential to help map disease outbreaks by automatically analysing the conversations of social media users. This, however, is reliant on high levels of social media use and the ability of the software to understand multiple languages and dialects. Translation tools and natural language processing could lead to a growth of reliable multi-lingual medical chatbots. These chatbots can help with triage, reducing demand on healthcare workers, and supporting patients who lack access to physicians. Combined with sophisticated image recognition, these technologies can help patients self-diagnose and support clinical pathways.

The potential of AI-enabled 3D printing lies in cheaper, high-quality drug production of both a tailored and generic kind. If the technology becomes affordable and readily available, healthcare systems in LLMICs may no longer need to rely on pharmaceutical giants for the production of medicines. They could produce the drugs they require locally. The challenge will be ensuring that the technology does not make it into the hands of counterfeit drug dealers. A 2017 study by WHO found that 10% of medical products circulating in low- and middle-income countries are 'substandard or falsified'. A modelling exercise by the University of Edinburgh estimated that between 72,000 and 169,000 children may be dying each year from pneumonia due to substandard and falsified antibiotics.[180]

Future non-tech trends

Looking further ahead into the future, we identified three key trends that those engaged with digital health should consider. These are primarily based on emerging trends we are beginning to see in many developed parts of the world. The first is related to the challenge of catering for ageing populations and a shift towards social care robotics. The second projects a greater focus on mental health provision. The third trend relates to the continuing challenges surrounding online misinformation.

Ageing populations and a shift towards social care

While the current focus on healthcare in LLMICs is centred around disease prevention, diagnosis and treatment, as life expectancy increases, this is likely to shift towards social care in the future. According to the latest data, the average life expectancy in low- and middle-income countries is 66 years.[181] If the average growth rates over the past 50 years are replicated in the future, this could reach 75 years by 2050.[182] This would be similar to levels experienced in upper-middle-income countries today.

> 'In Asia, you're looking at a rampantly ageing population. How do you take care of an old, ageing population?'
> *Runbin Dong, Digital Transformation, Prudential Corporation Asia*

Currently, a lot of digital health applications for older people are related to the IoT which may include sensors in the home or watches that can monitor heart rates. These technologies will require more than the relatively rudimentary technologies of mobile phones that we have today. These will require significant investment in digital infrastructure. Failure to invest in consistent electricity supplies, broadband and 5G over the coming decades may hinder today's LLMICs from benefiting from the social care technologies of tomorrow. This risks a further widening of the health inequality gap.

[180] WHO. (2017). 1 in 10 medical products in developing countries is substandard or falsified. Available at: https://www.who.int/news-room/detail/28-11-2017-1-in-10-medical-products-in-developing-countries-is-substandard-or-falsified, (accessed 19 July 2019).

[181] World Bank. (2019). Life expectancy at birth. Available at: https://data.worldbank.org/indicator/sp.dyn.le00.in, (accessed 19 July 2019).

[182] Future Advocacy estimate based on average growth rates for life expectancy in LMICs since 1960.

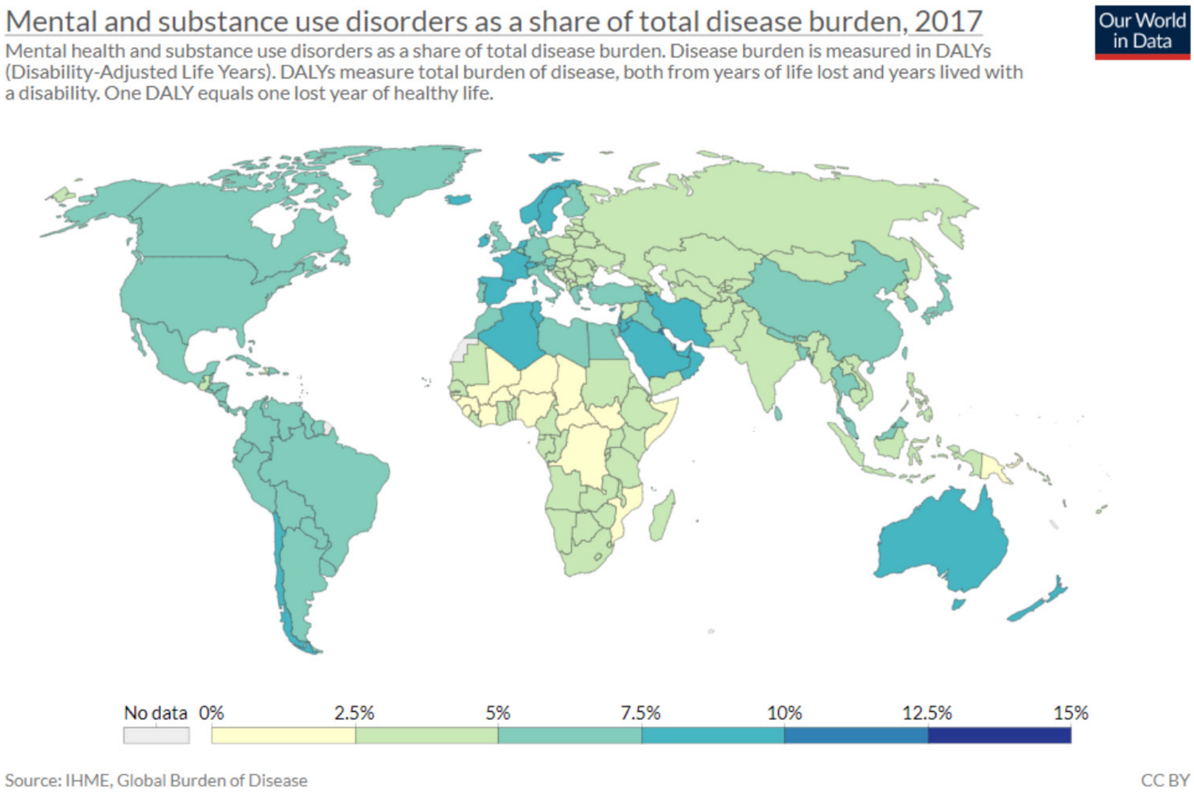
Case study 18: Shin-tomi nursing home in Japan

The Shin-tomi nursing home in Tokyo employs more than 20 different robotic models to care for its residents.[183] Some of these models are akin to sci-fi representations, such as Pepper, a semi-humanoid robot that can recognise emotions. Others, however, look nothing like those in popular culture. By the government's definition, robots need only contain sensors, a processor and an apparatus. Resyone, developed by Panasonic, for example, is a bed that splits in two, with one half turning into a wheelchair. It is hoped that Shin-tomi will become a model for future care homes to help the demands of an ageing population and a dwindling workforce.

Mental health

Assuming that, as LLMICs develop over the coming decades, there is a decline in the prevalence of communicable diseases and DALYs related to physical condition, there is the potential for mental health to become a greater area of focus for digital health initiatives. Worldwide, there is a problem of underreporting of mental health conditions. However, given the deficiencies in health data reporting generally, this is likely to be particularly underreported in LLMICs. As these reporting mechanisms improve, it may become clear that DALYs related to mental health is a significant, and insufficiently addressed problem in LLMICs.

Figure 13: Mental and substance use disorders as a share of total disease burden



183 Foster, M. (2018). Aging Japan: Robots may have role in future of elder care. Available at: https://uk.reuters.com/article/aging-japan-robots-may-have-role-in-future-of-elder-care-idUKKBN1H33AB, (accessed 19 July 2019).

Data from the Institute for Health Metrics and Evaluation show that mental disorders make up a greater share of the total disease burden in developed countries compared to low- and middle-income countries.[184]

Case study 19: Spring Health

Spring Health is a tech start-up in the US that was born out of a project at Yale University. It develops personalised mental health treatments for users.[185] Using AI and machine learning, the platform acts as a decision-support tool for clinicians by making a determination about which antidepressant would be the most effective for a patient suffering from depression. The platform claims the capability to provide guidance as granular as the specific dose of medication that should be taken.

Online misinformation

According to a recent report by WHO, global cases of measles rose by 300% in the first three months of 2019.[186] This has been linked to so-called 'anti-vax' misinformation campaigns that spread on social media, leading to phenomenon labelled as 'vaccine hesitancy'.[187] WHO has listed this as one of the top 10 threats to global health.[188] According to Skye Gilbert from Digital Square, social media was an 'amplifier' of misinformation during the Ebola outbreak.

> 'The web has lowered the barriers to presenting information as credible and authoritative. The medium is very much the message: it is near impossible to differentiate between information and misinformation on grounds of presentation online. This false parity presents a real threat to the deployment of public health initiatives.'
> Alex Krasodomski, Director of the Centre for the Analysis of Social Media

A number of individuals in low- and middle- income countries already suffer due to online misinformation. This is likely to increase with the proliferation of smartphones. Should this spread more widely into healthcare misinformation, it could cause a significant setback in disease-prevention efforts. The maturity of 'deepfake' technology in the coming decades will cause new, and potentially more difficult, challenges for policymakers and health professionals.

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184 Ritchie, H. and Roser, M. (2018). 'Mental health'. Available at: https://ourworldindata.org/mental-health, (accessed 19 July 2019).

185 Spring Health. (2019). About Spring Health. Available at: https://www.springhealth.com/about/, (accessed 19 July 2019).

186 WHO. (2019). New measles surveillance data for 2019. Available at: https://www.who.int/immunization/newsroom/measles-data-2019/en/, (accessed 19 July 2019).

187 Giordano, C. (2019). 'Measles cases hit 25-year high in US as anti-vax campaign blamed for return of deadly preventable diseases', *The Independent*. Available at: https://www.independent.co.uk/news/health/measles-outbreak-vaccination-anti-vax-cdc-autism-us-uk-a8885441.html, (accessed 19 July 2019).

188 WHO. (2019). Ten threats to global health in 2019. Available at: https://www.who.int/emergencies/ten-threats-to-global-health-in-2019, (accessed 19 July 2019).

Case study 20: NHS website

The UK's National Health Service (NHS) website provides a 'complete guide to conditions, symptoms, and treatments, including what to do and when to get help' as well as information on 'how your medicine works, how and when to take it, possible side effects, and answers to common questions'.[189] While it was not specifically created to combat misinformation (one of the key drivers may have been to reduce demand on telephone helplines and GP practices), having a trusted online source of medical advice will be essential in combating the risk of misinformation in the future. The NHS website is the UK's most popular health website, with more than 43 million visits per month.

In conclusion, technology will shape the future of healthcare over the coming decades across the world. In LLMICs, digital health has a great potential to strengthen healthcare provision for the most vulnerable. Our recommendations in the next chapter highlight some actions that could be taken to maximise the benefits and minimise the risks of digital health. If these associated risks and challenges are managed effectively, we envisage a future in which digital health applications play a significant role in helping healthcare systems in LLMICs respond to the complex and evolving challenges they face.

[189] NHS. (2019). *NHS website*. Available at: https://www.nhs.uk/, (accessed 19 July 2019).

5. Recommendations

These recommendations are based on our research and the evidence presented in this report. They are aimed at policymakers, donors, international bodies and development agencies, researchers and other stakeholders, including in the private sector, engaged in digital health:

At a national level

i) Aim to create digital health architectures and adopt standards that encourage interoperability and effectively manage health information exchanges.

A common thread throughout our research was the need for digital health data to be interoperable (shareable and combinable with data produced across organisational boundaries). Many of the experts we interviewed highlighted this as one of the keys to producing useful and analysable data. Incomplete training data for artificial intelligence (AI) that does not accurately reflect an entire population across gender, race and other demographic identifiers, results in skewed outcomes for any health application, but particularly for preclinical research, as any treatment generated may be effective only for certain subsets of the population.

A related challenge is that of language barriers. In low- and lower-middle-income countries (LLMICs), data is often recorded in a multiplicity of different languages, (if it is recorded electronically at all). World Health Organization (WHO) has also advocated for the adoption of standardised medical terminologies that would allow for easier comparison of health indicators across time and space.[190]

ii) Consider the health benefits of investing in robust national infrastructure related to electricity, broadband and mobile access.

According to the International Energy Agency, an estimated 1.1 billion people across the world do not have access to electricity, with many more suffering from poor quality supply.[191] Meanwhile, the UN's *State of Broadband 2018* report found that 48% of the world's population do not have internet access.[192] This lack of basic infrastructure is a major barrier to most digital health initiatives. While mobile data is a popular means of accessing the internet in low- and middle-income countries, a study of 75 countries conducted by Facebook found that, on average, 94% of those living within these countries live within range of a 2G signal.[193] As the UN report notes, 'it is virtually impossible to experience the internet effectively via a 2G connection'.

[190] Wahl et al. (2018). 'Artificial intelligence (AI) and global health: how can AI contribute to health in resource-poor settings?' *BMJ Global Health*. Available at: https://gh.bmj.com/content/bmjgh/3/4/e000798.full.pdf, (accessed 19 July 2019).

[191] International Energy Agency. (2019). Energy access database. Available at: https://www.iea.org/energyaccess/database/, (accessed 19 July 2019).

[192] ITU. (2018). *The State of Broadband 2018*. Available at: https://www.itu.int/pub/S-POL-BROADBAND.19-2018, (accessed 19 July 2019).

[193] Facebook. (2019). *The Inclusive Internet Index: Bridging digital divides*. Available at: https://theinclusiveinternet.eiu.com/assets/external/downloads/3i-bridging-digital-divides.pdf, (accessed 19 July 2019)

> ‘You need devices, computers, internet, back-up power systems. That’s one reason why things are tough to scale.’
> *Pratap Kumar, Founder and CEO of Health-E-Net Limited*

Given the dependence of electronic medical records and patient-facing applications on access to the internet and electricity, ensuring that communities have robust infrastructure will be key. Failure to do so will particularly hinder opportunities related to the internet of things (IoT), which will require much stronger connections than 2G, 3G, or even 4G. We recommend that governments should work towards bridging this gap and to consider the health benefits of doing so.

iii) Consider the health benefits of investing in nationwide digital literacy initiatives.

Strong digital literacy skills will be required among patients, physicians and community health workers if digital health tools are to be implemented and retained by users. Equally, these skills will be necessary to help combat the threat of misinformation so that patients are able to recognise good and bad sources of advice on the internet. The importance of digital literacy is reflected in the UN Sustainable Development Goals, with an indicator of Goal 4 (ensure inclusive and equitable quality education and promote lifelong learning opportunities for all) being the proportion of youth and adults with information, communications and technology skills.[194]

Ensuring that individuals feel comfortable using smartphones and computers will be critical for ensuring the success of digital health applications. We therefore recommend that policymakers and donors consider investing in digital literacy initiatives as part of their health strategies. An example of this in an LLMIC context is Intel’s She Will Connect programme which partners with NGOs in Kenya, Nigeria, and South Africa to educate women and girls in how to navigate the internet safely and effectively.[195]

iv) Design national action plans for implementing electronic medical records.

Electronic medical record (EMR) systems carry great potential to free up time and resources, by optimising back-end processes. As highlighted by several other recommendations, the foundations need to be laid before electronic medical records initiatives can scale up. Consistent electricity supply, reliable internet access, and strong digital literacy should all be prioritised in a country’s digital health strategy. A transformative innovation in this area has been open source technology, which can be adapted to different contexts.

It should be noted that this recommendation does not relate only to *nationwide* systems for electronic medical records. The use of EMRs in *localised* settings during a crisis, or to record basic information such as birth statistics, are still valuable initiatives. To scale up and ensure the best possible use of EMRs in LLMICs, we recommend that governments begin by designing national action plans, setting out a roadmap for long-term implementation.

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194 UN. (2019). Sustainable Development Goal 4. Available at: https://sustainabledevelopment.un.org/sdg4, (accessed 19 July 2019).

195 Intel. (2019). *She Will Connect: Connecting women in Africa to opportunity through technology*. Available at: https://www.intel.co.uk/content/www/uk/en/technology-in-education/she-will-connect-exec-summary.html, (accessed 19 July 2019).

v) Develop and implement clear, national frameworks and regulations for data protection.

Providing an open and secure data environment involves building frameworks that enable the sharing of (sensitive) information with other organisations and sectors. Despite the large number of internet users, countries including Kenya and Nigeria still lack data protection and privacy laws. The misuse of data is one of the great risks of digital health. Weak regulation or enforcement may lead to personal data being obtained without the patient's consent and used for diverse motives. A lack of regulation also means that there is no means of recourse for a patient should anything ever go awry with their data. The need for regulation was often cited throughout our research. While some argued that heavy-handed regulation would depress innovation in the sector, several interviewees argued that a lack of regulation is a rate-limiting factor for up-scaling technologies.

There is no consensus on the best way to regulate for privacy and data ownership. Policymakers in LLMICs must be given the opportunity to make their own decisions on these crucial and contentious issues. Existing frameworks such as the EU's General Data Protection Regulation[196] and the UK's NHS code of conduct for data-driven health and care technology could be used as resources.[197]

vi) Test AI tools on relevant and appropriate data sets to avoid data bias.

One of the risks highlighted in our research was that AI tools are not always trained on representative data sets. This is relevant to any AI health intervention, but particularly diagnostic tools. A diagnostic application tested only on Western European datasets may not have the same success rates on detecting conditions such as diabetes with individuals from other parts of the world. A study published in 2018 found that a genetic test commonly used to predict the risk of schizophrenia gave a score 10 times higher in people with African ancestry than those with European ancestry.[198] This was due to the genetic markers being derived primarily from studies of individuals with European ancestry.

> 'I think there are some things that can be done. For example, a country can ask that an AI-based digital health application coming from elsewhere should be validated on local datasets in that country. Global bodies like the WHO can support this by creating suitable guidelines for member states.'
> *Siddhartha Jha, Program Manager for Digital and AI, Fondation Botnar*

We recommend that policymakers consider establishing a requirement for these applications to be tested on appropriate datasets. Doing so will increase confidence that these tools achieve what they intend to, and minimise the risk of misdiagnosis.

196 EU. (2019). The EU General Data Protection Regulation (GDPR). Available at: https://eugdpr.org/, (accessed 19 July 2019).

197 Department of Health and Social Care. (2019). Guidance: Code of conduct for data-driven health and care technology. Available at: https://www.gov.uk/government/publications/code-of-conduct-for-data-driven-health-and-care-technology/initial-code-of-conduct-for-data-driven-health-and-care-technology, (accessed 19 July 2019).

198 Curtis, D. (2018). 'Polygenic risk score for schizophrenia is more strongly associated with ancestry than with schizophrenia', *Psychiatric Genetics*. Available at: https://insights.ovid.com/crossref?an=00041444-201810000-00002, (accessed 19 July 2019).

vii) Establish clear governing bodies to oversee implementation of the national digital health strategy and invest in leadership and capacity building.

Several interviewees highlighted the governance challenges in LLMICs as a major barrier to implementation of digital health initiatives. For example, often the responsibility for digital policy is split between multiple government departments. There is also frequently a shortage of leadership and management skills in the field of digital health. As Pratap Kumar emphasised, these programs need 'leadership at a high level', otherwise 'people at mid-management don't take the risk'.[199]

Establishing a governing body with the authority to make decisions and implement the national strategy is a crucial first step. It creates a clear set of actors with whom international partners can collaborate, and also establishes digital health as a sphere requiring leaders, managers and specialised staff. As Skye Gilbert told us, this body can decide on general principles to work towards and deliberate on which particular model to use. The role of international actors should be to support this country-led process.

At a global level

viii) Coordinate on digital health projects according to the Principles of Donor Alignment for Digital Health, in order to share resources, learning, and avoid duplication.

Several of our contributors commented that there is a notable lack of coordination among the many actors working in the digital health field in LLMICs, including donors, multilateral organisations, NGOs, developers and investors. Not only has this led international actors to behave in ways that run counter to national strategies and priorities, it is also a major cause of inefficiency and duplication. Important efforts have been made over the past year, to improve the alignment and coordination of the various actors. To ensure a cohesive strategy, we recommend that international actors actively adhere to the Principles of Donor Alignment for Digital Health and engage with financing tools like the Digital Square Initiative. Wherever possible, initiatives should aim to strengthen the wider health system, rather than only meeting narrowly defined disease reduction goals.

ix) Adhere to the Principles for Digital Development, including assessing user needs prior to the development or implementation of a digital health platform and adopting a problem-based approach.

User-interface design is essential for the long-term sustainability of interventions involving patient or clinician-facing tools. WHO suggests using its Classification of Digital Health Interventions 'in tandem with the of list Health System Challenges (HSC) in order to articulate how technology is addressing identified health needs, such as lack of service utilisation'. In particular, we would recommend that developers adopt the Principles for Digital Development, which cover themes such as user-centred design, sustainability and data privacy.[200]

199 Interview with Pratap Kumar, 27 June 2019

200 Principles for Digital Development. (2019). Available at: https://digitalprinciples.org/about/ (accessed 19 July 2019).

To avoid a situation where the tools designed fail to meet the real needs of their users, developers should adopt a problem-based approach. Users should be actively involved throughout the design process. Lesley-Anne Long also emphasised that a problem-based approach involves formulating new interventions around two specific questions: 'what are the behaviour changes that will lead to better health outcomes?'; and 'how might technology either make that behaviour change happen more quickly, or more cost effectively, or more efficiently?'

To alleviate the time-consuming task of data collection, user interfaces should be easily readable and allow for intuitive navigation by community health workers. Sufficient initial and ongoing training should be provided. In developing digital workflows, the extra burden of digital data entry should be weighed against the benefits and time savings of automated data aggregation and report generation.

x) Engage actively with international benchmarking processes for algorithmic validation, explainability and accountability.

One of the concerns highlighted in our interviews was the lack of standards to ensure the quality and safety of AI tools. While some require validation by US or EU bodies, not all do. AI medical applications will bring a whole host of new ethical and regulatory challenges. Diagnostic errors are a serious threat to healthcare quality and safety. Moreover, for scenarios in which humans are removed from the decision-making process altogether, clear accountability mechanisms need to be put in place.

To contribute to addressing these concerns, we recommend that all actors engage with the international benchmarking process established by WHO and the International Telecommunication Union (ITU).[201] This joint WHO-ITU Focus Group on AI for Health aims to produce a 'reliable, robust and independent evaluation system that can demonstrate the quality of AI models, but will also provide an independent test dataset for model validation consistent with best-practice recommendations for reporting multivariable prediction models in health'. Any outcome arising from this endeavour will be an important step towards developing regulatory (or at least pre-regulatory) frameworks for AI tools.

xi) Establish a globally accessible online health information hub, akin to the UK's National Health Service (NHS) website.

One of the key challenges of widespread internet use is the phenomenon of misinformation. This is commonly discussed in the context of democracy and elections, but presents a very significant threat to healthcare. Inaccurate medical advice can have serious effects on individuals and populations. A prominent example of this is the so-called 'anti-vax' movement giving rise to unprecedented levels of 'vaccine hesitancy', one of the top 10 threats to global healthcare as determined by WHO.

[201] Slachta, A. (2019). WHO, ITU establish benchmarking process for AI in medicine. Available at: https://www.aiin.healthcare/topics/business-intelligence/who-itu-establish-benchmarking-process-ai (accessed 19 July 2019).

Websites and applications that disseminate health advice are not uncommon. However, there is a challenge that, without robust regulation, they may dispense harmful and unverified advice. As more and more individuals in LLMICs gain internet access, this phenomenon is likely to grow. While this issue will be complex to solve, the creation of an accessible, multilingual, online health information hub, akin to the UK's NHS website, could go some way towards establishing a trusted source of medical advice. As an internationally recognised body, we recommend that WHO take responsibility for establishing such a hub.

xii) Consider the ethical challenges of AI in healthcare as set out in Future Advocacy's 2018 report, *Ethical, Social and Political Challenges of Artificial Intelligence in Health.*

The development of AI health tools brings a host of ethical, social and political challenges, as the 2018 report outlined.[202] Some of these will be experienced the world over, but others may hit hardest in the often under-regulated environments of LLMICs. All actors should seriously consider the specific risks of operating in these contexts.

[202] Fenech et al. (2018). *Ethical, Social and Political Challenges of Artificial Intelligence in Health.* Available at: https://futureadvocacy.com/wp-content/uploads/2018/04/1804_26_FA_ETHICS_08-DIGITAL.pdf, (accessed 19 July 2019).

Appendix
List of interviewees

Fazilah Allaudin, Senior Deputy Director, Planning Division of the Ministry of Health, Malaysia

Hila Azadzoy, Managing Director of the Global Health Initiative, Ada Health

Runbin Dong, Digital Transformation, Prudential Corporation Asia, former Head of Product at Prenetics

Delmiro Fernandez-Reyes, Reader in Digital Health and Intelligent Systems, University College London, Adjunct Reader in Paediatrics, College of Medicine, University of Ibadan, Nigeria

Skye Gilbert, Executive Director, Digital Square, PATH

Jonathan Jackson, Co-Founder and CEO of Dimagi, Co-Founder of Cogito Health

Antoine Geissbuhler, Professor and Director of Digital Transition, eHealth and Innovation at Geneva University

Siddhartha Jha, Program Manager for Digital and AI at Fondation Botnar

Akaliza Keza Ntwari, Founder of Girls in ICT Rwanda, Member of UN Secretary-General's High-Level Panel on Digital Cooperation

Alex Krasodomski, Director of the Centre for the Analysis of Social Media

Pratap Kumar, Founder and CEO of Health-E-Net Limited, Senior Lecturer at Strathmore University, Nairobi

Lesley-Anne Long, Consultant, former Director of Digital Square, former Global Director of mPowering Frontline Health Workers

Edmond Ng, Senior Statistical Analyst at the London School of Hygiene & Tropical Medicine

Carlos Otero, Head of Clinical Informatics at the Hospital Italiano de Buenos Aires, co-Chair of the Working Group on Health Informatics for Development, International Medical Informatics Association

Marcel Salathé, Associate Professor at École Polytechnique Fédérale de Lausanne, Head of Digital Epidemiology Lab

Merrick Schaefer, Digital Health Lead at USAID's Global Development Lab

Dr Raymond Francis Sarmiento, Director of the University of the Philippines Manila National Telehealth Center, 2019 National Academy of Science and Technology (Philippines) Outstanding Young Scientist for Public Health Informatics

Nina Schwalbe, CEO, Spark Street Consulting, former Principal Health Advisor at UNICEF

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Technology & Inclusive Development