The coronavirus disease global pandemic seized our day-to-day lives and, worse, killed millions of people or left them with long-term disabilities. No amount of “good” that comes from the pandemic can make up for the losses experienced by people all over the world. It can, however, give us hope that future pandemics could be detected sooner, contained with more precision, and treated more quickly and effectively. The pandemic ignited the ingenuity of scientists, health care providers, and engineers. In this column, I describe emerging technologies and innovations in care that can be used to transform health care in the years to come.

SURVEILLANCE AND DETECTION INNOVATIONS
Novel infections develop unexpectedly in local settings anywhere in the world. Depending on virulence and transmissibility, they may go unnoticed or generate data pointing to an epidemic or pandemic (Centers for Disease Control and Prevention [CDC], 2021). Emerging surveillance technologies will need to harness pockets of data and transform them into meaningful information for early detection of novel infections (Budd et al., 2020).

Systems were developed in some countries with COVID-19, but a global effort is needed to develop robust surveillance technologies using machine learning, natural language processing, bioinformatics, and privacy-preserving technologies. Table 1, adapted from Budd et al. (2020), shows three existing technologies—smartphone apps, digital diagnostics/genomics, and big data analysis/visualization—that can be innovated to find and diagnose novel infections. Although there are overlaps in the categories, I will discuss them this way for simplicity.

**Smartphone Apps**

Smartphone apps were some of the first innovations in the fight against COVID-19. For example, chatbots are artificial intelligence apps with natural language processing used to answer questions and guide humans to act. Providence Health System in the US North-west used chatbots to screen patients for COVID-19 symptoms and guide humans to act. Smartphone apps with natural language processing used to answer questions and guide humans to act. Providence Health System in the US North-west used chatbots to screen patients for COVID-19 symptoms and guide humans to act. Smartphone apps with natural language processing used to answer questions and guide humans to act. Providence Health System in the US North-west used chatbots to screen patients for COVID-19 symptoms and guide humans to act. Smartphone apps with natural language processing used to answer questions and guide humans to act.

Individuals with symptoms were directed to the health system’s telehealth portal for triage and possible testing. This approach prevented overcrowding in emergency departments and reduced transmission of the virus in waiting areas. The CDC’s Flu ChatBot could be repurposed for use in future epidemics or pandemics (CDC, 2021).

Symptom reporting apps and contact-tracing apps have been successful to some degree. In principle, these apps were designed to monitor small populations, such as universities and workplaces, as part of an overall strategy of mitigation for COVID-19, including masking, social distancing, and handwashing (Uohara et al., 2020). Some employees and students were reluctant to share their private health information, and even more had concerns about their smartphones collecting location information for contract tracing (Chen & Saqib, 2021).

Mobility pattern analysis using cell phone data early in the COVID-19 pandemic analyzed the effect of shelter-in-place mandates. Lower mobility rates were positively correlated to lower COVID-19 rates. This work demonstrated the benefits of working from home, travel restrictions, and other measures to lower the interactions among humans during the pandemic (Badr et al., 2020). Privacy-preserving technologies must be integrated into all apps collecting health and location information. If misinformation and correct messaging could be achieved, mobility pattern analysis shows promise as an infection-containing measure.

**Digital Diagnostics and Genomics**

Genetic sequencing played a primary role in the diagnosis of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) responsible for the infection COVID-19. Sharing genomic data can lead to quicker identification of viruses and other pathogens. Nextstrain is an open-source initiative for sharing genomic data with a bioinformatic analysis engine to visualize data from contributing scientists. It is sponsored by the National Institutes of Health, the Bill and Melinda Gates Foundation, and other international organizations (Nextstrain, 2021). DAMIAN (Detection & Analysis of Viral and Microbial Infectious Agents by NGS; Alawi et al., 2019) and RECoV-ERY (Reconstruction of Coronavirus Genomes & Rapid Analysis; Sabato, 2021) are two other open-source genomic data-sharing platforms. Global use of such systems would truly make a difference in detecting novel pathogens before they become spread into populations.

Widespread testing for COVID-19 with rapid results was a problem in the first and second waves of the pandemic in the United States. Widespread testing for COVID-19 with rapid results was a problem in the first and second waves of the pandemic in the United States.
Can differentiate the difference between two different coronaviruses

A group of scientists and engineers in Switzerland is developing a sensor for use in hospitals, mass transit, and other indoor public settings. The sensor can be worn at home for up to 168 hours and provide an early warning, giving health care providers time to treat patients before they become critically ill (Hastings, 2021).

Wearable surveillance devices or environmental sensors might provide ways to detect novel viruses in daily life. New technologies include a mask with a sensor and blister pack to test for exhaled proteases, which are enzymes that speed up the breakdown of proteins in viruses (Medgadget Editors, 2021). Other commonly owned wearables such as Fitbit, Apple watches, and Oura rings have shown they can be effective in predicting infection by monitoring and interpreting heart rate variability and temperature (Hacket, 2021). Innovators at Northwestern University, Rogers and Xu, have developed two wearable sensors for the neck and finger to pick up symptoms more closely related to COVID-19: shortness of breath, cough, fever, and oxygen saturation (Morris, 2020). A research group from the University of Texas, in collaboration with EnLiSense, a start-up company, have modified an existing sweat sensor to detect seven different cytokines associated with a cytokine storm in patients with COVID-19. The sensor can be worn at home for up to 168 hours and provide an early warning, giving health care providers time to treat patients before they become critically ill (Hastings, 2021).

Environmental biosensors are being developed to detect the presence of COVID-19 in asymptomatic or presymptomatic individuals. A company, Senseware, has developed a distributed network of sensors for use in buildings to detect and mitigate SARS-CoV-2 (Pantelic, 2020). The sensors use the following four approaches: 1) continuous measurement of CO₂ as a ventilation proxy, 2) air-handling filters with continuous monitoring of particulate size, 3) relative humidity monitoring and humidity regulation between 40 percent and 60 percent, and 4) ion generators to kill COVID-19 viruses with continuous monitoring of ozone levels to ensure safe oxygen levels. At the person level, General Electric announced receipt of a grant from the National Institutes of Health to develop a COVID-19 surface sensor for smartphones, computer keyboards, and tablets (Hacket, 2021). These environmental sensors, combined with wearable sensors, offer decentralized methods to detect SARS-CoV-2 and symptoms of COVID-19.

### Big Data Analysis and Data Visualization

Despite all innovations described play a vital part in surveillance and early treatment of novel pathogens, big data techniques and data visualization can be the most powerful set of tools to find novel infections. Aligning and analyzing big data are difficult because data are created from personal devices (smartphones, wearables, and sensors), connected medical devices, electronic health records, social media, online searching, among other sources. The COVID-19 Dashboard by the Center for Systems Science and Engineering (Johns Hopkins University, 2021) is the best known data visualization tool showing tracking, tracing, testing, and vaccinations around the world. The data visualization is completely dependent on the goodness of data being submitted into the system. Much more work is needed to develop data definitions. Work on using big data must resolve problems with the volume, variety, veracity, velocity, value, and visualization of data (Vendome Group, 2015) to provide trustworthy and actionable information, not only in the United States but across the globe.

### CONCLUSION

The COVID-19 pandemic showed us just how unprepared all countries were for this massive health crisis. Technology can provide valuable solutions to create surveillance and treatment solutions to save lives in the future. Now is the time to innovate even more for the next epidemic or pandemic.

### REFERENCES

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**Table 1: Digital Health Care Innovations for Future Pandemics**

| Machine Learning, Natural Language Processing, Bioinformatics, and Privacy-Preserving Technologies | Digital Diagnostics and Genomics | Big Data Analysis and Data Visualization |
|---|---|---|
| Smartphone Apps | Genomic data sharing | Electronic health records |
| • Chatbots | • Point-of-care testing | • Social media posts |
| • Symptom-reporting apps | • Home testing | • Online searches |
| • Contact-tracing apps | • Wearables | • Smartphone apps |
| • Mobility pattern analysis | • Sensors | • Data dashboards |

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