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COMMENTARY

Transforming Care and Outcomes with Digital Health Through and Beyond the Pandemic

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The Covid-19 pandemic has magnified fault lines in local, national, and global health systems, while simultaneously reinforcing the importance of fostering health system resilience. Nowhere has this been more obvious than with digital health solutions, which, for decades, have been much slower than promised in enabling excellence. The pandemic has greatly accelerated use of digital health in areas such as public health surveillance and virtual care in many countries, highlighting some of the many ways in which digital health can strengthen and enhance health care planning and delivery, as well as enable safer, higher-quality care. The stress test of the pandemic has also brought into focus gaps and challenges, including important health IT and governance barriers. Drawing on real-world international examples, the authors explore existing solutions that have been used in islands of excellence and can now scale widely; they also examine emerging opportunities to accelerate the transition to data-enabled health care systems that respond to everyday care needs and those of future pandemics. The article focuses on public health and clinical solutions, rather than those that support the research enterprise, logistics, or solutions not specific to health care. Proactive and pervasive use of effective digital health solutions is key to progress on the path to safer, higher-quality care for all, but progress also will depend on addressing persistent barriers to transformative change and alignment with overall health and care strategies.

Never in our lifetimes has there been a more collective focus on health — or more awareness of the power of information to shape patterns of health and well-being from individual to societal levels. Covid-19 has accelerated uptake of digital health globally, even though barriers and concerns about risks continue to slow adoption. The pandemic has put a spotlight on the need for new models of care and more rapid information flow, leading to rapid growth in digital health use — particularly virtual care — in many countries. At the same time, the pandemic has exposed substantial disparities in care delivery and outcomes, including in high-income countries.[1]

Despite such challenges, the proactive and pervasive use of effective digital health solutions is key to progress on the path to safe, higher-quality care, just as digital solutions have been transformative in other sectors. However, the nexus between *digital health* and*health care quality* is complex. Islands of progress — like the use of remote monitoring during Covid-19, the leveraging of artificial intelligence (AI) in imaging, the application programming interfaces (APIs) with electronic health records (EHRs) that enable more integrated care, and the opening of health records to patients — offer glimpses of the potential for health care transformation, but barriers to progress are also significant.

For the purposes of this paper, we have adopted the definition of *digital health* offered by the World Health Organization Regional Office for Europe: "*A broad umbrella term encompassing e-health, as well as developing areas such as the use of advanced computer sciences . . . [which] plays an important role in strengthening health systems and public health, increasing equity in access to health services, and in working towards universal health coverage.*"[2]

We offer an international perspective on the ways digital health has and has not been successfully deployed in the context of the pandemic. Our analysis includes both established technologies that have been selectively deployed, but have potential to scale, as well as emerging technologies that show promise for the future. We focus on public health and clinical solutions, rather than those that support the research enterprise, logistics, or social media and other tools not specific to health care. We review key barriers to more widespread deployment and effective use, as well as the potential of these digital health solutions to accelerate improvements in health and care in the context of planning for everyday care needs and future pandemics.

The Pandemic as a Stress Test for Digital Health

The potential for digital health to enable excellence in health care has been discussed for decades but realizing this promise has been much slower than hoped. The underlying barriers to progress — such as challenges related to strategic alignment and leadership, governance, capacity, change management, and solution design — are not new,[3] but have been highlighted by the urgent demands of the pandemic.[4]

Digital health is often separate from, and poorly integrated with, broader health and health care strategies. Alignment of leadership, goals, and implementation is needed to fully realize the potential power of digital health.[3] Throughout the pandemic, data systems have been implemented within days or hours to support urgent operational or policy decisions and to enable basic and clinical research, often leveraging existing research infrastructure and networks. On the other

hand, agreement on key information and indicators was not core to most national pandemic preparedness plans. This, of course, delayed the data governance, data flows, and dashboards needed to inform decision-making in near real time.

In the 21st century, robust information governance is pivotal. Digital solutions and information ecosystems evolve rapidly, making it challenging for governance structures and processes to keep pace. Inadequate and out-of-date information governance slows progress. For instance, in Scotland, numerous layers of permissions were required to populate its national pandemic surveillance platform,[5] whereas Israel leveraged established governance frameworks and data systems to accelerate surveillance, outbreak management, and vaccinations.[6] Likewise, the pandemic put health systems' capacity for learning to the test. Rapidly evolving pandemic science stretched capacities for knowledge synthesis and for moving from data to decision to implementation.

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The pandemic also highlighted long-standing digital determinants of health. This included gaps in the digital health literacy of the public, clinicians, and policy makers, as well as equity concerns.[7] While virtual care enabled expanded access to care, particularly during periods of high community spread, it was more difficult to flip to virtual care in regions with poor broadband or limited access to technology. Furthermore, existing data systems did not always track key data (e.g., ethnicity) needed to identify and address inequities in infection risk, severity of outcomes, and pandemic response.

The quality of underlying technology and infrastructure also matters. Poorly designed or integrated solutions, including underinvestment in people-centered design, were seen in many countries.[8] This included limitations of existing systems that were not sufficiently nimble to respond to evolving needs for pandemic response. A lack of focus on change management — a persistent challenge in pre-pandemic times — has also been an issue over the past 2 years. Finally, medical devices, electronic health records, and health-sector communications systems are among the critical areas that have been targeted by cyber criminals. Already common pre-pandemic, cyberattacks have increased significantly in recent years, with health care organizations as leading targets.[9] Cyber resilience in the health sector will require continued focus going forward, from improvements in the foundations of data and information governance and education to comprehensive systems for prevention of, and response to, cyberattacks.[10]

Optimizing Current Digital Health Solutions

Significant investments have been made in provider-facing, patient-facing, and population-based digital health solutions. They form the basis of a robust infrastructure for connected health and care now and into the future.

During the pandemic, the importance of a nimble and responsive digital health ecosystem that can enable resilient health systems has become clear. For instance, areas with an existing infrastructure that could be leveraged to track patterns of infection and vaccination, deliver test results in a timely way, or facilitate person-centered care with virtual care solutions were positioned to respond more quickly to evolving needs than those without this capacity. Most countries, regions, and health systems were able to leverage at least some existing solutions, such as electronic health records, but all had to develop new capabilities rapidly, too, such as those needed to enable rapid and effective vaccine sourcing and distribution. As a result, there are now opportunities for shared learning about key aspects of digital health to support health system transformation over the next decade and beyond.

Provider-Facing Electronic Health Records

Adoption of EHRs by health care providers is one of the largest transformations of the past 2 decades, one still in progress in many developed countries. Comprehensive EHRs are not merely documentation tools, but also include functions such as order entry, results management, decision support, and embedded clinical connectivity and virtual care tools. A range of functions have been shown to improve patient safety and quality,[11] while other design characteristics have been shown to contribute to clinician burnout.[12]

Globally, there has been steady growth in the adoption of EHRs, but progress has not been evenly distributed, even in high-income countries. For instance, federal incentive programs in the United States spurred adoption, but use of advanced EHR functions lags, particularly in small, rural hospitals.[13]

To optimize value, EHRs in the future need to evolve. Integration into clinical workflow and settings is key, potentially improving clinician and patient experience, as well as reducing risky work-arounds.[14] Voice-enabled capabilities may also improve provider experience and minimize demands that contribute to burnout, a particular challenge in the United States.[15] Finally, privacy-sensitive access to full health records across providers, coupled with improved search and knowledge management tools, would allow clinicians to access and use needed information more efficiently.

Computerized Decision Support

Computerized decision-support systems offer considerable potential to support clinicians to process large volumes of information, facilitating effective decision-making. These systems typically sit on top of EHRs. They have been most widely deployed for prescribing and medication management. While there is a growing body of evidence to indicate their effectiveness, there remain persistent concerns about issues such as variable clinical impact and alert fatigue.[16] It is also critical that organizations invest to maintain the underlying knowledge engines, which can quickly become out of date.

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Clinical Data Exchange

While clinical data exchange is a broadly held goal, progress varies across countries.[17,18] A few — such as Denmark, Estonia, Israel, Singapore, and Taiwan — have made progress in country-wide information exchange, but most others have limited systemwide transfer of health information. Key issues in enabling data exchange include agreeing on standards for the most important types of clinical data (e.g., medications, laboratory tests, problems and diagnoses, and images) and on what should be included in shared clinical data summaries.

The United Kingdom made some of the earliest broad progress in this area with the Spine, which is a system developed and maintained by the National Health Service through its Digital Delivery Centre. The Spine supports the IT infrastructure for health and social care in England, joining together health care IT systems in more than 20,000 organizations. This enables secure sharing of the electronic prescription service, the summary care record with a synopsis of care a patient has received, and the e-referral service.

In contrast, the United States set up a more decentralized approach. Progress was made in terms of establishing standards for key types of clinical data, such as medications, problems, laboratory tests, and radiological data. However, exchanges have been set up at the state and local levels. With some notable exceptions, these have been largely unsuccessful. A key issue appears to be that payers and employers benefit more than health care providers, but most have not been willing to invest to support the exchanges.[13]

As early adopters have demonstrated, moving clinical data exchange forward takes focus and leadership. Crises like the Covid-19 pandemic have the potential to accelerate these efforts. Many of the barriers are more policy related than technical. Key steps are becoming clear, including: (1) agreeing on standards and information governance for the main types of clinical data; (2) setting up clinical data summaries and establishing agreement for what should be included; (3) developing privacy-sensitive data exchanges to which data can be sent so that it can then be available to those who need it next and entered into central databases when appropriate; and (4) facilitating integration with clinical workflows.

Patient Portals

Patient portals represent an important "front door" to the EHR and clinical services for patients. In the United States, patient portal access was a key part of the Meaningful Use program, in which substantial incentives were given to providers using health care IT. But while more than 90% of patients have access in theory, far fewer patients have used these portals. Adoption rates in other countries vary considerably. A 2020 Commonwealth Fund survey found that 6%–53% of adults

across 11 countries reported having viewed online or downloaded their health information such as visit summaries or test/laboratory results in the past 2 years.[19]

Virtual Care

Many visits do not need to be conducted in person and can be performed in ways that are more efficient for both patients and providers through virtual modalities. This is true in a variety of settings, from rural primary care to intensive care.

At the outset of the pandemic, while some visits were postponed, some visits were shifted from in person to virtual, often aided by temporary changes in reimbursement policies. For instance, in April 2020, virtual care accounted for 35% of ambulatory visits in Australia, 42% for a large insurer in the United States (based on OptumLabs Data Warehouse data), and 77% in Ontario, Canada.[20] That said, the bulk of such remote visits happened by telephone, rather than video conference.[21-23] A recent Organisation for Economic Co-operation and Development (OECD) report based on interviews with experts in 13 countries found that the most common benefits reported from telemedicine were more cost-effective care (9 of 13 countries), improved quality of care (7 of 13), and improved access and reduction in inequality of supply (6 of 13).[24]

We have an opportunity to consider how best to leverage virtual care going forward. Sustained changes in reimbursement policies, clinical care pathways, and digital health literacy are among the challenges to be considered. This includes optimizing the mix of in-person care, as well as synchronous and asynchronous virtual care options in ways that support safety and quality. Equity is also a critical consideration because virtual care can both improve or worsen health disparities. For example, the ability to seek care without taking as much time off work or incurring travel costs may improve access. However, access to broadband may not be available for lower-income, marginalized, and rural populations, which can affect access to virtual care.

> *"Many of the barriers are more policy related than technical."*

Population-Based Data Repositories

The Covid-19 pandemic has highlighted the crucial importance of appropriate population-based digital and data infrastructures to support health decisions. Some functions, such as the need to understand transmission of infectious diseases in schools and or through international travel, extend beyond the boundaries of health care and national borders. Examples of innovations in this area include Covid-19 dashboards (such as those produced by Our World in Data), the development and deployment of applications to enable contact tracing, and the development and validation of population-based risk stratification algorithms to support decisions on prioritization of vaccines and shielding of vulnerable groups.[25]

Achieving the speed and breadth of information needed to support public health decisions has been challenging. Individuals generally do not have complete oversight of the range of data sets available within health systems, let alone at a regional or global level. There is, furthermore, no

consolidated understanding of their governance arrangements, costs to access data, or who has expertise and experience with using these data sets. Also, the value of data sets typically is greatly increased as they are linked together (e.g., integrating data on vaccination, contact tracing, and hospitalizations), but this continues to prove challenging to implement. A 2019 OECD study found that 13 of 19 countries had key national health and health care data sets with a unique personal identifier that could be used for approved linkages, with 10 saying that linkages take place on a regular basis with most of these data sets.[3]

To help overcome these issues, there is growing interest in creating data gateways, such as the Health Data Research Innovation Gateway(managed by Health Data Research UKin collaboration with the UK Health Data Research Alliance), which encourages data custodians to provide comprehensive meta-data on their data sets, the opportunity to deposit data within Trusted Research Environments (also known as*safe havens*), and a one-stop mechanism for investigators to request stand-alone or linked data sets. Such data gateways and repositories should be staffed by teams with a range of expertise, including data governance, data wrangling, processing, linkage, analysis, and visualization so that they can service the needs of novice to expert users.

Public Health Solutions

The global pandemic has highlighted effective uses of bioinformatics and digital health by individuals, public health professionals, governments, and others, as well as large gaps in their ability to support modern public health practice and adapt dynamically to changing situations.[26] Disease surveillance, risk communication, testing, vaccine development and distribution, and health workforce management are among the critical applications. In some cases, it has been possible to leverage existing solutions; others were not fit-for-purpose.

There are also significant differences in surveillance and other public health solutions across and within countries. For example, in a study of 15 federal democracies, no country met all elements of a Covid-19 data quality index based on World Health Organization reporting guidance, with scores varying from 0 (Papua New Guinea) to 0.75 (United States), where 0 indicates meeting no elements of the index and 1.0 indicates meeting all elements.[27] These and other experiences during the pandemic suggest a road map to advance digital health information solutions and the associated*infostructure* to strengthen future public health preparedness, practice, and management immediately and over the next decade.[28]

Developing Technologies with Promise

In addition to leveraging current technologies, emerging technologies have been considered during the pandemic, with some being deployed at scale in a few jurisdictions. There is also potential for use of these and similar technologies to support future health care transformation, but success is not guaranteed. Attention to safe and effective use in an integrated way to support health goals will be required to optimize progress.

Artificial Intelligence and Machine Learning

Artificial intelligence (AI) and machine learning represent potentially powerful technologies for improving care in a variety of ways. AI is the concept that machines can carry out tasks in ways that are "smart." In machine learning, machines have access large quantities of data to allow them to learn, in either supervised or unsupervised ways.[29] Both take large quantities of disparate data and develop insights from the data, with the aim of making care better. Both also raise important questions about governance, ethics, and safety. Some of the most advanced work so far has been in radiology, e.g., using artificial intelligence to interpret retinal scans and mammograms. In this pandemic, AI was explored early on but only used in a limited way to inform public health decisions and policy.[30]

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Sensing Technologies

Sensing technology creates abundant data that can be used to predict and prevent as well as improve care. For instance, wearable sensors can collect continuous vital signs or other parameters, such as tremor for Parkinson's disease or cough characteristics for asthma. Researchers have shown that activity tracking and health monitoring via consumer wearable devices may be used for the large-scale, real-time detection of Covid-19, often pre-symptomatically.[31] Remote patient monitoring has also been used to support home treatment and follow-up of patients with Covid-19.[32]

Other sensors will monitor the environment, such as in-hospital or home. For example, sensors that rely on cameras and on pulse-Doppler radar could be used in homes or care facilities to collect data about mobility to predict falls.[33] Regardless of the specific technology used, sensors, whether wearable or not, have the potential to play a role in our ability to provide more effective and efficient care when integrated into care plans.

Apps

While apps hold great potential for improving population health and helping people with chronic diseases manage their conditions, the current situation is somewhat chaotic. Although several hundred thousand health apps are available, quality and information governance vary significantly, coverage of many of the most important chronic conditions is sparse, and most apps are not tailored for high-cost, high-needs populations. Some novel approaches are currently being undertaken in this area. For example, Germany has a program that enables vendors to get paid by insurance for apps that produce documented improvement in outcomes.[34]

During the pandemic, Covid-19–specific apps have also been developed for information access, testing, contact tracing, vaccination booking, and other purposes. In addition, many regions and countries are now implementing or considering vaccine documentation or credentialling apps (often referred to aspassports) in areas such as air travel and large events. These apps are not without controversy and design challenges, even though vaccine records have been used since smallpox vaccination became widespread.

Precision Medicine

Precision medicine — giving specific therapies and tests to individuals in ways that consider their individual genetic, environmental, and lifestyle factors of the patient — offers great promise. The cost of whole-genome sequencing is falling rapidly, and it is likely that complete sequences will be available for many or most patients in developed countries soon. Leveraging these data in real time, however, will be nontrivial as whole genomes include huge amounts of information about single individuals, and accessing this in real time will require advances in computing. There also are important ethical, economic, and clinical considerations.

With better understanding of human physiology down to the molecular level, we will be able to tailor future diagnostic and therapeutic decisions to specific patients. At the same time, other factors help determine what diseases develop and respond to treatment, including variability in our gut microbiome and our environment and lifestyle. As we appreciate these complexities, we will need to look across data sources from various fields, or *omics*, in order to truly be able to predict and prevent, or provide person-specific care in a way that reflects their unique context.

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Virtual/Augmented Reality

Virtual and augmented reality (also termed *extended reality* or*XR*) also has the potential to make a significant mark on health care. Considered an entertainment tool for many years, it has started making its way into the health sector, such as with the use of XR for rehabilitation. The potential to immerse the patient in an entertaining experience was found to accomplish higher adherence and improvement in performance.[35] Another use of XR that is growing in popularity is training of health care practitioners. Recent years have also shown us the advantages of XR for surgical navigation, showing reduced surgery time and exposure to radiation as well as potentially improving safety. Finally, there is potential to treat patients using XR for such conditions as pain management, depression, and anxiety.

Robotics

Robots are beginning to impact on many aspects of day-to-day life and offer considerable opportunities to automate aspects of health and social care delivery. Yet, in the context of the current pandemic, deployment of robotic solutions has been minimal other than in the context of supporting laboratory testing and vaccine production/distribution. Other areas where deployment has been proposed or implemented include in cleaning of health care facilities, taking of swabs, and delivery of vaccinations.[36,37] A particular challenge that has limited their utility is in sterilizing the robots so as to minimize the risk that they contribute to nosocomial transmission.

Cloud Solutions

The cloud will be exceptionally important going forward, as it seems likely that most information will be stored there soon. The costs of keeping data in the cloud have been substantial but are coming down rapidly. Clearly, issues of security and privacy are pivotal in managing health information. Cloud solutions, which are already ubiquitous outside health care, have been important in the health sector during and prior to the pandemic, and further rapid adoption in the health sector seems inevitable, including to enable AI and connected care.[38]

Looking Ahead

The pandemic exposed the strengths and fault lines in public health and health care globally, including pressure to rapidly accelerate the use of digital solutions in the health sector. Some pre-pandemic solutions and governance structures proved fit for purpose, while others were abandoned in the face of urgent need. Likewise, although the promise of some emerging technologies has become clearer, many have remained niche solutions. The challenges we face will be to develop data resources and tools that enable effective decision-making and address barriers limiting the use of emerging technologies. Only thus will we achieve the fundamental changes required to support the digital transformation of health care beyond the current pandemic.

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