Applications of digital technology in COVID-19 pandemic planning and response

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With high transmissibility and no effective vaccine or therapy, COVID-19 is now a global pandemic. Government-coordinated efforts across the globe have focused on containment and mitigation, with varying degrees of success. Countries that have maintained low COVID-19 per-capita mortality rates appear to share strategies that include early surveillance, testing, contact tracing, and strict quarantine. The scale of coordination and data management required for effective implementation of these strategies has—in most successful countries—relied on adopting digital technology and integrating it into policy and health care. This Viewpoint provides a framework for the application of digital technologies in pandemic management and response, highlighting ways in which successful countries have adopted these technologies for pandemic planning, surveillance, testing, contact tracing, quarantine, and health care.

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Introduction

COVID-19, an infectious disease caused by the novel severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), is a global pandemic. With high transmissibility, a case fatality rate greater than 1%, and no effective antiviral therapy or vaccine, the mainstay of pandemic management has been containment and mitigation.[1] However, despite relying on established public health principles, countries across the world have had varying degrees of success in managing the burden of COVID-19.

Digital health technology can facilitate pandemic strategy and response in ways that are difficult to achieve manually (figure).[2] Countries such as South Korea have integrated digital technology into government-coordinated containment and mitigation processes—including surveillance, testing, contact tracing, and strict quarantine—which could be associated with the early flattening of their incidence curves.[3] Although South Korea has incurred only 0·5 COVID-19 deaths per 100 000 people,[3,4] the USA, with three times as many intensive care unit beds per 100 000 people and ranked number one in pandemic preparedness before the COVID-19 pandemic, has sustained ten times as many deaths per capita.[3,4]

This Viewpoint provides a framework for the application of digital technologies in pandemic management and response, highlighting ways in which successful countries have adopted and integrated digital technologies for pandemic planning, surveillance, testing, contact tracing, quarantine, and health care (table). The panel provides a brief glossary explaining some of these concepts.

Planning and tracking

Big data and artificial intelligence (AI) have helped facilitate COVID-19 preparedness and the tracking of people, and so the spread of infection, in several countries. Tools such as migration maps, which use mobile phones, mobile payment applications, and social media to collect real-time data on the location of people, allowed Chinese authorities to track the movement of people who had visited the Wuhan market, the pandemic's epicentre.[5,6] With these data, machine learning models were developed to forecast the regional transmission dynamics of SARS-CoV-2 and guide border checks and surveillance.[6,7]

As soon as China reported the outbreak, Taiwan initiated health checks for airline travellers from Wuhan, integrating data from immigration records with its centralised, real-time national health insurance database.[8] This integration allowed health-care facilities to access patients' travel histories and identify individuals for SARS-CoV-2 testing and tracking.[8] Taiwan's proximity to Wuhan, China, made the region particularly susceptible to COVID-19, but its efficient use of big data is credited for the low number of cases and deaths.[4,8]

In Sweden, authorities have developed a platform for health-care workers to report real-time data on volumes of patients with COVID-19, personal protective equipment, staffing, ventilator usage, and other resource information.[9] This information has been shared nationwide with health-care authorities to track the status of facilities, allocate health-care resources, and increase hospital bed capacity.[9]

The need to track COVID-19 has fuelled the innovation of data dashboards that visually display disease burden. UpCode uses data provided by the Singapore Ministry of Health to depict infection trends across age, sex, and location, and to plot the recovery time of infected individuals.[10] The Johns Hopkins University (MD, USA) coronavirus dashboard and the web-based platform HealthMap provide up-to-date visuals of COVID-19 cases and deaths around the globe.[4] AI algorithms allow the effect of the climate to be incorporated into the projections.[11]

AI is not without limitations and requires training with COVID-19 datasets. Most of the AI predictive models so far have used Chinese samples, which might not be generalisable.[12] In addition to the absence of historical training data, social media and other online traffic have created noise in big-data sets, potentially producing overfitted or so-called lucky good fit models.[12–14] This noise must be filtered before accurate trends and

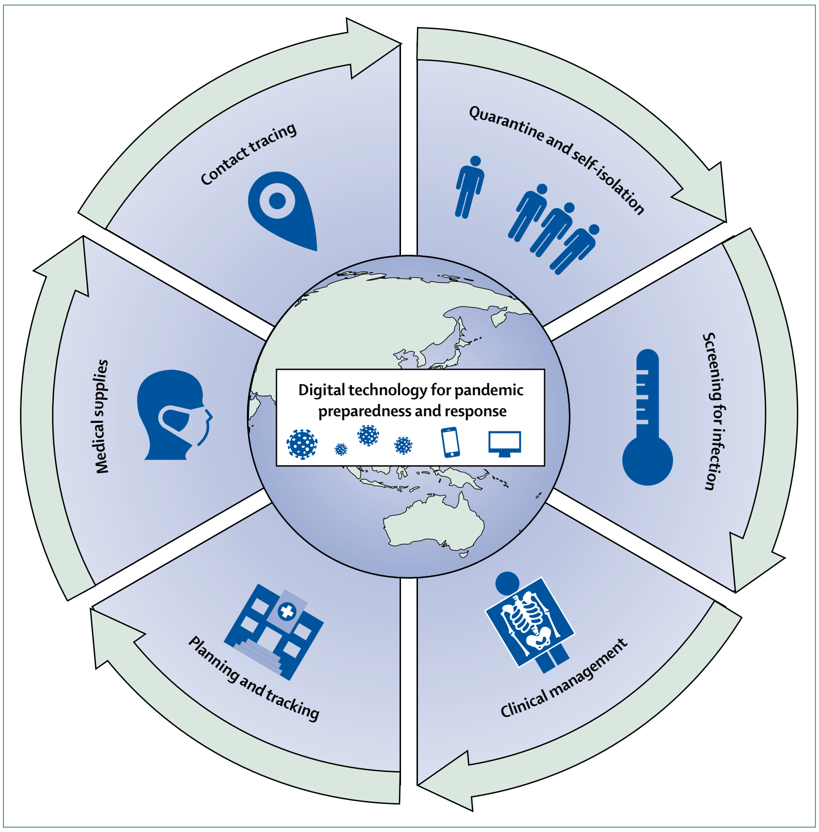

Figure: **Digital technology as a tool for pandemic preparedness and response**

predictions can be discerned. The accuracy, validity, and reliability of each AI forecast should be assessed when interpreting projections.[12,15]

Screening for infection

China uses free, web-based and cloud-based tools to screen and direct individuals to appropriate resources.[7] High-performance infrared thermal cameras set up in Taiwanese airports are used to capture thermal images of people in real time, rapidly detecting individuals with a fever.[8] In Singapore, people have their temperature measured at the entries of workplaces, schools, and public transport. The data from the thermometers is tracked and used to identify emerging hot spots and clusters of infection where testing could be initiated.[10]

Unlike most other countries, Iceland has launched widespread testing of asymptomatic individuals.[16] Using mobile technology, Iceland collects data on patient-reported symptoms and combines these data with other datasets such as clinical and genomic sequencing data to reveal information about the pathology and spread of the virus.[16] This approach has added to the knowledge base regarding the prevalence and transmission of asymptomatic COVID-19. To date, Iceland has had the highest per-capita testing rate and among the lowest per-capita COVID-19 mortality rate.[16] Other countries offering widespread testing include Germany and South Korea.[17,18]

In the USA, a private company has used digital thermometers to collect real-time data on clusters of febrile illness,[19] and a national study is capturing resting heart rate with a smartwatch application, which could be able to identify COVID-19 emerging outbreaks.[20] These initiatives are either enterprise-driven or investigational and are not integrated into policy and practice.

Systematic screening technologies are expensive and require trained personnel, restricting their uptake in many countries.[21] The incubation period and the relatively high prevalence of asymptomatic infection compared with other infectious diseases limits the effectiveness of digital systems that screen vital signs or self-reporting of symptoms.[21,22] Researchers at the European Centre for Disease Prevention and Control estimate that a majority of passengers from Chinese cities would not be detected by screening because of these factors.[23]

Contact tracing

South Korea has implemented tools for aggressive contact tracing, using security camera footage, facial recognition technology, bank card records, and global positioning system (GPS) data from vehicles and mobile phones to provide real-time data and detailed timelines of people's travel.[18] South Koreans receive emergency text alerts about new COVID-19 cases in their region, and people who could have been in contact with infected individuals are instructed to report to testing centres and self-isolate.[14] By identifying and isolating infections early, South Korea has maintained among the lowest per-capita mortality rates in the world.[4,18]

Singapore has launched a mobile phone application that exchanges short-distance Bluetooth signals when individuals are in proximity to each other. The application records these encounters and stores them in their respective mobile phones for 21 days. If an individual is diagnosed with COVID-19, Singapore's Ministry of Health accesses the data to identify contacts of the infected person.[10] Like South Korea, Singapore has maintained one of the lowest per-capita COVID-19 mortality rates in the world.[4,10]

Germany has launched a smartwatch application that collects pulse, temperature, and sleep pattern data to screen for signs of viral illness.[17] Data from the application are presented on an online, interactive map in which authorities can assess the likelihood of COVID-19 incidence across the nation.[17] With widespread testing and digital health interventions, Germany has maintained a low per-capita mortality rate, relative to other countries, despite a high prevalence of cases.[4,17]

Contact tracing applications are not without pitfalls.[24] Not all exposure requires quarantine, such as when the exposed individuals are wearing personal protective equipment or are separated by thin walls penetrable by

	Functions	Digital technology	Countries	Advantages	Disadvantages
Tracking	Tracks disease activity in real time	Data dashboards; migration maps; machine learning; real-time data from smartphones and wearable technology	China; Singapore; Sweden; Taiwan; USA	Allows visual depiction of spread; directs border restrictions; guides resource allocation; informs forecasts	Could breach privacy; involves high costs; requires management and regulation
Screening for infection	Screens individuals and populations for disease	Artificial intelligence; digital thermometers; mobile phone applications; thermal cameras; web-based toolkits	China; Iceland; Singapore; Taiwan	Provides information on disease prevalence and pathology; identifies individuals for testing, contact tracing, and isolation	Could breach privacy; fails to detect asymptomatic individuals if based on self-reported symptoms or monitoring of vital signs; involves high costs; requires management and regulation; requires validation of screening tools
Contact tracing	Identifies and tracks individuals who might have come into contact with an infected person	Global positioning systems; mobile phone applications; real-time monitoring of mobile devices; wearable technology	Germany; Singapore; South Korea	Identifies exposed individuals for testing and quarantine; tracks viral spread	Could breach privacy; might detect individuals who have not been exposed but have had contact; could fail to detect individuals who are exposed if the application is deactivated, the mobile device is absent, or Wi-Fi or cell connectivity is inadequate
Quarantine and self-isolation	Identifies and tracks infected individuals, and implements quarantine	Artificial intelligence; cameras and digital recorders; global positioning systems; mobile phone applications; quick response codes	Australia; China; Iceland; South Korea; Taiwan	Isolates infections; restricts travel	Violates civil liberties; could restrict access to food and essential services; fails to detect individuals who leave quarantine without devices
Clinical management	Diagnoses infected individuals; monitors clinical status; predicts clinical outcomes; provides capacity for telemedicine services and virtual care	Artificial intelligence for diagnostics; machine learning; virtual care or telemedicine platforms	Australia; Canada; China; Ireland; USA	Assists with clinical decision-making, diagnostics, and risk prediction; enables efficient service delivery; facilitates patient-centred, remote care; facilitates infection control	Could breach privacy; fails to accurately diagnose patients; involves high costs; equipment may malfunction

Table: **Digital technology initiatives used in pandemic preparedness and response**

mobile phone signals.[24] On the other hand, relevant exposure could be missed when individuals do not carry their mobile phones or are without mobile service.[24] In addition, researchers at Oxford University (UK) have suggested that 60% of a country's population would need to use a contact tracing application for it to be an effective mitigation strategy.[25]

Quarantine and self-isolation

The indiscriminate lockdowns for infection control in several countries have had severe socioeconomic consequences. With digital technology, quarantine can be implemented in individuals who have been exposed to or infected with the virus, with less strict restrictions imposed on other citizens. China's quick response (QR) code system, in which individuals are required to fill out a symptom survey and record their temperature, allows authorities to monitor health and control movement.[7] The QR code serves as a COVID-19 health status certificate and travel pass, with colour codes representing low, medium, and high risk; individuals with green codes are permitted to travel unrestricted, whereas individuals with red codes are required to self-isolate for 14 days. China also uses AI-powered surveillance cameras, drone-borne cameras, and portable digital recorders to monitor and restrict the gathering of people in public.[7]

In Australia, international travellers were quarantined in hotels on arrival, with travellers from Wuhan quarantined off the Australian mainland. In new legislation, individuals breaching quarantine will be forced to wear tracking devices, with fines levied for further instances of breaking the restrictions.[26] In Taiwan, electronic monitoring of home-quarantined individuals is facilitated through government-issued mobile phones

***Panel*: Glossary of pandemic terms**

- Contact tracing: the process of identifying people who might have come into contact with an infected person
- Containment: the use of available tools to restrict the spread of infection
- Lockdown: the active restriction and control of the movement of people by governments
- Incidence: the number of individuals who develop a condition during a particular time period
- Mitigation: the action of reducing the severity of the pandemic
- Per-capita mortality: a measure of deaths in a particular population, scaled to the size of that population
- Quarantine: the process of isolating and restricting the movement of potentially exposed or infected people
- Screening: assessing for signs of disease in an apparently asymptomatic population
- Testing: using medical procedures to confirm a diagnosis in individuals suspected of having a disease
- Tracking: monitoring the spread of infection across locations

tracked by GPS;[8] in the event of a breach in quarantine, this so-called digital fence triggers messages to the individual and levies fines.[8] In South Korea, individuals in self-isolation are instructed to download a mobile phone application that alerts authorities if they leave their place of isolation.[18] In Hong Kong, people in self-isolation are required to wear a wristband linked through cloud technology to a database that alerts authorities if quarantine is breached.[7] Iceland has launched a mobile phone solution to monitor individuals with COVID-19 and ensure that they remain in self-isolation.[16]

Mobile phone solutions for quarantine enforcement can be bypassed if individuals leave their quarantine location without their devices.[27] Self-reported surveys such as those used in QR code systems only work when individuals are symptomatic and report their symptoms accurately.[24] However, such technological innovations could provide benefits when used in combination with other strategies.[22]

Clinical management

AI can facilitate rapid diagnosis and risk prediction of COVID-19. A cloud-based AI-assisted CT service is used to detect COVID-19 pneumonia cases in China.[7] This technology processes CT images in seconds, differentiating COVID-19 from other lung diseases and speeding up the diagnostic process substantially.[7,11] COVID-Net, an open-source deep convolutional neural network design available to clinicians across the globe, can quickly detect COVID-19 cases from other lung diseases on chest x-rays.[28] Machine learning algorithms developed in China can predict the likelihood of developing acute respiratory distress syndrome and critical illness among infected patients.[7,28] These prediction models can guide clinical decision-making and resource allocation, identifying regions and hospitals in need of critical care resources and medical supplies.[7]

Virtual care platforms, using video conferencing and digital monitoring, have been used worldwide to deliver remote health care to patients as a means of reducing their exposure to SARS-CoV-2 in health-care institutions. In Canada, clinician-to-patient video visits have increased from approximately 1000 visits per day in February, 2020, to 14 000 per day by mid-May.[29] Countries such as the USA and Australia have also harnessed digital technology to provide remote care to patients with chronic conditions or with mild or moderate COVID-19 illness in their homes.[30,31] If implemented and delivered appropriately, virtual care can increase health-care access during the pandemic and after, but possible risks could include misdiagnoses, equipment malfunction, privacy breaches, and costs to the health-care system.[32,33]

Risks of digital technology

Digital health initiatives can amplify socioeconomic inequalities and contribute to health-care disparities. Digital technology typically involves the use of the internet and mobile phones. Although 4 billion people used the internet worldwide in 2019, usage was disproportionally higher in high-income areas than in low-income and middle-income areas (82% in Europe *vs* 28% in Africa).[34] Even within high-income countries, susceptible groups, such as those in low-income neighbourhoods or remote regions, might not have access to broadband signals, smartphones, or wearable technology such as smart-watches. To effectively implement digital technology globally, interventions should be tailored to the target regions; broadband access requires federal and private sector investment in technology and infrastructure.[35,36] At a regional level, subsidised mobile phone plans, loaner devices, free Wi-Fi hotspots, and training programmes could provide temporary solutions to these disparities.[37,38] In regions without infrastructure or sufficient funds to support cellular and data coverage, automated applications and devices that do not require continuous network access should be considered.[36]

Several digital health interventions, particularly those that track individuals and enforce quarantine, can infringe on privacy, while increasing risk among individuals with mental illness or restricted access to food or water. Government-implemented surveillance and control can instil fear and threaten civil liberties. To balance the need for contact tracing and privacy, European authorities have proposed that data be retained for only 14 days, the period of possible viral transmission, and that non-essential digital measures be lifted once the pandemic ends.[39] Some European countries are deploying an opt-in smartphone tracking application with anonymised data, no central database, and no GPS information.[40] The appropriate concerns about privacy and data security are potentially offset by facilitating a return to normal routine without a rebound in infections.

Conclusion

The integration of digital technology into pandemic policy and response could be one of several characteristic features of countries that have flattened their COVID-19 incidence curves and maintained low mortality rates. In the race to contain the spread of a highly transmissible virus, countries that have quickly deployed digital

Search strategy and selection criteria

We searched PubMed and Google to identify relevant English-language articles published up until May 21, 2020. Search terms included "coronavirus", "severe acute respiratory syndrome 2", "2019-nCov", "SARS-CoV-2", "SARS-CoV", "MERS-CoV", and "COVID-19" in combination with "digital health" and "technology". The search was not restricted by study design, and both peer-reviewed and grey literature were included.

technologies to facilitate planning, surveillance, testing, contact tracing, quarantine, and clinical management have remained front-runners in managing disease burden. The comprehensive responses of countries that have been successful at containment and mitigation can provide insight to other countries that are still facing a surge of cases.

Contributors

HGCV conceived the work, reviewed the literature, and wrote and edited the manuscript. SW reviewed the literature, and wrote and edited the manuscript. MAM and ET reviewed the literature and edited the manuscript. All authors approved the manuscript for submission.

Declaration of interests

We declare no competing interests.

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