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Consensus Statement | Health Policy

Successfully Implementing Digital Health to Ensure Future Global Health Security During Pandemics

A Consensus Statement

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Abstract

IMPORTANCE COVID-19 has highlighted widespread chronic underinvestment in digital health that hampered public health responses to the pandemic. Recognizing this, the Riyadh Declaration on Digital Health, formulated by an international interdisciplinary team of medical, academic, and industry experts at the Riyadh Global Digital Health Summit in August 2020, provided a set of digital health recommendations for the global health community to address the challenges of current and future pandemics. However, guidance is needed on how to implement these recommendations in practice.

OBJECTIVE To develop guidance for stakeholders on how best to deploy digital health and data and support public health in an integrated manner to overcome the COVID-19 pandemic and future pandemics.

EVIDENCE REVIEW Themes were determined by first reviewing the literature and Riyadh Global Digital Health Summit conference proceedings, with experts independently contributing ideas. Then, 2 rounds of review were conducted until all experts agreed on the themes and main issues arising using a nominal group technique to reach consensus. Prioritization was based on how useful the consensus recommendation might be to a policy maker.

FINDINGS A diverse stakeholder group of 13 leaders in the fields of public health, digital health, and health care were engaged to reach a consensus on how to implement digital health recommendations to address the challenges of current and future pandemics. Participants reached a consensus on high-priority issues identified within 5 themes: team, transparency and trust, technology, techquity (the strategic development and deployment of technology in health care and health to achieve health equity), and transformation. Each theme contains concrete points of consensus to guide the local, national, and international adoption of digital health to address challenges of current and future pandemics.

CONCLUSIONS AND RELEVANCE The consensus points described for these themes provide a roadmap for the implementation of digital health policy by all stakeholders, including governments. Implementation of these recommendations could have a significant impact by reducing fatalities and uniting countries on current and future battles against pandemics.

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Key Points

Question What digital health recommendations should be adopted by the global health community to address the challenges of current and future pandemics?

Findings By engaging a diverse stakeholder group of 13 leaders in the fields of public health, digital health, and health care, a consensus was reached on how to implement digital health recommendations to address the challenges of current and future pandemics across 5 main themes: team, transparency and trust, technology, techquity (the strategic development and deployment of technology in health care and health to achieve health equity), and transformation.

Meaning This consensus statement provides a roadmap for the implementation of digital health policy by stakeholders, including governments, to prepare for and address current and future pandemics.

+ Invited Commentary

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Introduction

The COVID-19 pandemic has highlighted weaknesses in global health care delivery systems and public health responses, particularly the long-term national underinvestment in digitization.[1] Many found it surprising that health care data still predominantly exist in silos and are not easily accessible among health care systems because of human and technical factors (ie, little collaboration between teams and a lack of interoperability) and a lack of integrity (thereby compromising trust in those data), and they are underpinned by redundant or not-fit-for-purpose technology. It also became clear that health care data are unequally available across the world, ultimately compromising the quality of health outcomes for individuals and society. At the onset of the COVID-19 pandemic, digital health care was highly fragmented in its support of population health, health systems, and individual patient management at the local, national, and international levels. The collection of data for public health surveillance was irregular owing to a historic lack of investment in digital technology,[2] and few countries or communities had pandemic preparedness plans that enabled them to rapidly expand their data capture abilities to accurately monitor and track key outbreak information.[3] Contact tracing had previously relied heavily on analog systems and could not be scaled up rapidly.[4] These shortcomings, in turn, limited countries' abilities to develop informed public health policies, plan appropriate and timely responses, or coordinate action. Illustrating this point, the *New York Times* called reliance on fax machines a "bottleneck" in the US's coronavirus response.[5] Similarly, in Australia, the second wave of infections sent Melbourne into strict lockdown when contact tracing teams were overwhelmed by a slow, manual, paper-based system of collecting, storing, and using health information.[6] In health care delivery systems (community, primary, and secondary), electronic health record (EHR) use varied widely and ranged from the most mature systems, in which a single EHR was used across a health care organization spanning many health care facilities, to organizations that used different EHRs in different specialties or those that remained paper based.[7,8] The importance of interoperability between health care systems for the transfer (and reuse) of data was recognized and widely discussed but rarely implemented in practice.[9]

Thus, the COVID-19 pandemic has focused the minds of health care professionals, policy makers, scientists, politicians, and citizens on these issues, highlighting the intertwined relationship of health care data, its management, and its impact on public health and generating widespread interest in digital health. Many of the shortcomings highlighted by the pandemic can be addressed through the application of data science and digital health,[10] which allow data to be effectively managed, shared, and used. Although there is no single agreed-on definition of *digital health*,[11] for the purposes of this consensus statement, we consider *digital health* to mean digital tools, technologies, and services that enable health teams (including all public, private, and academic organizations that provide or support health care) to transform care delivery and empower individuals and society to manage health and well-being.

Recognizing the impact of health care data and data management on public health, in August 2020, an international interdisciplinary team of medical, academic, and industry experts formulated the Riyadh Declaration on Digital Health at the Riyadh Global Digital Health Summit, a Group of Twenty (G20)–related event that provided an international forum to discuss the role of digital health in addressing pandemics.[12] This declaration presents 9 recommendations on data and digital health (**Box**) for adoption by the global health community (health care professionals, hospital administrators, local or national politicians, policy makers, academics, and scientists) to address the challenges of the COVID-19 pandemic and future pandemics. However, the declaration did not specify how to implement the recommendations in practice.

We therefore reconvened the expert panel to reach a consensus on how best stakeholders can deploy digital health and data and support public health in an integrated manner to overcome the COVID-19 pandemic and future pandemics. This consensus statement provides a roadmap for digital health policy implementation by all stakeholders, including governments. As a foundation for this consensus statement, we propose that stakeholders must consider digital health, data, and public

health collectively to overcome the challenges of the current pandemic and, importantly, any future pandemics (**Figure**). Such a holistic view of the digital health environment is required to enact the 9 recommendations from the Riyadh Declaration on Digital Health in an effective, practicable, and impactful manner. Perhaps more important, however, implementing the guidance set out in this consensus statement lays the foundation for a more efficient and effective global health delivery system to face future global health threats.

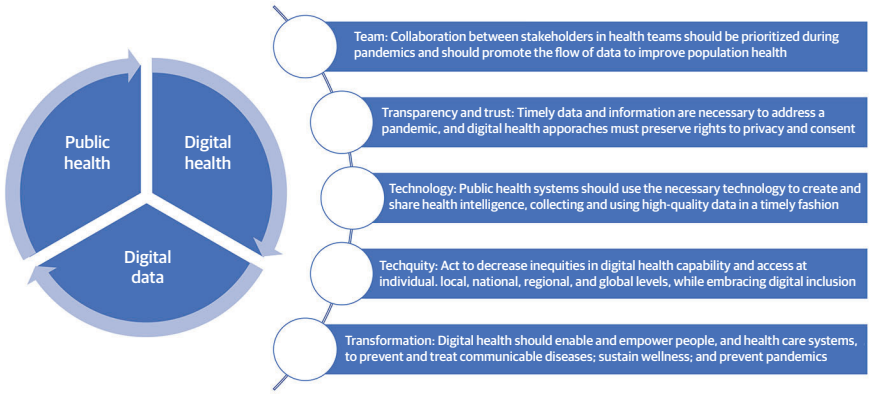
Methods

This study followed the Standards for Quality Improvement Reporting Excellence (SQUIRE 2.0) guidelines.[13] The 13 expert panel members were selected based on their internationally recognized expertise in the fields of public health, digital health, or health care leadership across the government, industry, nongovernmental organizations, and academic sectors. Most of the panel members were involved with formulating the Riyadh Declaration on Digital Health[12]; all were participants at the G20 Riyadh Global Digital Health Summit. The evidence used to reach consensus was from the presentations at the Riyadh Global Digital Health Summit from various interest groups and experts who were not members of the decision-making group, as well as PubMed and Google Scholar database searches for relevant articles related to our synthesis. Therefore, all evidence can

Box. Recommendations From the Riyadh Global Digital Health Summit

1. Implement data-driven and evidence-based protocols for clear and effective communication with common messaging to build citizens' trust.
2. Work with global stakeholders to confront the propagation of misinformation or disinformation through social media platforms and mass media.
3. Implement a standard global minimum data set for public health data reporting and a data governance structure tailored to communicable diseases.
4. Ensure that countries prioritize digital health, particularly improving digital health infrastructure and reaching digital maturity.
5. Enable health care organizations by providing the necessary technology to collect high-quality data in a timely manner and promote sharing to create health intelligence.
6. Cultivate a health care workforce with the knowledge, skills, and training in data and digital technologies required to address current and future public health challenges.
7. Ensure surveillance systems combine an effective public health response with respect for ethical and privacy principles.
8. Develop digital personal tools and services to support comprehensive health programs (in disease prevention, testing, management, and vaccination) globally.
9. Maintain, continue to fund, and innovate surveillance systems as a core component of the connected global health system for rapid preparedness and optimal global responses.

Figure. Digital Health, Public Health, and Data Underpinning the Main Identified Themes



be regarded as level 5 evidence (opinion of respected authorities) according to the Oxford Centre for Evidence-based Medicine Levels of Evidence.[14]

Recommendations were determined by first reviewing the literature and conference proceedings and by the authors independently contributing ideas. Then, 2 rounds of review were conducted until all experts agreed on the recommendations, using a nominal group technique to reach consensus.[15] Prioritization was based on how useful the recommendation might be to a policy maker. The group was encouraged to attempt to reach a consensus, but the chair also encouraged members to include minority or alternative views when a consensus could not be achieved.

Results

Participants came to consensus on high-priority questions within 5 themes: team, transparency and trust, technology, techquity (decreasing inequities in digital health capability and access), and transformation. The concrete action points for adopting digital health to address the challenges of current and future pandemics build on the previously published Recommendations on Digital Health (Box)[12] and are described.

Theme 1: Team

Collaboration between stakeholders in health teams during pandemics to promote the flow of data must be prioritized.

Consensus Points

- Create health teams that include the full range of major stakeholders including policy makers (governments and local authorities), education and research institutions (laboratories and universities), funders (insurers and investors), companies (eg, the airline industry and telecommunications), the third sector (charities and associations), health and social care (professionals and clinicians), and, most important, patients and citizens.
- Build competencies in data and digital technologies and systems among health teams, especially, but not limited to, health care workers, so that they have the knowledge, skills, and training to address pandemics.
- Collaborate across sectors to move rapidly from the development to the in-person or virtual delivery of new health innovations.
- Coordinate public health messaging among stakeholders to ensure clear communications and combat misinformation, recognizing that communicating effectively is critical for health and other sectors, government authorities, the media, and the general public.
- Ensure joint planning and action by ministries of health and other government ministries, national pandemic management agencies, the private sector, communities, and community-based organizations, assisted by the international community.
- Place strong emphasis on community participation and action to build resilience and establish the foundation for effective prevention, preparedness, response, and recovery.

Notes

The consensus panel recognized that health is already a core dimension in disaster risk management, and health emergency and disaster risk management (Health EDRM) has recently emerged as a critical field for research, policy, and practice that provides an existing and successful framework for pandemic preparedness, particularly in the area of collaboration.[16] Although the World Health Organization (WHO) Health EDRM aims to build capacity and systems across both health and nonhealth sectors to reduce the health risks and consequences associated with all types of emergencies and disasters, the principles can as easily be applied to pandemic preparedness. Although not specifically related to digital health, this framework nevertheless provides a proven model for the scale and composition of the teams required to respond to major health threats and

disasters and has formed a solid foundation for consensus around relevant stakeholders, collaborations, and community involvement.

Another existing and useful model for collaboration related to data is the Committee on Data (CODATA) of the International Science Council, which promotes international collaboration to advance open science and to improve the availability and usability of data in research. CODATA supports the principle that research data should be as open as possible and as closed as necessary. CODATA also works to advance the interoperability and the usability of such data, with the view that research data should be FAIR (findable, accessible, interoperable, and reusable). CODATA achieves these objectives through several standing committees, strategic executive-led initiatives, and its task groups and working groups. For example, in the related field of disaster risk reduction, the CODATA task group FAIR Data for Disaster Risk Research develops clear processes to ensure that data are accessible and available following the FAIR principles for disaster risk reduction and climate risk management, but as applicable to pandemic preparedness.[17]

Theme 2: Transparency and Trust

Digital health approaches must preserve rights to privacy and consent.

Consensus Points

- Securely interconnect data sets using agreed-on data standards, produce common outputs (such as standard minimum data sets), and account for their inherent biases.
- Especially for patients and citizens, practice transparency regarding data collection, generation, and use; biases in the data; and the adoption of new technologies and systems. If machine learning is used to make important decisions, be transparent about how those decisions were made.
- Ensure that data and insights belong to the stakeholder organizations who generate them and that data policies are fair and equal. Empower patients and citizens with their data, including consideration of policies such as "the right to be forgotten" (eg, Europe's General Data Protection Regulation[18]).
- Ensure that surveillance systems combine an effective public health response with respect for ethical and privacy principles.
- Make relevant health data disaggregated by population cohorts and interoperable to support public health, and foster the collaboration that is necessary to do so.
- Enable the aggregation of large quantities of health-related data from multiple pandemics and establish appropriate rules regarding who can use the data and for what purposes, and whether the data will be identifiable.
- Enlist trusted community leaders to bolster public trust in digital health care tools and systems. Invest time in building relationships so that trust exists prior to an emergency, such as a pandemic.
- Accelerate the scientific review process and keep the scientific review process objectively focused on the data.

Notes

Discussions highlighted an issue that the blurring of lines between objective scientific debate and politics could potentially erode trust in data. A notable example of this issue is the ongoing debate around the benefits associated with face masks, with the most important factor associated with mask use often cited as political partisanship rather than COVID severity.[19] Therefore, an important aspect of building trust is to ensure a clear separation between science and policy (ie, let data be data and leave policy making to policy makers).

Theme 3: Technology

Public health systems should use necessary technology to create and share health intelligence and to collect and use high-quality data.

Consensus Points

- Leverage digital technologies for surveillance and crisis communication to unlock meaningful information for public health and research and to provide public health interventions. This information should encompass consumer-generated data and should complement traditional surveillance data by providing (1) information about heterogeneous populations, including those with a range of symptoms; (2) information about individuals' daily experiences of a condition or disease state outside the clinic; (3) longitudinal data; and (4) timely data and information.
- Ensure technology and data literacy and offer scalable information delivery via the cloud to disseminate timely information based on data-driven and evidence-based protocols.
- Use interactive data visualization techniques to impart necessary health knowledge (eg, how to properly wear a face mask) to the public, probably via the media, and improve citizens' situational awareness.
- Adopt the "6 Vs" of big data[20,21] (ie, volume, velocity, variety, variability, veracity, and value of the data) to use them effectively.
- Ensure that data analysis systems are instrumental, interoperable, and intelligent to create meaning from the vast amounts of available data for the modeling and prioritization of policies in a pandemic situation.
- Gain valuable knowledge and insights through the application of traditional and nontraditional analytics, including artificial intelligence and machine learning methods.
- Given that the nexus of digital health is often clinical information systems, ensure their interoperability through preemptive discussions between health care professionals, EHR vendors, and public health authorities.
- Put processes in place to ensure that data are FAIR.

Theme 4: Techquity

Inequities in digital health capability and access at the individual, local, national, regional, and global levels should be decreased, and digital inclusion should be embraced.[22]

Consensus Points

- Continue to support internet connectivity in its many forms while increasing efforts to improve digital skills.
- Monitor health inequities in the relevant dimensions (demographic, socioeconomic, geographical, and technological). Collect data for evidence-based, equity-related policies, programs, and practices that aim to bridge gaps and promote health and well-being.
- Mitigate inequities by enhancing access to digital health services, developing the accessibility and use of services and devices, training staff, providing local community organization support, hosting local community events, and promoting digital champions. At the global scale, digital inequality can be addressed through policy work and advancing internet connectivity in its many forms while increasing efforts to enhance digital skills.
- Invest in technology and infrastructure, such as low-cost wireless and satellite connectivity, subsidized mobile phone plans, loaner devices, free WiFi hotspots, and training programs. Federal and private sector investments should be devoted to technology and infrastructure.

Theme 5: Transformation

Digital health should transform individual and population health and the health and care systems that support them.

Consensus Points

- Implement data-sharing standards and a standard global minimum data set for public health data reporting, as well as a data governance structure tailored specifically to communicable diseases.

- Embark on a digital transformation of existing health care systems to strengthen the public health surveillance system by using health technologies, such as public health surveillance systems, EHRs, clinical decision support systems, and patient management systems.
- Empower citizens to use mobile technologies to manage their health and thus contribute to disease prevention.
- Develop digital personal tools and services to support comprehensive health programs (in disease prevention, testing, management, and vaccination) globally.
- "Think locally and act globally" to ensure that the digital transformation shift is implementable to serve local needs yet interoperable across the wider health care digital environment globally and that it does not stray from its intended purpose to advance individual and population health.
- Implement public-private partnerships to support the development of systems and data sharing.

Discussion

Using a nominal group technique, we engaged a diverse stakeholder group across multiple sectors to reach consensus on how best to deploy digital health and data and support public health in an integrated manner to overcome the COVID-19 pandemic and future pandemics. In doing so, participants came to consensus on high-priority questions within 5 themes: team, transparency and trust, technology, techquity, and transformation.

Working in teams and public-private partnerships represents a critical foundation of accelerated science (ie, delivering results based on data in a timely manner), such as witnessed for the COVID-19 vaccine development and delivery. Our action points encourage partnerships that intertwine comprehensive ecosystems, a culture of collaboration and cooperation, and engaged patients and citizens with full knowledge, rights, and consent on how their data are used and processed. Adopting such an approach from discovery to development to the delivery of innovation in health care should accelerate the delivery of regulatory requirements. In practice, stakeholders should have a diverse set of interests, but each should fulfill a specific role in the health of citizens, and this collaboration will act to integrate and synergize the best knowledge, skills, and training that all health team stakeholders (especially patients and citizens) have to offer.

However, engaging different stakeholders to effectively collaborate and share data and information relies on trust and transparency, without which they will be unwilling to share data to enable digital health technologies, such as digital surveillance, to address pandemics.[23] Our consensus action points specifically address the factors that erode trust, especially among the public, such as data generation in poorly secured systems[24] and restricting data sets to individual stakeholders in silos.[25] Our framework combines a public health response with a respect for ethical and privacy principles, which is fundamental for building trust and transparency in the use of digital tools,[26] because a lack of public trust may decrease compliance with public health advice or recommendations, adversely impacting health outcomes.[27] Community leaders should be enlisted at the grassroots level to bolster public trust in digital health care tools and systems wherever possible because it is difficult to build a trusting relationship through mobile technologies alone.

Digital health technologies and consumer-generated data have the potential to provide timely and accurate data and information about disease, but this potential is hampered by aging systems, obligations to submit data to multiple programs in different formats (potentially an error-prone process), and underreporting that may affect data quality and, ultimately, the sensitivity and predictive value of a surveillance system. There was consensus that digital technologies can overcome these problems. However, the existence of technology and data does not necessarily equate to usable data. Although most industrialized nations have extremely high EHR penetration and use, these technologies presented a limiting factor throughout the pandemic. Data remained trapped within EHRs and subject to software vendors and proprietary relationships and burdens placed on the EHR user. Essentially, the capacity for health care professionals to provide public health authorities with needed data became almost intractable. Compounding the issue was the public

health authorities' absence of understanding and knowledge of clinical and laboratory operations and information systems, limitations that ultimately led to untenable policies and rule making. For future pandemic preparedness, this bottleneck needs to be anticipated through an already existing collaboration.

Successful pandemic preparedness relies on uniform, global digital health capability and access. The rate of mobile technology adoption is very high in developed countries (94%) and is rapidly increasing in developing nations (78%),[28] but barriers to access to internet connectivity and, consequently, to digital health care can reinforce serious inequalities. Groups that are digitally excluded have a greater risk of poor health.[29] Techquity means that specific people or groups should not be denied the means of achieving a state of health that is available to others through digital skills development, internet access, digital health literacy, and minimization of the effects of harmful digital marketing on health and well-being. Our consensus mitigates against digital exclusion at the global, regional, national, local, and individual levels and addresses the need to train and include those from disadvantaged populations to contribute to and participate in decision-making related to digital health.

Will the COVID-19 pandemic be a tipping point for digital health? In 2022 and beyond, the inevitable transformation of health will be accelerated owing to a strengthened focus on the need for data and digital access to advance population health and wellness. The guidance provided in this consensus statement, if followed, would lay the foundation for much greater resilience to future pandemics.

Similar to our 5 themes, the WHO Global Strategy on Digital Health provides a blueprint for how to transform current systems to address future pandemics and has 4 main objectives: collaboration and knowledge transfer, implementation of digital strategy, digital health governance, and provision of human-centered health systems at the global level.[30] Furthermore, the recently published report of the Health Information Technology Advisory Committee (HITAC) Public Health Data Systems Task Force, which examined the effectiveness of public health data systems to support high-consequence public health threats, provides targeted actions and recommendations, including cross-cutting recommendations to create a preparedness plan and data standards for collecting public health information; working with federal partners to create a health data ecosystem that fully supports public health; working with payers to promote the adoption of health care information tehnology standards and secure data exchange; and supporting data modernization and standardization initiatives.[31] As such, our consensus statement complements the WHO Global Strategy on Digital Health and HITAC recommendations by providing actions specific to pandemic preparedness that create the preconditions at local and national levels on which the WHO action plan and HITAC recommendations can be implemented at supranational levels.

Limitations

This study has some limitations. The results and the derived guidance represent the consensus of 13 subject-area experts. Other stakeholders, including those from government and the community, must be included in ongoing dialogue and must represent a wider array of public and private sector entities (eg, artificial intelligence).

Conclusions

This consensus statement, building on the Riyadh Declaration on Digital Health, is intended to inform the digital health strategy for the broadest range of stakeholders around the world. We hope that the public, governments, the private sector, nongovernmental organizations, and/or civil society organizations will adopt these principles to influence national, regional, local, and international policies and actions and thereby achieve a connected global health system to prepare for and respond to the continuing COVID-19 pandemic and other global health crises to come.

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REFERENCES

1. Dixon BE, Caine VA, Halverson PK. Deficient response to COVID-19 makes the case for evolving the public health system. *Am J Prev Med*. 2020;59(6):887-891. doi:10.1016/j.amepre.2020.07.024

2. Vandenberg O, Kozlakidis Z, Schrenzel J, Struelens MJ, Breuer J. Control of infectious diseases in the era of European clinical microbiology laboratory consolidation: new challenges and opportunities for the patient and for public health surveillance. *Front Med (Lausanne)*. 2018;5:15. doi:10.3389/fmed.2018.00015

3. Whitelaw S, Mamas MA, Topol E, Van Spall HGC. Applications of digital technology in COVID-19 pandemic planning and response. *Lancet Digit Health*. 2020;2(8):e435-e440. doi:10.1016/S2589-7500(20)30142-4

4. Blom AG, Wenz A, Cornesse C, et al. Barriers to the large-scale adoption of a COVID-19 contact tracing app in Germany: survey study. *J Med Internet Res*. 2021;23(3):e23362. doi:10.2196/23362

5. Kliff S, Sanger-Katz M. Bottleneck for US coronavirus response: the fax machine. *New York Times*. July 13, 2020. Accessed December 8, 2021. https://www.nytimes.com/2020/07/13/upshot/coronavirus-response-fax-machines.html

6. McCauley D. "Trashed their fax machines": Health Department scraps paper contact tracing. *The Age*. August 26, 2020. Accessed December 8, 2021. https://www.theage.com.au/national/victoria/trashed-their-fax-machines-health-department-scraps-paper-contact-tracing-20200826-p55pnr.html

7. Meyer GS, Britton O, Gross D. Seven challenges and seven solutions for large-scale EHR Implementations. *NEJM Catalyst*. October 12, 2018. Accessed December 8, 2021. https://catalyst.nejm.org/doi/full/10.1056/CAT.18.0073

8. Tutty MA, Carlasare LE, Lloyd S, Sinsky CA. The complex case of EHRs: examining the factors impacting the EHR user experience. *J Am Med Inform Assoc*. 2019;26(7):673-677. doi:10.1093/jamia/ocz021

9. Reisman M. EHRs: the challenge of making electronic data usable and interoperable. *P T*. 2017;42(9):572-575.

10. Al Knawy B. Global data and digital public health leadership for current and future pandemic responses. *Front Digit Health*. 2021;3:632568. doi:10.3389/fdgth.2021.632568

11. Sonnier P. The story of digital health. Accessed December 8, 2021. https://storyofdigitalhealth.com/definition

12. Al Knawy B, Adil M, Crooks G, et al. The Riyadh Declaration: the role of digital health in fighting pandemics. *Lancet*. 2020;396(10262):1537-1539. doi:10.1016/S0140-6736(20)31978-4

13. Ogrinc G, Davies L, Goodman D, Batalden P, Davidoff F, Stevens D. SQUIRE 2.0 (Standards for QUality Improvement Reporting Excellence): revised publication guidelines from a detailed consensus process. *BMJ Qual Saf*. 2016;25(12):986-992. doi:10.1136/bmjqs-2015-004411

14. Oxford Centre for Evidence-Based Medicine. Levels of evidence (March 2009). Accessed January 18, 2022. https://www.cebm.ox.ac.uk/resources/levels-of-evidence/oxford-centre-for-evidence-based-medicine-levels-of-evidence-march-2009

15. Murphy MK, Black NA, Lamping DL, et al. Consensus development methods, and their use in clinical guideline development. *Health Technol Assess*. 1998;2(3):i-iv,1-88. doi:10.3310/hta2030

16. World Health Organization. Health emergency and disaster risk management framework. Accessed October 11, 2021. https://apps.who.int/iris/bitstream/handle/10665/326106/9789241516181-eng.pdf

17. Committee on Data (CODATA) International Science Council. FAIR data for disaster risk research. Accessed October 11, 2021. https://codata.org/initiatives/task-groups/fair-data-for-disaster-risk-research/

18. Politou E, Alepis E, Virvou M, Patsakis C. The "right to be forgotten" in the GDPR: implementation challenges and potential solutions. In: *Privacy and Data Protection Challenges in the Distributed Era*. Springer; 2022:41-68.

19. Milosh M, Painter M, Sonin K, Van Dijcke D, Wright AL. Political polarisation impedes the public policy response to COVID-19. Accessed October 11, 2021. https://european.economicblogs.org/voxeu/2020/painter-sonin-van-dijcke-wright-political-polarisation-impedes-public-policy-response-covid-19

20. Moura J, Serrão C. Security and privacy issues of big data. In: Zaman N, Seliaman ME, Hassan MF, Marquez FP, eds. *Handbook of Research on Trends and Future Directions in Big Data and Web Intelligence*. IGI Global; 2015:20-52. doi:10.4018/978-1-4666-8505-5.ch002

21. Yoo Y. It is not about size: a further thought on big data. *J Inf Technol*. 2015;30(1):63-65. doi:10.1057/jit.2014.30

22. Rhee K, Dankwa-Mullan I, Brennan V, Clark C. What is TechQuity? *J Health Care Poor Underserved*. 2021;32(2):xiii-xviii. doi:10.1353/hpu.2021.0045

23. Garattini C, Raffle J, Aisyah DN, Sartain F, Kozlakidis Z. Big data analytics, infectious diseases and associated ethical impacts. *Philos Technol*. 2019;32(1):69-85. doi:10.1007/s13347-017-0278-y

24. Hay JA, Nouvellet P, Donnelly CA, Riley S. Potential inconsistencies in Zika surveillance data and our understanding of risk during pregnancy. *PLoS Negl Trop Dis*. 2018;12(12):e0006991. doi:10.1371/journal.pntd.0006991

25. Al Manir MS, Brenas JH, Baker CJ, Shaban-Nejad A. A surveillance infrastructure for malaria analytics: provisioning data access and preservation of interoperability. *JMIR Public Health Surveill*. 2018;4(2):e10218. doi:10.2196/10218

26. Kluge HHP. Statement—digital health is about empowering people. World Health Organization. June 25, 2020. Accessed December 8, 2021. https://www.euro.who.int/en/media-centre/sections/statements/2020/statement-digital-health-is-about-empowering-people

27. Ienca M, Vayena E. On the responsible use of digital data to tackle the COVID-19 pandemic. *Nat Med*. 2020;26(4):463-464. doi:10.1038/s41591-020-0832-5

28. Silver L, Smith A, Johnson C, et al. *Mobile Connectivity in Emerging Economies*. Pew Research Center; 2019:7.

29. Heponiemi T, Jormanainen V, Leemann L, Manderbacka K, Aalto AM, Hyppönen H. Digital divide in perceived benefits of online health care and social welfare services: national cross-sectional survey study. *J Med Internet Res*. 2020;22(7):e17616. doi:10.2196/17616

30. World Health Organization. Global strategy on digital health 2020-2025. Accessed December 8, 2021. https://www.who.int/docs/default-source/documents/gs4dhdaa2a9f352b0445bafbc79ca799dce4d.pdf

31. Health Information Technology Advisory Committee. Final report of the Health Information Technology Advisory Committee's Public Health Data Systems Task Force 2021. Accessed October 11, 2021. https://www.healthit.gov/sites/default/files/page/2021-08/2021-07-14_PHDS_TF_2021_HITAC Recommendations Report_Signed_508_0.pdf