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Mobilising digital technologies for public health in response to COVID-19

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Abstract

Digital technologies are being harnessed to support the COVID-19 public health response worldwide, including population surveillance, case identification, contact tracing, evaluation of interventions based on mobility data and communication with the public. These rapid responses leverage billions of mobile phones, large online data sets, connected devices, relatively low-cost computing resources and advances in machine learning and natural language processing. This review aims to capture the breadth of digital innovations for the public health response to COVID-19 worldwide, their limitations, barriers to implementation, including legal, ethical, privacy, as well as organisational and workforce barriers. The future of public health is likely to become increasingly digital, and we review the need for alignment of international strategies for the regulation, evaluation and use of digital technologies to strengthen pandemic management, and future preparedness for COVID-19 and other zoonotic infections.

Introduction

COVID-19, a previously unknown respiratory illness caused by SARS-CoV-2[1,2], was declared a pandemic by the World Health Organization (WHO) on 11 March 2020, less than three months after cases were first detected. With now over 9.8 million confirmed cases and more than 495,000[3] deaths recorded worldwide, there are grave concerns about the global health, societal, and economic impacts of this virus, particularly on vulnerable and disadvantaged populations, and in low- and middle-income countries (LMICs) with fragile health systems[4,5]. At the time of writing, 7.1 billion people live in countries that have had significant travel and social restrictions[6].

Like outbreaks and pandemics before it, controlling the COVID-19 pandemic rests on the detection and containment of clusters of infection and the interruption of community transmission to mitigate the impact on human health. During the plague outbreak that affected fourteenth century Europe, isolation of affected communities and the restriction of population movement were used to avoid further spread[7]. These public health measures for outbreak response remain relevant today, including surveillance, rapid case identification, interruption of community transmission, and strong public communication. Monitoring how these measures are implemented and their impact on incidence and mortality is essential.

All countries are required by the International Health Regulations (2005)[8] to have core capacity to ensure national preparedness for infectious hazards that have the potential to spread internationally. Research and development of new methods and technologies to strengthen these core capacities often occurs during outbreaks when innovation is an absolute necessity[9]. During the SARS outbreak, Hong Kong identified clusters of disease following the use of electronic data systems[10]. During the Ebola outbreaks in West Africa, mobile phone data was used to model travel patterns[11] and hand-held sequencing devices permitted more effective contact tracing and a better understanding of the dynamics of the outbreaks[12]. Similarly, digital technologies also have been deployed in the COVID-19 pandemic[13,14] to strengthen each of the four public health measures listed above.

The digital revolution has transformed many aspects of our lives. As of 2019, 67% of the global population subscribe to mobile devices, of which 65% are smartphones - with the fastest growth in Sub-Saharan Africa[15]. In 2019, 204 billion apps were downloaded[16], and as of January 2020, 3.8 billion people actively use social media[17].

Here we critically review how digital technologies are being harnessed for the public health response to COVID-19 worldwide. We discuss the breadth of innovations, their limitations, barriers to implementation, including legal, ethical, privacy, as well as organisational and workforce barriers. This systems-level approach is needed to inform how digital strategies can be incorporated into COVID-19 control strategies, and help prepare for future epidemics.

Digital Epidemiological Surveillance

A core public health function of outbreak management is understanding infection transmission in time, place and person, and identifying risk factors for disease to guide effective interventions. A range of digital data sources are being used to enhance and interpret key epidemiological data gathered by public health authorities for COVID-19.

Online Data Sources for Early Disease Detection

Established population surveillance systems typically rely on health-related data from laboratories, notifications from cases diagnosed by clinicians and syndromic surveillance networks. Syndromic surveillance networks are based on reports of clinical symptoms rather than a laboratory diagnosis, for example 'influenza-like-illness', from hospital and selected sentinel primary and secondary healthcare facilities, which agree to provide regular surveillance data of all cases. These sources however, ultimately miss cases where healthcare is not sought. In England for example, where until recently only hospitalised individuals and healthcare workers were routinely tested for COVID-19, confirmed cases represent an estimated 4.7% of symptomatic COVID-19 cases[18]. Identifying undetected cases would help understand the magnitude and characteristics of the outbreak[19], and reduce onward transmission.

In the last two decades, data from online news sites, news aggregation services, social networks, web searches and participatory longitudinal community cohorts have aimed to fill this gap. Data aggregation systems, including *ProMED-mail*[20], *GPHIN*[21], *HealthMap*[22], and *EIOS*[23], which use natural language processing and machine learning to process and filter online data have been developed to provide epidemiological insight. These data sources are increasingly being integrated into the formal surveillance landscape[24] and play a role in COVID-19 surveillance. The WHO's platform *EPI-BRAIN* brings together diverse data sets for infectious disease emergency preparedness and response, including environmental and meteorological data[25]. Several systems have claimed detection of early disease reports for COVID-19, using crowd sourced data and news reports, before the WHO released a statement about the outbreak[14,20,26]. The UK's automatic syndromic surveillance system scans NHS digital records[27] to pick up clusters of respiratory syndrome that could signal COVID-19. There is also interest in using online data to estimate the true community spread of infectious diseases[28,29]. Preliminary work on the epidemiological analysis of COVID-19 related social media content has been reported[30–32]. Work adapting web search algorithms created by *i-sense*[33], a UK-based interdisciplinary research programme, to COVID-19[34] is included in Public Health England's weekly reports[35].

Crowdsourcing systems used to understand the true burden of disease are also supporting syndromic surveillance. *InfluenzaNet*, gathers information about symptoms and compliance with social distancing from volunteers in several European countries through a weekly survey[36]. Similar efforts exist in other countries such as *COVID Near You*[37] in the USA, Canada and Mexico. The *COVID-19 symptom tracker* app has been downloaded by 3.9 million people in the UK and USA[38,39] and is feeding into national surveillance. While rapid and informative, these systems can suffer from selection bias, over-interpretation of findings, and lack of integration with official national surveillance that report established surveillance metrics. A fragmented approach has meant that there are 39 initiatives in the UK alone collecting symptoms from people in the community, with no centralised data collection[40].

Data Visualisation Tools for Decision Support

Data dashboards are being used extensively in the pandemic, collating real-time public health data, including confirmed cases, deaths, and testing figures, to keep the public informed and support policy makers in refining interventions[41–43]. COVID-19 dashboards typically focus on time-series charts and geographic maps, ranging from region-level statistics to case-level coordinate data[42,44]. Several dashboards show wider responses to the pandemic, such as clinical trials[45], policy and economic interventions[46] and responses to social distancing directives[47]. Few dashboards include data on contact tracing, or community surveillance from apps and their effectiveness. Challenges with the quality and consistency of data collection remain a concern. Lack of official standards and inconsistencies in government reporting of statistics across countries make global comparisons difficult. Up-to-date and accurate offline statistics from governments are also not always accessible. Novel visualisation approaches are emerging, such as the *NextStrain* open repository, which presents viral sequence data to create a global map of the spread of infection[43]. This is enabled by open sharing of data and based on open source code. The speed of sharing of such data has not been witnessed in previous global outbreaks[48].

Rapid Case Identification

Early and rapid case identification is crucial during a pandemic[49] to isolate cases and appropriate contacts in order to reduce onward spread and understand key risks and modes of transmission. Digital technologies can supplement clinical and laboratory notification, using symptom-based case identification and widespread access to community- and self-testing, and with automation and acceleration of reporting to public health databases.

Case identification by online symptom reporting, as seen in Singapore[50] and the UK[51], is traditionally used for surveillance, but now offers advice on isolation and referrals to further healthcare services, such as video assessments[52] and testing. These services can be rapidly implemented, but must be linked to ongoing public health surveillance, and action such as isolation of cases and quarantine of contacts. Although this approach is suitable for symptomatic cases, widespread individual and population testing, as well as contact tracing, plays a crucial role in case identification as an estimated 80% of COVID-19 cases are mild or asymptomatic[19]. Sensors, including thermal imaging cameras and infrared sensors are being deployed to identify potential cases based on febrile symptoms, for example at airports. Large numbers of false positives and negatives mean that this is unlikely to have a significant effect beyond increasing awareness[53,54]. Wearable technologies are also being explored to monitor COVID-19 in populations[55].

There has been increasing interest in decentralised, digitally-connected rapid diagnostic tests (RDTs) to widen access to testing, increase capacity, and ease strain on the healthcare system and diagnostic laboratories[56–58]. Several ‘near-patient’ COVID-19 PCR tests are in development[59,60], however, their use is still limited to healthcare settings. Drive through testing facilities and self-swab kits have widened access to testing. There are inherent delays between sampling, sending samples to centralised labs, waiting for results and follow up. By contrast, point-of-care RDT antibody tests, could be implemented in home or community or social care settings, giving results within minutes. Linking to smartphones with automatic readout using image processing and machine learning methods[61,62] could allow mass testing to be linked with geospatial and patient information rapidly reported to both clinical and public health systems and speeding up results. For this to work effectively, data standardisation and integration into electronic patient records is required.

Identifying past infections by antibody testing is also central to population-level surveillance and evaluating the efficacy of interventions such as social distancing. To date, these serology tests have inadequate performance characteristics[63–65] and, it remains unclear how they would assist in pandemic control. Some have argued that seropositive workers who must remain active in the economy could receive a digital 'immunity passport' to demonstrate protection from infection, though such a strategy is fraught with operational and clinical uncertainty[65,66]. Machine learning algorithms are also being developed for case identification by automated differentiation of COVID-19 from community-acquired pneumonia using hospital chest CT scans[67–69]. Further evaluation of their utility is recommended[70,71].

Interrupting Community Transmission

Following case identification and isolation, rapid tracing and quarantining of contacts is needed to prevent further transmission[72]. In areas of high transmission, the implementation and monitoring of these interventions is needed at a scale that is becoming increasingly unfeasible or at least challenging by traditional means[73].

Digital Contact Tracing

Digital contact tracing automates tracing on a scale and speed not easily replicable without digital tools[73]. It reduces the reliance on human recall, particularly in densely populated areas with mobile populations. In the COVID-19 pandemic, digital contact tracing applications have been developed for use in several countries, relying on approaches and technologies not previously tried on this scale, and controversial in terms of privacy. Evaluating their accuracy and effectiveness is essential.

Early digital tracing initiatives raised concerns around privacy[80]. In South Korea, contacts of confirmed cases were traced using linked location, surveillance, and transaction data[76]. In China, the *AliPay HealthCode* app automatically detected contacts by concurrent location and automated the enforcement of strict quarantine measures by limiting the transactions permitted of users deemed to be high-risk[77,78]. More recent voluntary contact tracing apps are being launched in collaboration with governments, collecting location data by GPS or cellular networks[79], proximity data collected by Bluetooth[80,81], or a combination[82,83]. Concerns have been raised over centralised systems (**Figure 2**) and GPS tracking. Norway halted use and data collection from its *Smittestopp* app after the country's data protection watchdog objected to the app's collection of location data as disproportionate to the task, and called for a Bluetooth-only approach[84]. Several international frameworks with varying levels of privacy preservation are emerging, including Decentralised Privacy-Preserving Proximity Tracing[85], the Pan-European Privacy-Preserving Proximity Tracing initiative[86], and the joint Google-Apple framework[87].

A key limitation of contact tracing apps is that they require a high proportion of the population to use the app and comply with advice for them to be effective in interrupting community transmission ($R<1$)[73]. To place this in perspective, national app uptake in Singapore of *TraceTogether* reached only 30% (as of June 2020)[80]. Adoption is also limited by smartphone ownership, user trust, usability, and handset compatibility. Key practical issues remain with understanding time spent with contacts and which contacts are deemed to be close enough to trigger an alert. System effectiveness in identifying transmission events is not well described and it is therefore arguable that human interpretation is still important.

Evaluating Interventions Using Mobility Data

Aggregated location data collected by smartphones via GPS, cellular network, and Wi-Fi can monitor real-time population flows[88], identify potential transmission hotspots and give insight into the effectiveness of public health interventions such as travel restrictions on actual human behaviour. Access to mobility data is a major challenge and these approaches have raised ethical and privacy concerns[89].

Mobility data with privacy-preserving aggregation steps has recently been made available by several tech and telecoms companies for the purposes of COVID-19 control, however the data sets are limited and there is no long-term commitment for data sharing in place. Daily aggregated origin-destination data from Baidu[90] is being used to evaluate the effect of travel restrictions[91] and quarantine measures[92] on COVID-19 transmission in China. Analysis of the location data of Italian smartphone users estimated a reduction of 50% of the total trips between Italian provinces in the week following the lockdown being announced on 12 March 2020[93]. Google has released weekly mobility reports with sub-national granularity, including breakdown by journey type and destination such as workplaces and parks, and has made their data set publicly downloadable[94]. Apple has similarly released a data set with daily figures for mobility and assumed method of transport[95]. There is no standardisation of these data sets between providers, however, and not all countries or regions are included in these datasets.

Assessing local differences in mobility and contact patterns may be critical to predicting the heterogeneity of transmission rates between different communities and in different regions where household size and age-stratified contact patterns may differ. This contextual information can provide insight into the effect of interventions to slow transmission, including the impact of handwashing[96], social distancing and school closures[97]. The monitoring of social distancing measures could also be used to forecast health system demands[98], and will be important in assessing the easing of restrictions when appropriate. Concerns have been raised over breaches of civil liberties and privacy when tracking individuals to monitor adherence to quarantine and social distancing, including with the use of wearables[99] and drones[100].

Public Communication – Empowering Populations Through Information

Effective implementation of interventions during a pandemic relies on public education and cooperation, supported by an appropriate communications strategy that includes active community participation to ensure public trust. With 4.1 billion people accessing the internet[101] and 5.2 billion unique mobile subscribers[15], targeted communication through digital platforms has the potential to rapidly reach billions and encourage community mobilisation (**Figure 3**). Key challenges persist, including the rise of potentially harmful misinformation[102,103] and digital inequalities[104] (see later discussion).

Online data and social media has played an ongoing, important role in public communication[105] since the first reports of an unusual influenza-like-illness resistant to conventional treatment methods emerged in China[106]. Public health organisations and tech companies are stepping up efforts to mitigate the spread of misinformation[107,108] and prioritise trusted news sites, for example Google's SOS alert intervention[109] prioritises WHO and other trusted sources to the top of search results. There are few reports about the impact of these interventions[110,111] and difficulties in defining misinformation[112]. A United Nations study found that 86% of member states had placed COVID-19 information on national websites by early April[113] and many are using text messaging to reach populations who do not have access to the internet. Chat-bots are also providing information to reduce burden on non-emergency health advice call centres[114] and clinical practice is being transformed by the rapid adoption of remote health service delivery including telemedicine, especially in primary care[52]

Digital communication platforms are also supporting adherence to social distancing measures. Video-conferencing is allowing individuals to work and attend classes from home[115], online services are supporting mental health[116], and digital platforms are enabling community mobilisation efforts by providing ways to assist those in need[117]. Nevertheless, the security and privacy of freely available communication platforms remains a concern, particularly for confidential healthcare information flow.

Future Directions

Digital technologies join a long line of public health innovations that have been at the heart of disease prevention and containment strategies for centuries. Public health has been slower to take up digital innovations than other sectors, with the first WHO guidelines on digital health interventions for health system strengthening published in 2019[118,119]. The unprecedented humanitarian and economic needs presented by COVID-19, are driving the development and adoption of new digital technologies at scale and speed. We have highlighted the potential of digital technologies to support epidemiological intelligence with online data sets, identify cases and clusters of infections, rapidly trace contacts, monitor travel patterns during lockdown, and enable public health messaging at scale. Barriers remain to the widespread use of digital solutions.

Implementation

Digital technologies cannot operate in isolation and need to be integrated into existing public health care systems[120]. For example, South Korea and Singapore successfully introduced contact tracing apps to support large teams of manual contact tracers as one of many measures, including strict isolation of cases and quarantine[76].

Digital data sources, like any data source, need to be integrated and interoperable, for example with electronic patient records. Analysis and use of this data will depend on the digital infrastructure and readiness of public health systems, spanning secondary, primary and social care systems. Logistics of delivery to ensure population impact are often given too little attention and can lead to over focus on the individual technology and not its effective operation in a system. The coordination of interventions is also a challenge with multiple symptom reporting sites in a single country, risking fragmentation.

Looking ahead, there is a need for systems-level approach for the vision for the ideal fit–for-purpose digital public health system[121], which links symptom tracking apps, rapid testing and case isolation, contact tracing, and monitoring of aggregated population mobility levels, access to care and long-term follow-up and monitoring, with public communication (**Figure 4**). These types of integrated online care pathways are not new concepts, having been shown to be highly acceptable and feasible for other infectious diseases, such as chlamydia[122].

Data Sharing and Data Quality

Big data and AI approaches are only as good as the empirical data sets that are put into them, yet detailed public health and private data sets are often inaccessible, due to privacy and security concerns, and often lack standardised formats or are incomplete. Researchers are calling[89,123,124] for technology and telecoms companies to share their data in a proportionate, ethical and privacy-preserving manner, often citing a moral imperative for these companies to contribute where there is justification for data use. Some companies are making subsets of aggregated data available [90,94,95,125,126]. These data are not consistent or provided within the same timeframe and there is no standard format or long term commitment. Researcher-led international collaborations have aimed to aggregate multiple international data-sources of voluntarily reported information[43,127].

Equally, governments should provide much greater transparency in their data sets, including epidemiological data and risk factors for acquisition, with downloadable formats for researchers. Several governments have made available de-personalised individual-level data sets for research purposes[128,129], although this raises potential privacy concerns. Open source data, code and scientific methods are being rapidly and widely shared online, including increased use of preprints, which speed up data availability, but lack peer review[130].

Evidence of Effectiveness and Regulation

Evidence of the effectiveness of any new technology is needed for wider adoption, but as the current pandemic is ongoing many digital technologies have not yet been peer reviewed, integrated into public health systems, undergone rigorous testing[131], or been evaluated by digital health evidence frameworks, such as the National Institute for Health and Care Excellence, *Evidence standards framework for digital health technologies*[132]. Contact tracing apps have been launched in at least 40 countries[133], but there is currently no evidence of effectiveness of these apps[134], such as the yield of identified cases and contacts, costs, compliance with advices, empirical estimates of reduction in R, the effective reproduction number, or a comparison with traditional methods. Although challenging, due to the urgency of the pandemic, evaluation of the effectiveness of interventions is essential. Researchers, companies and governments should publish the effectiveness of their technologies in peer reviewed journals and through appropriate clinical evaluation.

There is an urgent need for coordinated international digital public health strategies, but these have been slow to emerge. On 22 March 2020 WHO release a draft global strategy on digital health 2020-2024[135]. On 8 April the EU called for a pan-European approach on the use of apps and mobile data for COVID-19[136,86].

Legal, Ethical and Privacy Concerns

Highly granular or personal data for public health surveillance raises legal[137], ethical[138,139], security and privacy concerns[140]. Not all digital interventions have allowed consensual adoption, or made the option of consent for specific purposes explicit[78], and some have been used to enforce measures as well as to monitor them. In many cases, widespread adoption is related to effectiveness, highlighting the need for public trust and engagement. There is concern that emergency measures set precedent and may remain in place beyond the emergency, leading to ongoing collection of information about private citizens with no emergency related purpose[141,142]. All systems will need to be proofed against invasions of privacy and comply with appropriate legal, ethical and clinical governance[78]. Data can be shared under a legal contract for a well-defined purpose and time, with requirements for independent audit[74] to ensure data is not used for purposes outside of the pandemic. Dynamic consent processes could also allow users to share their data, and privacy-preserving technologies, such as differential privacy and homomorphic encryption, could ensure that access is only possible for specific purposes, and available in a tamper proof manner[13,143] to allow audit.

Inequalities and the Digital Divide

In 2018, the World Health Assembly Resolution on Digital Health recognised the value of digital technologies in advancing universal health coverage and the Sustainable Development Goals. Although trends are narrowing, today there remains a digital divide, and 51% of the world population are not mobile internet subscribers[15]. The lack of access to mobile communications, is seen in low- and middle-income countries although individuals with lower socio-economic status in high income countries are also affected[144]. The Pew Research Center reported large age disparities in mobile communication access, between 18-29 year olds and those aged over 50[145]. There are also reports of restricted mobile internet access, such as in areas of Myanmar, leaving some populations unware of the pandemic[146]. This outbreak has also disproportionately affected some communities more than others, such as black and minority ethnic groups[147]. It is therefore essential to develop tools and messaging that are accessible[104] and can be tailored to specific risks, languages and cultural contexts.

Workforce and Organisational Barriers

The spread of the COVID-19 pandemic has exposed the need for government leadership to accelerate the evaluation and adoption of digital technologies. Successful implementation strategies will require carefully accelerated and coordinated policies, with collaboration between multiple areas of governments, regulators, companies, NGOs and patient groups. Public health has long been under-funded compared to other areas of health[148]. Long-term changes will necessitate investment in national and international digital centres of excellence, with the necessary balance of partners and pre-agreed access to digital data sets. A significant investment is essential in workforce education and skills to grow digital public health leadership[149].

Conclusion

The COVID-19 pandemic is ongoing and it is too early to fully quantify the added value of digital technologies to the pandemic response. While digital technologies offer tools to support pandemic response they are not a silver bullet. The emerging consensus is that they have an important role in a comprehensive response to outbreaks and pandemics, complementing conventional public health measures and thereby contribute to reducing the human and economic impact of COVID-19. Cost-effectiveness and sustainability will require systems-level approaches to build digital online care pathways that link rapid and widespread testing with digital symptom checkers, contact tracing, epidemiological intelligence, and long-term clinical follow up. The COVID-19 pandemic has confirmed the need for data sharing, but also the need for rigorous evaluation and ethical frameworks with community participation to evolve alongside the emerging field of mobile and digital healthcare. Building public trust through strong communication strategies across all digital channels and demonstrating a commitment to proportionate privacy is imperative[150].

The future of public health is likely to be increasingly digital, and it has become urgent to recognise the importance of digital technology in this field and in pandemic preparedness planning. Key stakeholders in the digital field, such as tech companies, should be long-term partners in preparedness rather than only when emergencies are ongoing. Viruses know no borders, and increasingly neither do digital technologies and data. There is an urgent need for alignment of international strategies for the regulation, evaluation and use of digital technologies to strengthen pandemic management and future preparedness for COVID-19 and other zoonotic infections.

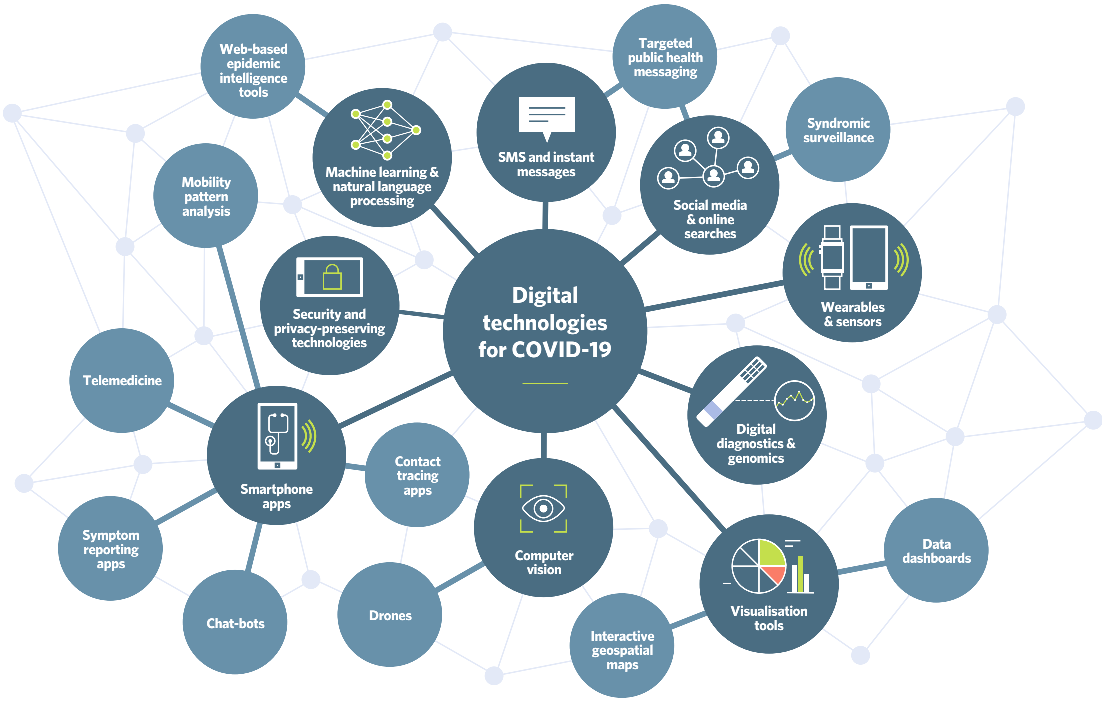

Figure 1: Illustration of the range of interconnected digital technologies that have been used in the public health response for COVID-19. Many approaches use a combination of digital technologies and may rely on telecommunications infrastructure and internet availability. Although machine learning is shown here as a separate branch for clarity, it also underpins many of the other technologies. Much of the data generated from these technologies feeds into data dashboards.

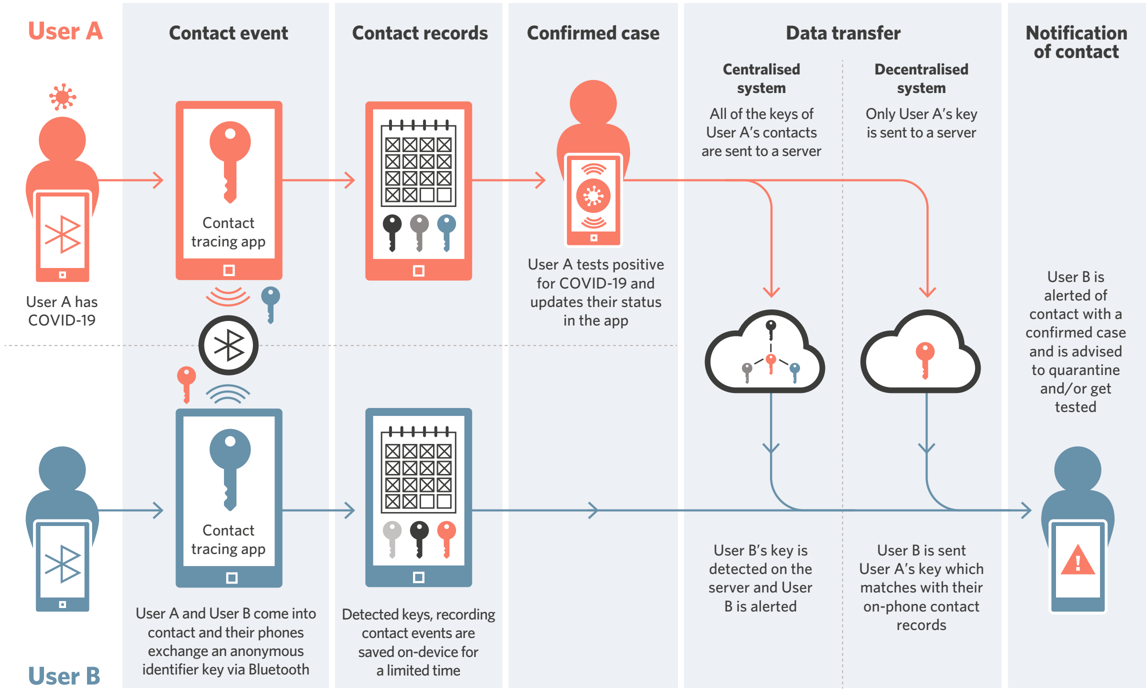

Figure 2: Contact tracing for COVID-19 with Bluetooth-enabled smartphone apps for proximity detection, comparing centralised and decentralised data storage systems. Proximity-detecting contact tracing apps use Bluetooth signals emitting from nearby devices to record contact events. Centralised apps share information about contacts and contact events with a central server. The centralised *TraceTogether*[80] app, uploads information when a user reports testing positive for COVID-19. Some centralised Bluetooth-enabled contact tracing apps (not depicted here) upload the contact graph for all users[151]. Decentralised apps, such as *SwissCovid*[152] upload only anonymous identifiers of the user reporting testing positive for COVID-19. This identifier is then broadcast to all users of the app, which compares the identifier with on-phone contact event records.

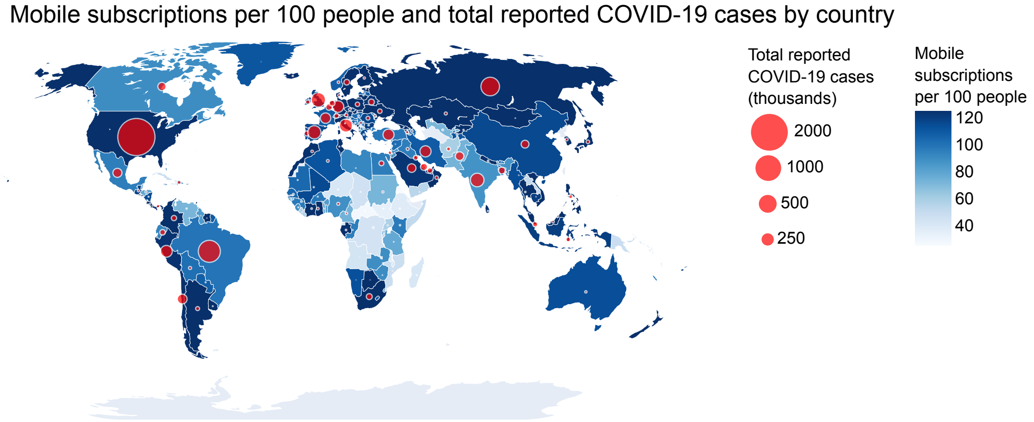

Figure 3: A map to illustrate the global reach of mobile phones to areas affected by COVID-19. Mobile subscriptions per 100 people (blue, International Telecoms Union[153], 2018) and reported COVID-19 cases by country (red, World Health Organization[154], 8 June 2020). COVID-19 is a global pandemic, yet some countries may be better resourced to respond with digital health interventions than others. There may be intra-country inequalities in mobile subscription rates. Case detection, definitions, testing strategies and reporting practice differ between countries, with variable underestimation of true case counts.

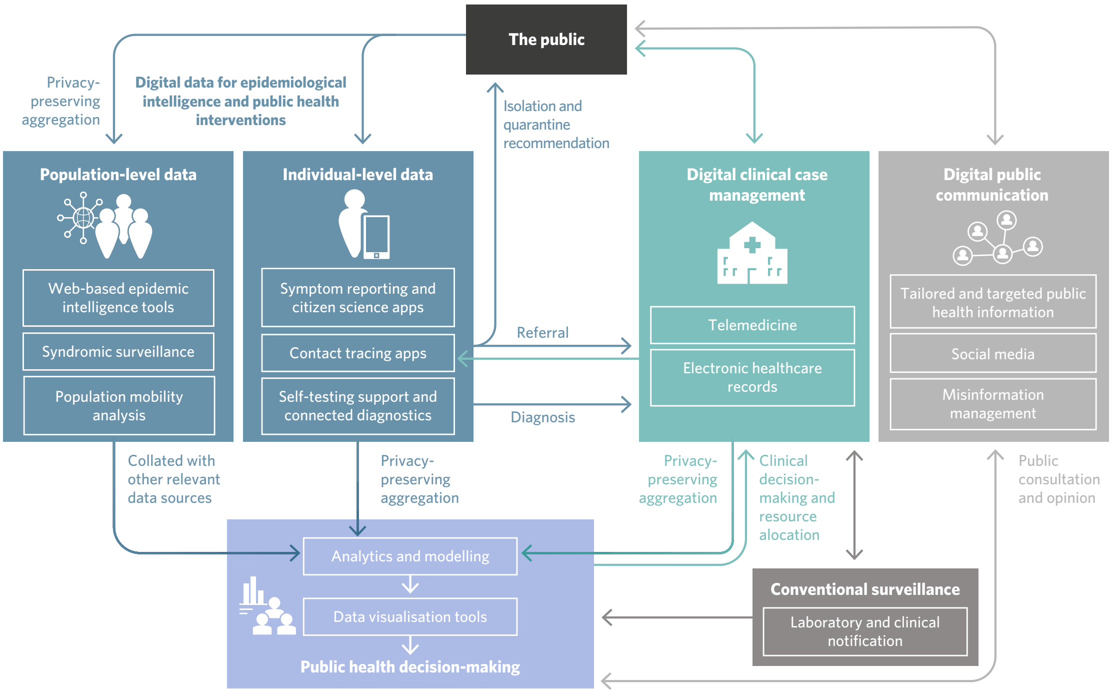

Figure 4: The flows of digital information in a digitally-enabled and integrated public health system during an infectious disease outbreak. Digital data are created by the public, both at population and individual levels, for epidemiological intelligence and public health interventions, and to support clinical case management. They are also informed by conventional surveillance via laboratory and clinical notification. This feeds into public health decision-making and their communication with the public through digital channels. Other relevant data sources include population, demographic, economic, social, transport, weather and environmental data.

Table 1: A summary of digital technologies deployed in public health interventions for the COVID-19 outbreak, showing key publications, examples, and resources.

Public health need	Digital tool/ technology	Example of use	Reference
Digital Epidemiological Surveillance	Machine learning	Web-based epidemic intelligence tools and online syndromic surveillance	Web-based epidemic intelligence tools: 20, 21, 22, 23, 25 Based on social media or online search data: 30, 31, 32, 34
	Survey apps and websites	Symptom reporting	37, 38, 39, 50, 51
	Data extraction and visualisation	Data dashboard	41, 42, 43, 44, 45, 46, 47
Rapid Case Identification	Connected diagnostic device	Near-patient diagnosis	60
	Sensors including wearables	Febrile symptoms checking	53, 54, 55
	Machine learning	Medical image analysis	67, 68
Interrupting Community Transmission	Smartphone app, Bluetooth low energy	Digital contact tracing	Paper: 73 Apps: 79, 80, 81, 82, 83 Frameworks: 85, 86, 87
	Mobile phone location data	Mobility pattern analysis	Analysis: 88, 91, 92, 93, 97 Datasets: 90, 94, 95, 126
Public Communication	Social media platforms	Targeted communication	108, 111
	Online search engine	Prioritised information	109
	Chat-bot	Personalised information	114
Clinical Care	Tele-conferencing	Telemedicine, referral	52

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