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CDC
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Leveraging and Adapting Global Health Systems and Programs During the COVID-19 Pandemic

Supplement to December 2022

Vasundhara Tolia (1950–), *The World United*, 2020. Mixed media on canvas, 30 in x 20 in/76.2 cmx 50.8 cm. Digital image courtesy of the artist. Michigan, United States

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December 2022

On the Cover

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Partnerships, Collaborations, and Investments Integral to CDC's International Response to COVID-19

Rochelle P. Walensky

Since SARS-CoV-2 was first identified, the world has witnessed more than 641 million confirmed cases of COVID-19, resulting in more than 6.6 million deaths (*1*). The global spread of the virus and the resulting destruction of lives and livelihoods brought into sharp focus the interconnectedness of local, domestic, and global public health infrastructure and the global need for a trusted, resilient public health workforce to overcome systemic inequities.

As the public health agency for the United States, the Centers for Disease Control and Prevention (CDC) invests in global and domestic public health to improve core public health capabilities. CDC collaborates with partners in the interdependent global public health ecosystem to strengthen the systems needed for disease surveillance and reporting, diagnostic testing, outbreak and pandemic responses, and clinical service delivery, including treatment, immunizations, and infection prevention and control.

Internationally, CDC staff work side-by-side with the staff of ministries of health and other public health institutions in more than 60 countries, providing technical guidance, training the next generation of disease detectives and public health emergency responders, and addressing both global and local public health challenges. Recognizing historic power imbalances that continue today, together we are building, modernizing, and bolstering health programs and developing integrated, functional, and flexible public health systems that are country-owned and sustainable. This technical assistance is driven by science and data and is designed to address the unique needs of each country. Support did not begin with the arrival of SARS-CoV-2; rather, these alliances date back many decades.

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To help strengthen a stronger path to the future, it is important to recognize the role these long-standing partnerships and investments in country infrastructure played when SARS-CoV-2 arrived. This infrastructure included (to name a few) facility-based testing, treatment, and prevention services; surveillance and laboratory systems; workforce and institutional development; and emergency preparedness infrastructures developed through the US President's Emergency Plan for AIDS Relief (PEPFAR) since 2003 (*2*). Taken together and coupled with the implementation of the Global Health Security Agenda in 2014, countries have strengthened capacities to prevent, detect, and respond to public health threats (*3*). In many countries, laboratory systems supported through PEPFAR and global health security investments facilitated rapid roll-out of SARS CoV-2 diagnostic testing (*4*,*5*). This supplement issue of the Emerging Infectious Diseases journal highlights these foundational health systems, programs, and platforms that not only continued to support the public health challenges upon which they were built, but swiftly adapted to the complexities of COVID-19 (*6*).

In partnership with CDC, some countries drew on public health workforce and institutional development programs to respond to COVID-19. By July 2021, a total of 32 Field Epidemiology Training Programs (FETPs), CDC's flagship program for training a global workforce of field epidemiologists, engaged nearly 10,000 FETP residents and graduates to support global COVID-19 epidemiologic investigations, data collection and analysis, and information dissemination (*7*). In addition, the Stop Transmission of Polio (STOP) Program, a collaboration between CDC, the World Health Organization, and the United Nations Children's Fund (UNICEF) that has recruited, trained, and deployed international public health professionals since 1998 to strengthen national immunization systems for polio eradication and the control

and prevention of all vaccine-preventable diseases, also supported COVID-19 response activities (*8*).

During recent visits to Tanzania and Uganda, I saw firsthand how these collaborations and investments were leveraged to benefit COVID-19 response activities. In Tanzania, where CDC has enjoyed a 2-decade long collaboration with the Ministry of Health, HIV treatment facilities and local partners provided COVID-19 vaccines to clients during appointments for antiretroviral therapy. HIV clinics were dually purposed to provide COVID-19 vaccines and to train on-site staff in their administration; more than 1,000 of these vaccine stations were supported by CDC. Through these efforts and broader vaccination campaigns and community outreach to underserved communities, Tanzania vaccinated millions of people for COVID-19 (*9*).

In Uganda, more than 3 decades of partnership and national public health progress against HIV and other infectious diseases built the foundation for quick action and early successes during the COVID-19 response (for example, the laboratory network for HIV and TB diagnostics developed through PEPFAR was used for COVID-19 testing and specimen transport) (*10*). Uganda FETP fellows and graduates supported all aspects of the COVID-19 response, including conducting contact tracing and case surveillance (*11*). Those assets and capacities were essential for rapid response to COVID-19 and continue to be used for other emerging and reemerging infectious disease outbreaks, including the most recent Ebola outbreak (*7*,*10*–*12*).

Vietnam's work to develop national guidelines, strengthen laboratory testing, and provide infection prevention and control training to hospital staff (*13*); Thailand's COVID-19 testing in refugee camps and work to strengthen border health activities and point-of-entry assessments (*14*); Brazil's investigation of the second wave of COVID-19 and the P.1 and B.1.162 variants (*15*); and Ukraine's implementation of a COVID-19 mitigation strategy for a 2021 religious pilgrimage that drew tens of thousands of pilgrims to the city of Uman (*16*) were all enhanced through longstanding CDC partnerships. In 2020, a total of 41 PEPFAR-supported countries had overall gains in HIV treatment and viral load suppression because of innovations and adaptations in HIV service delivery (*17*) implemented in the context of the COVID-19 pandemic, which also were made possible because of collaborations with CDC.

In the pandemic's aftermath, decades of global progress against vaccine-preventable diseases remains threatened. From 2019 to 2021, the number of unvaccinated and under-vaccinated children around the world increased from 19 to 25 million, the highest number recorded since 2008, and the number of zero-dose children (those completely unvaccinated against diphtheria, tetanus, and pertussis) substantially increased, from 13 to 18 million (*18*). Global efforts to recover from these setbacks are focused on bolstering national immunization programs to reach every child through catch-up vaccinations for polio, measles, and other vaccine-preventable diseases. Other efforts include capitalizing on COVID-19 vaccination rollouts to strengthen essential immunization programs.

We must continuously build and invest in public health capacity in the United States and globally to protect our nation and the world against dangerous and costly health threats so that we are well-positioned to swiftly respond when and where those threats arise. We also need to strategically increase surveillance and laboratory capacity for existing outbreak-prone and new emerging pathogens, constantly assess and strengthen partnerships, support equitable access to medical countermeasures, and regularly evaluate indicators that measure progress. CDC's science needs to be proactively shared with the public in an understandable, accessible, timely and implementable manner.

Through investments, ongoing collaborations, and partnerships, we work hand-in-hand in-country to provide lifesaving COVID-19 public health assistance, turning vaccines into vaccinations, training healthcare and public health workers, and strengthening critical health capabilities to better prepare us and the world for future health threats. To be successful, we are leveraging ongoing relationships and building upon trusted networks and partnerships to help countries assess their preparedness and readiness for future outbreaks and pandemics, as well as the sustainability of programs. At the same time, CDC is evaluating its own response readiness and is training and preparing the public health workforce for the future. In that work, CDC's mission for health equity is a core feature of our public health actions, both in the United States and around the world (*19*). Global health security requires equity; no community, district, or province will be truly healthy until all are.

No nation, including the United States, will be truly safe until all nations have the core public health capabilities and health systems in place to protect the groups that have been economically, socially, and historically marginalized. Through partnership, shared goals, and a global commitment, we can learn from our experience with the global COVID-19 pandemic, advancing health equity and building a strong public health system in every country to prevent and protect against the next inevitable global health threat.

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Global Responses to the COVID-19 Pandemic

Cynthia H. Cassell, Pratima L. Raghunathan, Olga Henao, Katina A. Pappas-DeLuca, Whitney L. Rémy, Emily Kainne Dokubo, Rebecca D. Merrill, Barbara J. Marston

Confronted with a novel coronavirus, countries worldwide were forced to rapidly adjust their public health systems, platforms, and tools to respond to COVID-19. The US Centers for Disease Control and Prevention (CDC) and its global partners adapted health systems and programs originally developed for other purposes, such as controlling the HIV/AIDS pandemic through the US President's Emergency Plan for AIDS Relief (PEPFAR), Global Health Security Agenda implementation, influenza surveillance, and vaccine-preventable disease elimination and eradication. This special supplement of *Emerging Infectious Diseases* highlights responses to the early phases of the COVID-19 pandemic from >80 countries, spanning 6 continents and representing >130 organizations. This article summarizes global adaptations of core public health functions during COVID-19: surveillance, information, and laboratory systems; workforce, institutional, and public health capacity; and clinical and health services delivery.

Surveillance, Information, and Laboratory Systems

CDC has provided longstanding support to strengthen surveillance, health information, and laboratory systems globally. Examples of such platforms used during the COVID-19 pandemic include the early warning and response surveillance system (*1*); respiratory (*2*), influenza (*3*), and acute febrile illness surveillance systems (*4*); global health security–supported information systems (e.g., District Health Information Software, version 2 [DHIS2]) (*5*); and PEPFAR-supported HIV and tuberculosis (TB) information systems (*6*,*7*). Respiratory disease surveillance guidance was developed for COVID-19 in 9 temporary camps for displaced persons along the Thailand–Myanmar border, showing that such systems can be effective during pandemics (*2*). Countries' ministries of health (MOH), the World Health Organization (WHO), CDC, academic institutions, and nongovernmental organizations adapted international influenza surveillance systems for SARS-CoV-2 infections (*3*). CDC collaborated with MOH and partners to leverage existing acute febrile illness surveillance systems in 5 countries to collect and generate COVID-19 data needed for action (*4*). Kinkade et al. described 3 countries' experience strengthening surveillance systems and reporting using DHIS2 for COVID-19 (*5*). Mirza et al. showed how health information systems for HIV and TB were modified for COVID-19 (*6*). PEPFAR-supported HIV and TB information management systems and diagnostic networks were adapted for SARS-CoV-2 testing in 16 low- to middle-income countries during the pandemic (*7*). Surveys provided key data on SARS-CoV-2 cases in Pakistan (*8*) and Malawi (*9*). Ohlsen et al. found international disparities in SARS-CoV-2 sequencing capacity and timeliness while viral genomic surveillance coverage increased globally (*10*). Smith-Sreen et al. compared 3 waves of the pandemic in 10 countries in southern Africa (*11*). Three neighboring countries in Africa used toolkits to analyze population movements and prioritize surveillance, cross-border collaboration, and communication strategies (*12*). Kenu et al. explained how geographic information systems were used for contact tracing to identify COVID-19 cases in Ghana (*13*). Chiou et al. developed a COVID-19 infodemic surveillance system to produce actionable insights to help address misinformation (*14*).

Workforce, Institutional, and Public Health Capacity Development

CDC-supported Field Epidemiology Training Programs (FETPs) (*15*,*16*), Public Health Emergency Management (PHEM) Fellowships (*17*), and national public health institutes (NPHIs) (*18*) have contributed to leadership, disease detection and surveillance, and response and workforce capacity during the pandemic. Bell et al. described contributions to COVID-19 preparedness and response from 32 FETPs with 2,300 trainees and ≈7,400 graduates, representing >80

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countries and 3 regions (*15*). Since 2013, CDC has offered the PHEM Fellowship to develop an international emergency response workforce; an assessment examined PHEM graduates' roles during the pandemic (*17*). Zuber et al. reviewed the pivotal role NPHIs have played in pandemic response and identify gaps and priorities for further research (*18*).

Longstanding partnerships with MOH and other governmental bodies helped strengthen COVID-19 response capacity in Kenya (*19*), Nigeria (*20*), South Africa (*21*), and Cameroon (*22*). In Kenya, COVID-19 helped advance establishment of NPHIs and national and county-level emergency operations centers, workforce development and deployment, and training in surveillance, laboratory diagnostics, and infection prevention and control (IPC) (*19*). The Nigeria Presidential Task Force on COVID-19 worked with partners to develop a comprehensive National Pandemic Response Plan (*20*). In Cameroon, CDC's global health programs were leveraged to respond to COVID-19, helping ensure continued delivery of HIV services and other health programs (*22*). Through PEPFAR, CDC used HIV Project Extension for Community Healthcare Outcomes programs, a model for virtual clinical mentorship, to address and assess healthcare workers' response to COVID-19 (*23*). In 2021, the Public Health Center of Ukraine, Ukraine's NPHI, engaged with faith communities to address public health measures during religious gatherings (*24*).

Clinical and Health Services Delivery and Impact

The pandemic also affected clinical and health services delivery. This supplement describes impacts on vaccine-preventable disease surveillance (*25*), expansion of COVID-19 vaccinations (*26*), and the effects of decreased hepatitis B immunization coverage (*27*). In the WHO Africa region, more than 200 Stop Transmission of Polio (STOP) Program consultants were surveyed to clarify how vaccine-preventable disease surveillance systems were disrupted during the pandemic (*25*). CDC's COVID-19 International Vaccine Implementation and Evaluation program applied lessons learned from Ebola, influenza, and meningococcal serogroup A conjugate vaccine introductions for the delivery of COVID-19 vaccines (*26*). Experiences from past rubella vaccination programs (*28*), yellow fever and polio immunization campaigns for COVID-19 vaccine deployment and safety monitoring in Ghana (*29*), and the effectiveness of inactivated whole-virus COVID-19 vaccine among healthcare personnel in Peru (*30*) can also inform future responses. Zambia integrated COVID-19 vaccination at HIV treatment centers and combined activities planned for 2021 World AIDS Day to help increase vaccination outreach (*31*). Kimani et al. assessed IPC strategies and health facility readiness for responding to COVID-19 in Kenya, providing important data to guide IPC improvements (*32*). Gomes et al. described initiatives to strengthen IPC in healthcare facilities in 4 countries for the prevention of healthcare-associated transmission of SARS-CoV-2 (*33*).

COVID-19 affected other clinical services, including male circumcision for HIV prevention in sub-Saharan Africa (*34*) and care offered to survivors of sexual violence in Kenya (*35*). COVID-19 also caused clinical and socioeconomic impacts on agricultural workers in Guatemala (*36*). Protocols on community-based management of acute malnutrition in Uganda, Ethiopia, and Somalia needed modification to continue essential feeding services during the pandemic (*37*).

Conclusion

International responses to COVID-19 demonstrated diverse adaptations, effects, and some improvements to public health systems and institutions; long-term global partnerships and collaborations across technical domains were central. The articles in this supplement issue contribute to ongoing efforts to stop outbreaks at their source and advance health equity to make the world safer, healthier, and more prepared for future public health emergencies.

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Lessons Learned from CDC's Global COVID-19 Early Warning and Response Surveillance System

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Early warning and response surveillance (EWARS) systems were widely used during the early COVID-19 response. Evaluating the effectiveness of EWARS systems is critical to ensuring global health security. We describe the Centers for Disease Control and Prevention (CDC) global COVID-19 EWARS (CDC EWARS) system and the resources CDC used to gather, manage, and analyze publicly available data during the prepandemic period. We evaluated data quality and validity by measuring reporting completeness and compared these with data from Johns Hopkins University, the European Centre for Disease Prevention and Control, and indicator-based data from the World Health Organization. CDC EWARS was integral in guiding CDC's early COVID-19 response but was labor-intensive and became less informative as case-level data decreased and the pandemic evolved. However, CDC EWARS data were similar to those reported by other organizations, confirming the validity of each system and suggesting collaboration could improve EWARS systems during future pandemics.

On December 31, 2019, newspapers in China reported a cluster of 27 pneumonia cases of unknown etiology in Wuhan and noted concern for the re-emergence of severe acute respiratory syndrome (SARS) coronavirus (*1*), which caused a global outbreak of respiratory illness during 2002–2003 (*2*). On January 13, 2020, the novel respiratory illness now known as COVID-19 was detected outside of China. By May 13, 2022, a total of 517,648,631 confirmed COVID-19 cases and 6,261,708 deaths had been reported from 231 countries, territories, and locations (*3*).

In response to the COVID-19 outbreak, the US Centers for Disease Control and Prevention (CDC) activated its emergency operations center on January 20, 2020, to direct CDC's domestic and international preparedness and response efforts. The breadth and speed of COVID-19's spread presented considerable challenges to global early warning and response (EWAR), for which the objective is early detection of public health events that require rapid investigation and response (*4*). EWAR incorporates 2 different surveillance systems, indicator-based surveillance (IBS) and event-based surveillance (EBS). IBS is the systematic collection, monitoring, analysis, and interpretation of structured data (i.e., indicators), produced by numerous identified, predominantly, health-based formal sources (*4*). IBS data are not used solely for EWAR purposes, but are collected for other surveillance objectives, such as measuring impact of programs or identifying priority health problems (*4*). However, IBS systems are often constrained by reporting delays and limited surveillance capacity. These constraints led the World Health Organization (WHO), through its International Health Regulations (IHR), to encourage member states to build and strengthen their IBS and EBS capacities as part of EWAR systems for public health threats (*5*).

EBS is the organized collection, monitoring, assessment, and interpretation of mainly unstructured, ad hoc information regarding health events or risks that could represent an acute threat to human health (*4*). EBS is a functional component of EWAR. The information collected for EBS is diverse and originates from multiple, often unpredetermined sources, both official and unofficial, including rumors reported by

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the media or ad hoc reports from informal networks. The information collection process is mainly active and conducted through a systematic framework specifically established for EBS purposes (*4*). IBS and EBS are complementary systems within EWAR, but EBS is used more frequently (Figure 1) (*4*,*6*).

As part of CDC's response to COVID-19, the agency implemented the CDC global COVID-19 Early Warning and Response Surveillance (CDC EWARS) system to collect, process, analyze, interpret, and disseminate data about COVID-19 cases and deaths that occurred outside of the United States. In contrast to CDC EWARS, WHO's IBS system is considered the benchmark for international surveillance data, because its IBS is based on direct reporting of case-level data from national health authorities (*7*). However, several other institutions also established global surveillance systems to monitor the COVID-19 epidemic during the prepandemic phase, including the Johns Hopkins University (JHU) Center for Systems Science and Engineering and the European Centre for Disease Prevention and Control (ECDC) (*8*,*9*). The COVID-19 pandemic is occurring in an era of crowdsourcing—defined as engaging a large group of persons to rapidly gather data (*10*)—an approach used by JHU. We describe CDC EWARS during the prepandemic period, January 20–March 7, 2020, and its use to guide evidence-based decisions. To validate CDC EWARS case, death, and affected country counts, we compared them to counts reported by WHO; to assess the consistency of CDC EWARS counts, we compared them with counts reported by JHU and ECDC.

Methods

Description of CDC EWARS

CDC EWARS was established to collect data on all laboratory-confirmed COVID-19 cases reported outside the United States. Formal information sources included press statements and situation reports from ministries of health, national public health institutions, laboratory networks, and WHO. Informal sources included media reports; social media feeds; the data aggregator Epidemic Intelligence in Open Source (*11*); and information shared by email from partners, CDC colleagues, and CDC's 59 country offices. Informal reports of suspected or confirmed COVID-19 cases and deaths were verified as confirmed cases or deaths by using official websites and other official social media platforms, including Twitter (https://www.twitter.com), Facebook (https://www.facebook.com), and Instagram (https://www.instagram.com). We downloaded and archived source documents. Surveillance activities were conducted daily, including weekends, from 8:00 AM to 11:59 PM Eastern Time.

We recorded the daily COVID-19 data for officially confirmed cases and deaths in narrative format and abstracted these into an Excel spreadsheet (Microsoft, https://www.microsoft.com) to create a case line list (Figure 2). Any variable lacking an explicit affirmative or negative narrative statement was coded as missing. Because mainland China data were in aggregate, those data were not included in the line list. The global case line list data were available for analyses each weekday morning, including data entered up to midnight the preceding day, and were maintained

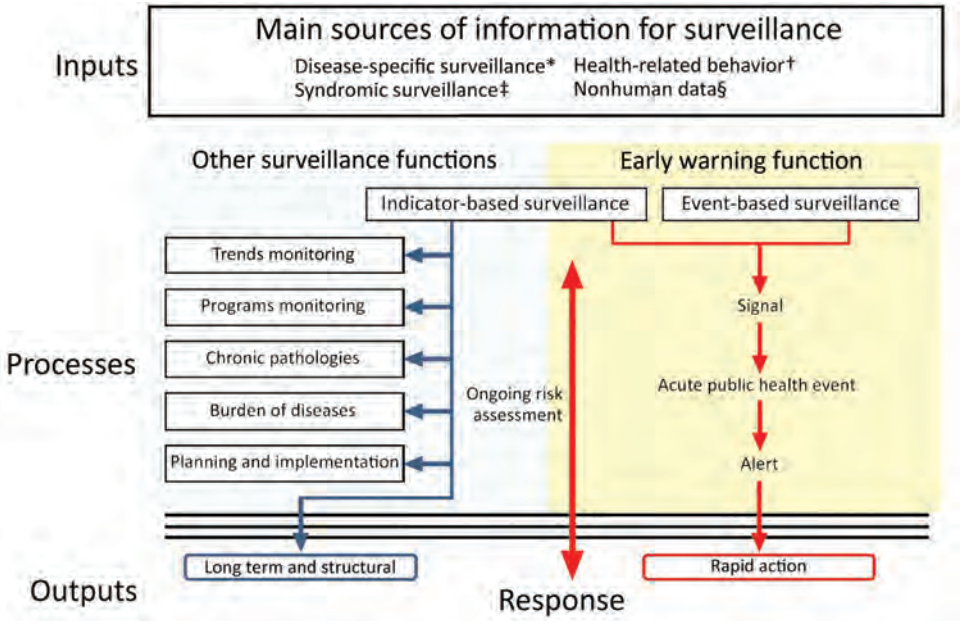

Figure 1. Overview of public health surveillance and response functions used in an evaluation of the Centers for Disease Control and Prevention Early Warning and Response Surveillance system. Adapted from the World Health Organization (*4*). *Conventional human surveillance based on biological confirmation of cases.†Human case data based on syndromic definition. ‡Data and information in relation to human health (e.g., media reports, sick leave, medicine sales, population movement, social unrest, etc.). §Veterinary surveillance (zoonosis), environmental or biological surveillance (e.g., meteorological, vector density, water and air quality, etc.).

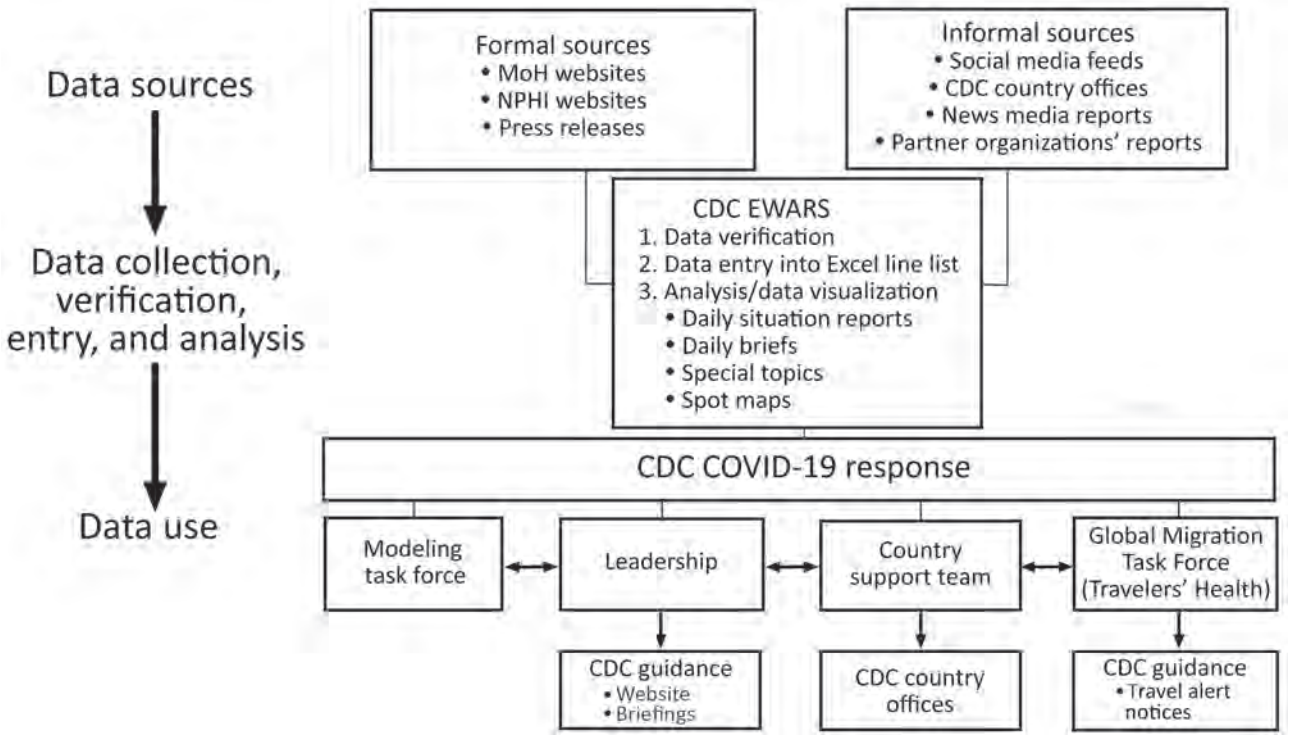

Figure 2. Work and information flow for CDC EWARS during epidemiologic weeks 3–9, January 20–March 7, 2020. CDC EWARS, US Centers for Disease Control and Prevention global COVID-19 Early Warning and Response Surveillance system; MoH, ministry of health; NPHI, national public health institutions.

through epidemiologic week (EW) 9, ending March 7, 2020. Deaths often were reported in aggregate; therefore, we maintained data on country aggregate death counts in a separate spreadsheet through EW 8, after which we used WHO death counts. The case line list included 57 variables, encompassing demographic, case detection management (e.g., hospitalization and isolation), clinical, and exposure information data.

Data Collection Methods for Other Surveillance Systems

We identified 3 additional daily sources for global COVID-19 case, death, and country count data: WHO, JHU, and ECDC (Table 1). WHO collects IBS data in accordance with the IHR (*12*), under which member states submit daily laboratory-confirmed COVID-19 case-level data to WHO by using a standardized case reporting form or line list, following WHO technical guidance on COVID-19 surveillance (*13*). However, on February 27, 2020, WHO recognized that reporting case-level data was not always feasible and provided explicit guidelines for submission of aggregate daily incidence and deaths and weekly submission of aggregate data on other demographic, clinical, and exposure information (*14*). WHO daily COVID-19 situation reports were published in the late afternoon Eastern Time, and data were current as of 5:00 AM Eastern Time. We downloaded daily situation report data for these analyses on March 2 and March 7, 2020 (*15*,*16*).

The JHU dashboard began online publication on January 22, 2020, to provide real-time data on laboratory-confirmed case (WHO definition), death, and recovery counts in affected countries. The JHU system started with morning and evening manual data

Table 1. Comparison of surveillance methodology among the 4 global COVID-19 surveillance systems used in an evaluation of CDC's global COVID-19 EWARS system*

Methodology	CDC EWARS	WHO IBS	JHU IBS and EBS	ECDC EWAR
Only report on confirmed cases and deaths	Y	Y	Y	Y
Case-level data	Y	Y	N	Y
Data cutoff time	11:59 PM ET	5 AM ET	Evening	5 AM ET
Reporting time	Morning, next day	Afternoon, same day	Evening, same day	Afternoon, same day

*CDC, Centers for Disease Control and Prevention; EBS, event-based surveillance; ECDC, European Centres for Disease Control; EWAR, early warning and response; EWARS, Early Warning and Response System; IBS, indicator-based surveillance; JHU, Johns Hopkins University Center for Systems Science and Engineering; WHO, World Health Organization.

collections from various sources, but on February 1, 2020, JHU migrated the system to a semi-automated living system strategy that included manual updates throughout the day (*8*). JHU collected data from Twitter feeds, online news services, and direct crowdsource communications sent through the dashboard. Data were verified manually by using case counts from official country and international sources. For comparative analysis, we downloaded JHU data from a Github repository on March 22, 2020 (*17*).

ECDC collected data during 1:00–5:00 AM Eastern Time for its daily COVID-19 situation reports, following a standard process (*9*). ECDC data comprised IBS and EWAR data submitted by health agencies in Europe and international partners, complemented by information from official government websites and official social media accounts. ECDC also screened several unofficial media and social media sources, but ECDC only aggregated confirmed cases and deaths reported by the national and regional authorities for their database. ECDC's daily COVID-19 situation reports were published in the afternoon Eastern Time (*18*), along with a copy of the database of daily case and death counts. We downloaded ECDC data for our analyses on March 19, 2020.

Descriptive Methods for CDC EWARS

We describe the personnel and person-hours needed to develop and maintain CDC EWARS for EW 3, ending January 25 (the first week of COVID-19 CDC EOC activation) through EW 9, ending March 7, 2020. We also describe data provided to CDC leadership from the line list's daily analyses and use of the line list by other response teams for decision-making. We examine data completeness by assessing the percentage of nonmissing data for selected variables.

Analytic Methods to Assess Validity and Consistency of CDC EWARS Data

To assess the validity of case, death, and country count data collected through CDC EWARS, we compared the weekly cumulative counts during EW 3–9 to counts reported by WHO; to assess consistency, we compared the weekly cumulative counts to counts from JHU and ECDC. For all comparisons, we excluded data for mainland China and the United States because those data were obtained from different sources by the different systems. We also performed head-to-head comparisons of CDC EWARS data to data from the other 3 systems by subtracting CDC EWARS weekly cumulative country case counts from those reported in the 3 other systems and examining scatter plots of the differences. Because CDC and JHU implemented surveillance aimed at providing the most up-to-date information, we also compared dates of report for each country's first case. We analyzed data in SAS version 9.4 (SAS Institute, https://www.sas.com). This activity was reviewed by CDC and was conducted consistent with CDC policy and applicable federal law, including 45 CFR part 46.102(l)(2); 21 CFR part 56; 42 USC §241(d); 5 USC §552a; and 44 USC §3501.

Results

Person-Time and Expertise Required to Implement and Maintain CDC EWARS

The CDC EWARS team was formed January 20, 2020, starting with 1 person and eventually expanding to a 7-person team (Table 2); all members had at least a master's degree. The team's growth coincided with the increase in global case counts and increased number of countries reporting cases. Team members worked an average of 8.2 hours/day, 7 days/week (Table 2), but various team members still worked considerable overtime (i.e., >40 hours/week), from 5–45 hours of overtime per person per week. The weekly total person-hours increased from 70 in EW 3 to 345 in EW 9, for a 7-day workweek; 1,726 person-hours were required to develop and maintain the CDC EWARS system.

Application of CDC EWARS Data

Data from the CDC EWARS were used to develop daily internal and high-level situation reports and spot maps. Situation reports included global, regional, or country-specific cumulative and incident case and

Table 2. Hours worked by CDC EWARS team during COVID-19 epidemiologic weeks 3–9, January 20–March 7, 2020*

Indicator	Epidemiologic week; beginning date							Total
	3; Jan 25	4; Feb 1	5; Feb 8	6; Feb 15	7; Feb 22	8; Feb 29	9; Mar 7	
No. team members	1	4	5	6	7	7	7	9†
Average no. hours worked/d‡	10.0	10.2	9.2	7.6	6.7	6.8	7.0	8.2
Total person-hours/wk	70	184	294	235	296	302	345	1,726
Cumulative no. reporting countries	13	25	28	29	32	63	103	–
No. new cases	38	135	186	331	1,037	5,238	17,346	24,311

*Data are based on a 7-day work week. CDC, US Centers for Disease Control and Prevention; EWARS, early warning and response surveillance; –, not applicable.
†The team comprised 9 different persons during study period.
‡Accounts for the average no. hours each person worked per day during the week.

Table 3. Data completeness collected by CDC EWARS system for selected variables during epidemiologic weeks 3 thru 9, January 20–March 7, 2020*

	Epidemiologic week						
Variables	3	4	5	6	7	8	9
Total new cases	38	135	186	331	1,037	5,238	17,346
Patient demographics							
Age	33 (86.8)	106 (78.5)	87 (46.8)	97 (29.3)	156 (15)	156 (3)	325 (1.9)
Sex	38 (100)	115 (85.2)	91 (48.9)	97 (29.3)	157 (15.1)	190 (3.6)	291 (1.7)
Nationality	37 (97.4)	66 (48.9)	54 (29)	52 (15.7)	48 (4.6)	82 (1.6)	121 (0.7)
Place of residence	27 (71.1)	39 (28.9)	28 (15.1)	17 (5.1)	61 (5.9)	161 (3.1)	47 (0.3)
Clinical indicators							
Date of illness onset	16 (42.1)	74 (54.8)	58 (31.2)	59 (17.8)	57 (5.5)	60 (1.2)	36 (0.2)
Date person sought care	20 (52.6)	67 (49.6)	58 (31.2)	45 (13.6)	13 (1.3)	13 (0.3)	8 (0.1)
Fever	21 (55.3)	46 (34.1)	45 (24.2)	32 (9.7)	29 (2.8)	28 (0.5)	27 (0.2)
Cough	12 (31.6)	33 (24.4)	34 (18.3)	27 (8.2)	20 (1.9)	30 (0.6)	15 (0.1)
Exposures							
Travel, China	38 (100)	126 (93.3)	95 (51.1)	77 (23.3)	59 (5.7)	63 (1.2)	27 (0.2)
Travel, excluding China	1 (2.6)	20 (14.8)	46 (24.7)	43 (13)	34 (3.3)	190 (3.6)	297 (1.7)
Contact with confirmed COVID-19 case	15 (39.5)	65 (48.2)	142 (76.3)	153 (46.2)	386 (37.2)	135 (2.6)	74 (0.4)
Any exposure information†	38 (100)	129 (95.6)	161 (86.6)	163 (49.2)	389 (37.5)	274 (5.2)	336 (1.9)
First exposure date	3 (7.9)	10 (7.4)	13 (7)	6 (1.8)	0	0	0
Last exposure date	18 (47.4)	63 (46.7)	26 (14)	16 (4.8)	0	1 (<0.001)	0

*Values are no. (%) of total new cases per week. Total data points collected, n = 24,311. CDC, US Centers for Disease Control and Prevention; EWARS, Early Warning and Response Surveillance.
†Includes any information regarding travel or contact with a confirmed case.

death counts, epidemic curves, analyses of case exposure and case demographic characteristics, and identification and description of geographic spread, clusters, and transmission chains (*19*). The CDC EWARS team provided daily information to CDC leadership to identify countries at risk, prioritize support for at-risk countries, and assess importation risk to the United States. Moreover, the team also provided these reports and data to the 59 CDC country offices and other response teams for situational awareness, which informed additional analyses and preparedness and response activities.

CDC's COVID-19 Response Modeling Team used the line list data from CDC EWARS to estimate the preliminary case fatality ratios outside mainland China; provide estimates of the incubation period and time-to-death; and evaluate the risk for COVID-19 importation to the United States and other countries. These analyses contributed to the early understanding of the basic epidemiology of COVID-19, informed risk assessments, and helped identify geographic areas that might be at greater risk for COVID-19 introduction and transmission (*20*).

Daily data from the CDC EWARS line list were also pivotal to determining the alert level for travel health notices that were posted during the study period (*21*). Information used included increases in the number of cases in a short period, geographic distribution of cases, evidence of sustained (multi-generational) transmission, transmission chains, and international exportations. The information also was used to inform targeted risk assessment and public health management of arriving international travelers.

Data Quality

Completeness of Data Collection

By March 7, 2020, CDC EWARS had detected 24,311 confirmed cases and 405 deaths globally. Analysis of exposure patterns revealed that 100% of weekly cases had exposure information in EW 3 and 87% had information in EW 5 (Table 3). However, as case counts began increasing in EW 6, countries provided less information on exposure; by EW 9, only 1.9% of cases had an exposure determination (Table 3). Data also were incomplete for other variables. During the first week of the epidemic, the 2 variables with the most complete data were age (87%) and sex (100%), but both variables decreased to <2% completeness at EW 9, by which time all variables had <2% completeness (Table 2).

Validity and Consistency among Surveillance Systems

By the end of EW 9, March 7, 2020, COVID-19 cases had been reported from 104 countries, excluding mainland China and the United States, across the 4 surveillance systems. At the end of EW 9, the total reported confirmed cases reported by CDC was 24,311; by WHO was 21,063; by JHU was 24,767; and by ECDC was 21,026 (Figure 3). The 4 different surveillance systems all recorded the same general trend in cumulative cases across EW 3–9 (Figure 3). However, whereas CDC and JHU case counts were similar, WHO and ECDC case counts were close to one another but lower than those for CDC and JHU. The number of reported deaths and reporting countries described by the 4 systems was initially similar but diverged in EW 8 (Figure 4).

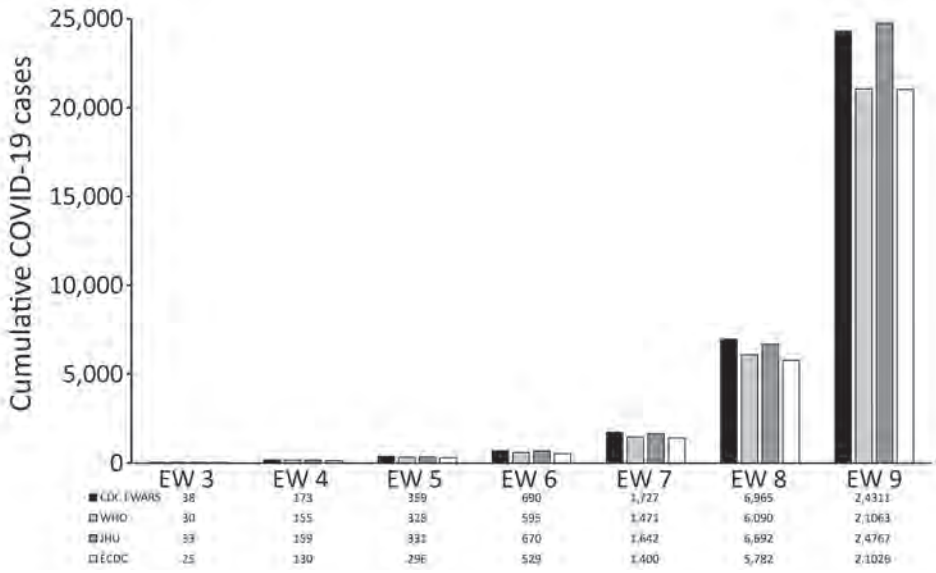

Figure 3. Cumulative confirmed COVID-19 cases reported outside of mainland China and the United States by CDC EWARS and other surveillance systems during epidemiologic weeks 3–9, January 20–March 7, 2020. CDC EWARS, US Centers for Disease Control and Prevention global COVID-19 Early Warning and Response Surveillance system; ECDC, European Centers for Disease Control; EW, epidemiologic week; JHU, Johns Hopkins University Center for Systems Science and Engineering; WHO, World Health Organization.

Agreement between CDC EWARS and the other 3 systems decreased over time, and dispersion of differences increased as the outbreak progressed and the case numbers rapidly rose (Figure 5). We also noted decreased agreement between JHU and WHO and between JHU and ECDC but noted less disagreement between JHU and CDC EWARS (data not shown). Differences of >50 cases between CDC EWARS and WHO or ECDC for cumulative country case counts occurred in 6% (18/295) of instances during the study period, primarily in countries with rapid increases in case counts during EW 7–9, which sometimes resulted in multiple daily updates. Differences of >50 cases between CDC EWARS and JHU occurred in only 1% (4/295) of instances. In identifying new countries reporting cases, CDC EWARS and JHU both reported the same date for 67% (70/104) of new countries; JHU reported an earlier date for 5% (5/104) and CDC EWARS reported an earlier date for 28% (29/104), of which 4 countries reported cases before JHU began its reporting.

Discussion

CDC EWARS data were used to inform the agency's international response activities, modeling efforts, travel health notice decisions, and manage arriving international travelers. When validated against data from WHO, CDC EWARS reported similar case, death, and country counts and was consistent with data from JHU and ECDC for most epidemiologic

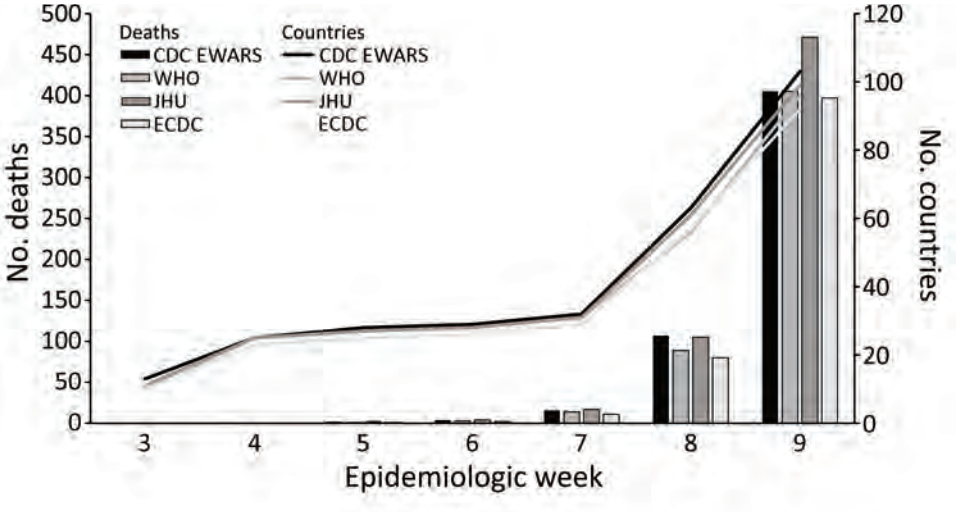

Figure 4. Cumulative reported confirmed COVID-19 deaths and cumulative number of countries reporting confirmed COVID-19 cases for CDC EWARS, JHU, WHO, and ECDC systems during epidemiologic weeks 3–9, January 20–March 7, 2020. WHO death counts were used as CDC EWARS inputs after epidemiologic week 8. Scales for the y-axes differ substantially to provide data on 2 different indicators and are not intended for direct comparisons. CDC EWARS, US Centers for Disease Control and Prevention global COVID-19 Early Warning and Response Surveillance system; ECDC, European Centers for Disease Control; JHU, Johns Hopkins University Center for Systems Science and Engineering; WHO, World Health Organization.

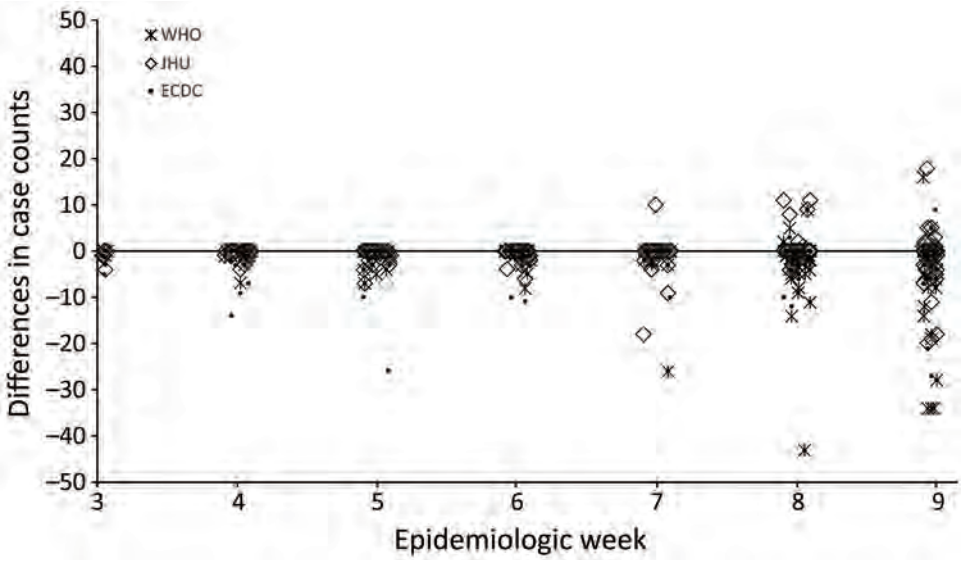

Figure 5. Scatterplot showing differences in individual country COVID-19 cumulative case-counts outside of mainland China and the United States between JHU, WHO, or ECDC systems, and CDC EWARS system during epidemiologic weeks 3–9, January 20–March 7, 2020. A value of zero indicates CDC EWARS and the other system had the same number of weekly cumulative cases for a given country; a negative value means that CDC EWARS reported a higher number of cases; and a positive value means that the other surveillance system reported more cases than CDC EWARS. Differences of >50 cases between CDC EWARS and WHO or ECDC for cumulative country case counts occurred in 6% (18/295) of instances, and between CDC EWARS and JHU in 1% (4/295) of instances. CDC EWARS, US Centers for Disease Control and Prevention global COVID-19 Early Warning and Response Surveillance system; ECDC, European Centers for Disease Control; JHU, Johns Hopkins University Center for Systems Science and Engineering; WHO, World Health Organization.

weeks assessed. The similarity of results between CDC EWARS and JHU also supports JHU's finding of comparable case counts between its system and WHO and the validity of real-time data reporting on the JHU dashboard (*8*). Most higher counts reported by CDC EWARS were likely the result of different cutoff times for data collection and the different time zones of reporting countries (Table 1), which was compounded for WHO by the lag in reporting through the IHR mechanism.

The primary objective of EWARS is early detection of unusual events that might indicate an outbreak and enable a rapid response; however, in the context of an epidemic or pandemic, timely, valid, and useful systems to inform decision-making are even more imperative. In line with this consideration, CDC EWARS was most useful in the early phase of the epidemic, when case counts were relatively small and detailed data were publicly available to help address the many unanswered questions. The system was useful for providing broad overviews of the global situation but also flexible enough to target specific country and regional issues to inform CDC guidance and travel health notices, which are a critical CDC function during international outbreaks.

Data collection by multiple systems might be redundant and inefficient in the context of a rapidly developing pandemic, but each system's objectives might differ. The JHU's primary objective was to develop a public-facing interface that tracked COVID-19 cases, deaths, and recoveries, and it was a crucial public source for up-to-date information. CDC EWARS, however, was an internal system used to clarify the epidemiology of COVID-19 and thus help determine the agency's international and domestic response. Although CDC EWARS contained official, publicly available data on confirmed cases and deaths, analyses of these data were not disseminated publicly, perhaps representing a missed opportunity to provide information to the public and to demonstrate transparency regarding the basis for certain policy decisions. However, other sources were available for these data. For instance, WHO and ECDC reported aggregate data on age and sex, and these data were officially provided by member countries. For CDC, making this information public would have required additional validation steps, resources, and clearances that were not in place during the early phase of the pandemic. Although providing more data to the public could be valuable, its usefulness and effects are more difficult to judge because of the large amount of missing data among the additional variables on which CDC could have reported and the intercountry variability of data completeness and comparability. In addition, providing yet another data source with different numbers could be confusing. CDC's new Data Modernization Initiative could put the agaency in a stronger position to collect and report early surveillance data in the future.

The first limitation of the CDC EWARS system is that it was based on publicly available data, so content for some of the variables collected, especially clinical information, might be less accurate than medical records. Second, detailed reporting of COVID-19 cases by official sources declined as countries began to report more cases. Thus, data completeness in later weeks was low relative to earlier weeks, and data for age, which usually had high completeness, was <50% in the third week of data collection. Third, data reported for each case was not standardized, and a bias toward recording positive statements might have been introduced, leaving negative responses missing from the narrative. Finally, death counts were often provided in aggregate and could not be attributed to specific patients in the line list, thus precluding case-level analyses using death as the outcome.

The main lessons learned in implementing CDC EWARS were related to human resources, monitoring, and evaluation. The numbers of cases and affected countries made CDC EWARS labor-intensive. Because of the need to collect data from multiple time zones, expanding staffing to provide 24-hour shift coverage and surge capacity at system start-up would have been helpful. We found it necessary to evaluate the surveillance system as the outbreak progressed. By frequently monitoring the level of missing information and staff workload, we were able to discontinue the CDC EWARS system after EW 9 and transition the team to using official data from WHO and China to monitor aggregate non-US case and death counts. In retrospect, we could reasonably have discontinued CDC EWARS or greatly reduced the number of data collection variables after EW 6. However, limited knowledge of the novel agent at the time led us to continue CDC EWARS for a few additional weeks. After EW 9, we reduced the global line list to only 13 countries, which we selected on the basis of the quality of data, regional relevance, and potential impact on the United States. During the same period, the unfeasibility of case-based surveillance led WHO to continue to require countries to report daily case and deaths counts but to only require weekly aggregate reporting of case-level characteristics.

In conclusion, CDC EWARS was a useful tool for timely elucidation of the epidemiology and geographic distribution of COVID-19 and helped inform US response decisions and priorities, including travel health notices. The system was most useful in the early weeks of the epidemic, when case-level data were needed and available, enabling analysis of transmission dynamics, incubation period, and levels of community transmission. However, the evolution of an epidemic into a pandemic limits an organization's ability to sustain case-level global EWARS beyond the early weeks. EWARS systems can still be useful at national and regional levels for early detection of events and timely decision-making, but global EWARS systems are most effective when countries publicly share data about critical variables on a structured, timely, and ongoing basis. The comparable incidence and mortality data found in our analysis across the 4 different surveillance systems indicated that future strategic collaboration among global systems could help leverage resources and reduce redundancies, particularly for longer-term surveillance. Such practices could enable different surveillance systems to expand their scopes to include other factors, such as interventions and their effectiveness, so that countries can quickly share best practices and other systems could focus on rapid reporting of fewer but more highly referenced variables.

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Enhancing Respiratory Disease Surveillance to Detect COVID-19 in Shelters for Displaced Persons, Thailand–Myanmar Border, 2020–2021

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We developed surveillance guidance for COVID-19 in 9 temporary camps for displaced persons along the Thailand–Myanmar border. Arrangements were made for testing of persons presenting with acute respiratory infection, influenza-like illness, or who met the Thailand national COVID-19 Person Under Investigation case definition. In addition, testing was performed for persons who had traveled outside of the camps in outbreak-affected areas or who departed Thailand as resettling refugees. During the first 18 months of surveillance, May 2020–October 2021, a total of 6,190 specimens were tested, and 15 outbreaks (i.e., ≥1 confirmed COVID-19 cases) were detected in 7 camps. Of those, 5 outbreaks were limited to a single case. Outbreaks during the Delta variant surge were particularly challenging to control. Adapting and implementing COVID-19 surveillance measures in the camp setting were successful in detecting COVID-19 outbreaks and preventing widespread disease during the initial phase of the pandemic in Thailand.

SARS-CoV-2, the causative agent of COVID-19, is a highly transmissible coronavirus that easily infects persons living in high-density environments, especially when distancing is difficult and fresh air ventilation is limited. Numerous COVID-19 outbreaks in such settings have been described (e.g., nursing homes, prisons, cruise ships); attack rates have reached and often exceeded 20% (*1*–*4*). Crowded and resource-limited conditions make refugee and displaced persons' shelters, or camps, particularly prone to communicable disease outbreaks, and numerous previous examples of residents being affected by waterborne (*5*,*6*), vectorborne (*7*,*8*), and respiratory pathogens (*9*,*10*) have been documented. From the start of the COVID-19 pandemic, many experts have raised concerns about the particular risk in the setting of temporary camps for displaced persons (*11*,*12*), and outbreaks have been reported among displaced populations in several countries, including Bangladesh (*11*), Greece (*13*), and Brazil (*14*).

Early detection is key to rapid and successful response efforts in such environments, and existing syndromic surveillance systems can be successfully adjusted to include COVID-19 screening. In this study, we describe the development of an enhanced surveillance program to detect and respond to COVID-19 in displaced persons' camps on the Thailand–Myanmar border.

Currently, 9 distinct camps in 4 Thailand provinces along the Myanmar border exist (Mae Hong

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Son, Tak, Kanchanaburi, and Ratchaburi), with a total population of ≈92,000 (*15*). Nongovernmental organizations (NGOs) provide healthcare following guidance of international standards (*16*). Patients whose conditions cannot be managed in the camp setting are referred to Thai Ministry of Public Health (MOPH) facilities for specialized care as needed. The Committee for Coordination of Services to Displaced Persons in Thailand (CCSDPT) consists of 13 NGOs that work to implement and maintain programs and services for refugees (*17*), including health programs. A Health Information System (HIS) for general disease surveillance and reporting was introduced in 2001 and is active across all 9 camps, overseen by CCSDPT. Weekly reports are submitted to the United Nations High Commissioner for Refugees Integrated Refugee Health Information System and shared with Thai MOPH (*18*,*19*). Notifiable disease conditions include severe respiratory disease caused by influenza or coronaviruses and with classifications for immediate notification to the system.

After COVID-19 was declared a pandemic by the World Health Organization (WHO) in mid-March 2020 (*20*), CCSDPT and the United Nations High Commissioner for Refugees developed a coordinating mechanism for COVID-19 preparations and response in the camps (*21*), which included a Surveillance and Outbreak Response Pillar group that developed an enhanced surveillance system. In this study, we describe this system's development and its progress in the first 16 months after inception (May 2020–October 2021). Existing surveillance to detect acute respiratory infection (ARI) and influenza-like illness (ILI) was used as a platform for COVID-19 testing, which might have enhanced SARS-CoV-2 detection within this population. We also briefly describe the COVID-19 outbreaks (defined as ≥1 laboratory-confirmed case) detected through this system.

Materials and Methods

Surveillance Guidelines and Procedures

The Surveillance Pillar working group reviewed existing Thai MOPH guidance (*22*) and built consensus plans for essential control and response areas. Plans were written into surveillance guidelines and shared with local and national public health entities for review and approval (Appendix, https://wwwnc.cdc.gov/EID/article/28/13/22-0324-App1.pdf). The Thai MOPH and Thai Ministry of Interior (MOI) reviewed the guidelines and procedures described. The camp surveillance guidelines have the following sections, each of which we describe briefly.

Prevention of COVID-19 Introduction through Movement Controls and Social Mobilization

Unauthorized entry into the camps was not permitted according to MOI requirements. All persons entering camps were screened for signs of COVID-19, such as elevated temperature or obvious signs of illness, and asked about symptoms. Risk communication and community engagement campaigns were enacted in the camps to promote awareness of COVID-19 and encourage sanitation and disease prevention measures such as handwashing, social distancing, and mask use.

Surveillance Case Definitions and Case Reporting

All patients receiving inpatient or outpatient services at camp health clinics were screened for respiratory symptoms and history of travel outside the camp. We set criteria for reporting suspected or confirmed cases according to MOPH (*22*) and HIS general infectious disease case definitions (*18*). Patients were tested if they met the national case definition for a Person Under Investigation (PUI) (*21*). In addition, patients who met the existing HIS case definitions for ILI and ARI (Appendix) were tested for COVID-19. Testing for patients meeting the ILI or ARI case definitions was conducted on a voluntary basis. Initially, 100% of patients with ILI and 10% of patients with ARI were offered testing, but as COVID-19 incidence increased in Thailand and testing capacity expanded, larger proportions of these patients were offered testing.

Camp residents were resettling in other countries as refugees throughout the surveillance period. As part of the requirements for international travel, all resettling refugees were tested using reverse transcription PCR (RT-PCR) shortly before their departure.

In accordance with MOPH requirements, District Health Officers were immediately notified of all persons meeting the PUI case definition. All laboratory-confirmed COVID-19 cases were reported through the official MOPH COVID-19 system and in parallel through the existing HIS surveillance system (Appendix). At the start of surveillance in the camps, COVID-19 cases had not yet been detected. Because a single laboratory-confirmed COVID-19 case necessitated outbreak response measures, an outbreak of COVID-19 was defined as any new detection of a case that was not associated in time or place with other COVID-19 cases in the same camp. An outbreak was considered finished after 28 days (2 incubations periods of 14 days) had passed with no new confirmed cases.

Care Provision

PUIs were isolated at a designated facility at the camp or were referred to designated district hospitals while COVID-19 testing was pending, depending on the availability of referral hospital beds, symptom severity, and local situations. Patients meeting ARI or ILI case definitions were advised on social distancing measures and asked to self-isolate at their house while tests were pending. Confirmed COVID-19 case-patients were isolated either in camp isolation units or referred to district hospitals according to MOPH standards (*23*). As the number of confirmed cases increased in an outbreak, healthcare providers developed additional community isolation units for asymptomatic and mildly symptomatic patients; when the case count exceeded the capacity of these community isolation units, house isolation for asymptomatic and mild cases was initiated.

Laboratory Testing

Healthcare staff collected nasopharyngeal swabs according to national protocols (*22*); swabs were placed in commercial transport media and transported to the laboratory following recommended cold chain requirements. As per national reporting requirements, positive results were immediately reported to the MOPH district health office and to the NGO providing healthcare.

Starting in July 2021, camp staff used commercial antigen test kits (ATKs) authorized by the Thai Food and Drug Administration from 3 manufacturers (Abbott, https://www.abbott.com; Roche, https://www.roche.com; Humasis, http://www.humasis.com). ATK sensitivity, as reported through real-world testing, varied from 56% to 65%, and specificity varied from 79% to 100% (*24*). ATK-positive results were recorded as probable cases, but only RT-PCR–positive cases were recorded as confirmed and reported to MOPH. Camp medics performed RT-PCR testing after antigen testing if a patient had a negative ATK result but had symptoms consistent with COVID-19 or if the patient was a close contact of a confirmed SARS-CoV-2–positive person (Appendix). Camp staff collected specimens and performed the antigen test in camp laboratory settings.

Case Investigation

When a PUI was identified, camp-based investigation teams interviewed the patient to complete the national Case Investigation Form as per MOPH requirements (*22*). To the extent possible, the teams documented the PUI's exposures before and after disease onset.

Contact Tracing

Camp-based contact tracing teams began contact tracing as soon as a PUI was identified, because laboratory confirmation required 3–5 days in some remote camps. High-risk and low-risk contacts were defined according to Thai MOPH guidelines (*22*).

Quarantine

Quarantine was used for 2 groups in the camp setting: close contacts of confirmed cases and persons with a history of travel outside the camp in the past 14 days (travel quarantine). Quarantine was administered at a designated facility or in the person's house, depending on availability of resources. For both types, persons were notified of their quarantine status and received instructions on social distancing measures. Support was provided in the form of meals, medications, daily living supplies, and other necessary services. Persons were checked by camp-based staff daily, and RT-PCR testing of a nasopharyngeal swab specimen was performed 1–2 times during the 14-day follow-up period.

Active Case Finding

During outbreak investigations, persons in the general community who were not known close contacts of cases were offered testing as a means to identify additional cases and chains of transmission within the community. Depending on resources, RT-PCR or ATK testing was used.

Laboratory Methods

Given the geographic distribution of the 9 camps (*15*), SARS-CoV-2 RT-PCR testing was performed in 5 different Thai MOPH-approved laboratories: Shoklo Malaria Research Unit, Tak Province; CDC-Thailand Division of Global Health Protection Laboratory, Nonthaburi Province; Paholpolpayuhasena Laboratory, Kanchanaburi Province; Sri Sam Wan Provincial Laboratory, Mae Hong Son Province; and IOM Migration Health Division, Tak Province. As per Thai MOPH requirements, all laboratories authorized to perform SARS-CoV-2 RT-PCR participated in a national quality assurance program and used primers, probes, and reagents that are authorized through WHO Emergency Use Listing procedures.

Data Collection and Analysis

Health NGOs at each camp compiled weekly surveillance metrics reports, which described numbers of persons tested and numbers in quarantine. When an outbreak was detected, additional information was shared

summarizing the outbreak dynamics and case report information. Weekly summaries were combined into a database and analyzed to provide descriptive statistics using the Power Bi statistical analysis software (Microsoft, https://www.microsoft.com). We included data reported during May 1, 2020–October 29, 2021 in the analysis.

Community Engagement and Training

Health NGOs recruited camp residents and trained them as community response staff in the COVID-19 control and prevention response. Refresher trainings were held regularly to share new updates on MOPH recommendations, requirements, and procedures. Simulation exercises were conducted to practice various scenarios involving the healthcare team and the wider community.

Funding Sources, Nonresearch Determination Status

Funding for the surveillance and outbreak response activities was provided by the US Centers for Disease Control and Prevention COVID-19 response funds, with additional support provided by the US Department of State Bureau for Population, Refugees, and Migration; the European Union; Malteser International; and International Rescue Committee. The Shoklo Malaria Research Unit is part of the Wellcome Trust Mahidol University Oxford Tropical Medicine Research Unit, which is funded by the Wellcome Trust 220211. For the purpose of open access, the author has applied a CC BY public copyright license to any author accepted manuscript version arising from this submission. Surveillance activities were determined to be public health response and not research by the Centers for Disease Control and Prevention, International Rescue Committee, and Malteser International COVID-19 response oversight committees.

Results

During May 2020–October 2021, camps submitted a total of 6,190 specimens collected as part of enhanced surveillance (i.e., not as part of an outbreak investigation) (Figure 1). Of these, 2,091 (34%) were specimens submitted from persons in travel quarantine, 3,791 (61%) were patients with ARI, 129 (2%) were patients with ILI, and 179 (3%) were PUIs. In addition, 13,586 specimens were collected as part of outbreak response activities; 4,350 (32%) were specimens from close contacts and 9,236 (68%) were specimens collected in the community as part of active case finding. Surveillance tests performed per person varied from 0.02 in Mae La to 0.13 in Tham Hin.

A total of 14 COVID-19 outbreaks were detected in the camps during the 18-month surveillance period for a total of 1,342 cases reported (Table 2). In 10 outbreaks, <10 cases were identified; 5 outbreaks were limited to a single case. Five outbreaks were detected by testing done during travel quarantine, and 9 were detected by testing patients with ARI symptoms. The index cases for all 14 outbreaks were identified and laboratory confirmed. Probable introduction of COVID-19 into the camp was estimated to have occurred 1–2 weeks before detection for all outbreaks.

The first outbreak with >10 cases was at Tham Hin camp, Ratchaburi Province, in April 2021. At the time, Alpha variant was the predominant strain in Thailand. Case investigation found that the index case-patient had been visited by family members who circumvented travel quarantine. The index case-patient was a religious leader and had close contact with nearly 100 persons during the infectious period. The large number of high-risk close contacts overwhelmed quarantine facilities, so a house quarantine approach was started. Community isolation facilities were used for all close contacts who tested positive,

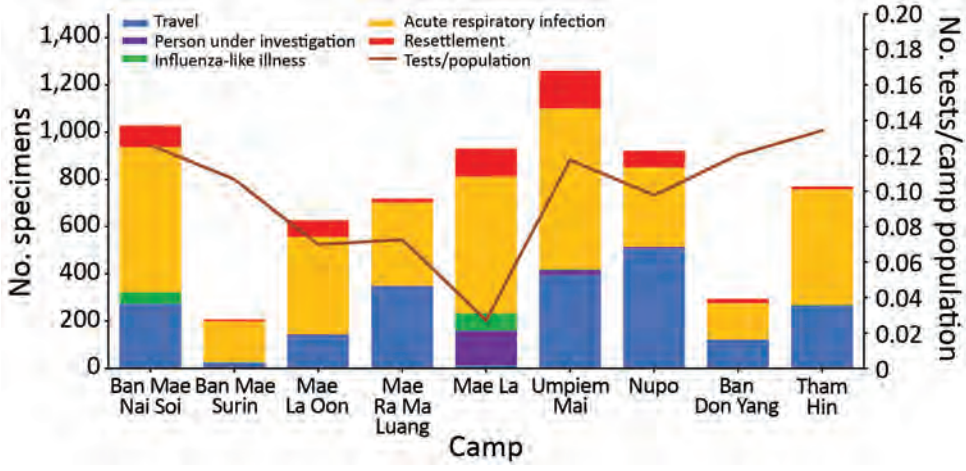

Figure 1. Total number of nasopharyngeal swab specimens tested for SARS-CoV-2 by reverse transcription PCR by camp and reason for testing as part of enhanced surveillance for COVID-19 in displaced persons' shelters, Thailand–Myanmar border, May 2020–October 2021. Travel indicates persons who had traveled outside of the camp in the previous 14 days. Resettlement refers to persons tested before international travel to a third country as part of refugee resettlement. For reference, population sizes of each camp are given in Table 1.

Table 1. Summary of COVID-19 surveillance and outbreaks detected at 9 displaced persons' shelters, Thailand–Myanmar border, May 2020–October 2021*

Camp	Population†	Surveillance start date (wk)	No. surveillance specimens tested‡	PUI	Persons with ARI	Persons with ILI	Persons under travel quarantine	No. outbreak response specimens tested§	No. outbreaks detected
Ban Mae Nai Soi	8,152	2020 Aug 1 (wk 31)	936	0	614	48	274	NA	0
Ban Mae Surin	1,939	2020 Aug 1 (wk 31)	199	0	172	2	25	NA	0
Mae La Oon	8,971	2020 May 9 (wk 19)	556	4	412	0	140	379	1
Mae Ra Ma Luang	9,884	2020 May 9 (wk 19)	701	3	352	0	346	195	1
Mae La	34,211	2020 Aug 1 (wk 31)	812	145	579	73	15	7,151	2
Umpiem Mai	10,715	2020 Aug 1 (wk 31)	1,101	20	682	3	396	3,236	5
Nupo	9,429	2020 Aug 1 (wk 31)	851	6	336	0	509	177	2
Ban Don Yang	2,440	2021 Mar 8 (wk 10)	276	1	154	0	121	127	2
Tham Hin	5,738	2020 Aug 29 (wk 35)	758	0	490	3	265	2,136	2
Total	91,479	NA	6,190	179	3,791	129	2,091	13,401	15

*ARI, acute respiratory illness; ILI, influenza-like illness; NA, not applicable; PUI, persons under investigation; wk, epidemiological week.
†Population verified by United Nations High Commissioner for Refugees and The Border Consortium as of November 2020.
‡Surveillance specimens were collected from persons meeting the case definition criteria for PUI, ARI, or ILI, and from persons who had returned from travel outside the camp in the previous 14 days and were under quarantine.
§Outbreak response specimens include specimens collected from close contacts of confirmed cases and active case finding in the community. Totals may not include some specimens that were tested by the Thai Ministry of Public Health during first outbreaks in Umpiem Mae and Tham Hin camps.

regardless of clinical symptoms. A lockdown of the camp was instituted for 4 weeks after detection of this outbreak, in which only 1 designated person in each nonquarantined household was allowed to move about the camp to pick up food rations and other necessary supplies. After 6 weeks of intensive contact tracing, 110 total confirmed cases were identified, and the outbreak was considered controlled.

The number of outbreaks detected increased during August 2021 and continued until the time of this report in November 2021, after the wave of community transmission across Thailand from the Delta variant (Table 2). When outbreaks were detected in camps and confirmed by RT-PCR, active case-finding using ATKs was performed. Movement restrictions in certain camp sections were implemented on the basis of evidence of transmission in the general community. As the outbreaks grew in size, house isolation was implemented for patients with asymptomatic or mild infections, and teams were deployed to provide hygiene materials and daily check-ups on clinical status. Contact tracing, home quarantine, and testing of high-risk contacts continued.

Discussion

Over 18 months during 2020–2021, a novel COVID-19 surveillance system was launched in 9 refugee camps along the Thailand–Myanmar border; this system tested >6,000 specimens and detected 15 outbreaks. The system incorporated national surveillance recommendations and adapted them for the camp-based setting, where human and physical resources are more limited than in other parts of Thailand. To account for these limitations, laboratory testing was expanded and offered to patients demonstrating symptoms of ARI and ILI to increase sensitivity of the surveillance to detect COVID-19. In total, 9 outbreaks were detected through testing of symptomatic persons at the camps' clinics. In addition, testing of residents under quarantine after travel outside the camp detected 5 outbreaks during this period. This system operated in parallel with and was complementary to the existing camp HIS and national COVID-19 surveillance systems, and all cases were reported in the relevant systems.

Although direct comparisons of COVID-19 surveillance across different humanitarian settings is challenging because of differences in disease detection, reporting, and local outbreak conditions, reports from other countries offer other examples of functional case detection. In Greece, during the initial 9 months of the pandemic in 2020, a total of 25 outbreaks were detected in 39 refugee and asylum-seeker reception facilities with a total population of ≈60,000 (*13*). In Yemen, a community-based surveillance system generated 91 alerts and detected 5 COVID-19 outbreaks in an internally displaced population of 1,806 persons over a 5-month period (*25*). At Cox's Bazar in

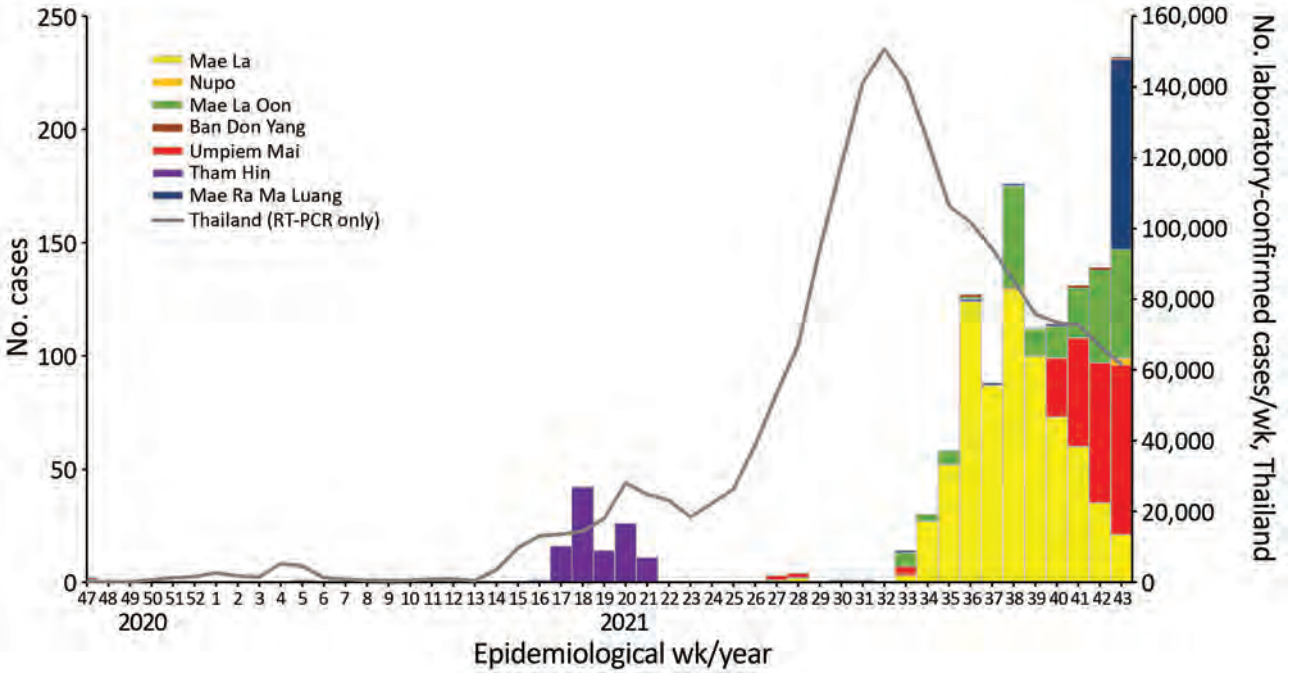

Figure 2. Epidemiologic curve of the total number of laboratory-confirmed COVID-19 cases per week by displaced person camp, Thailand–Myanmar border, November 8, 2020–October 31, 2021. For reference, population sizes of each camp are given in Table 1. RT-PCR, reverse transcription PCR.

Bangladesh, 3,084 cumulative cases had been reported out of 63,776 total tests performed as of September 2021, for a positivity rate of ≈4.8% (*26*).

The establishment and conduction of laboratory surveillance in the camps themselves was critical. The remote locations of several camps necessitated special transportation arrangements to preserve cold chain requirements and reach laboratories in appropriate times. Relying on testing through official channels would have led to delays in detection and outbreak response because of the challenges in transport and the more stringent PUI case criteria for testing by MOPH laboratories. Some patients who were tested met PUI criteria, but they were a small subset (n = 146), and no outbreaks were detected from PUI testing. Additional patients would possibly have met PUI criteria, but their exposure risk was either not assessed or they were not forthcoming about potential exposure risks.

Thailand did not have widespread community transmission until mid-2021, when the Delta variant became the predominant strain. This timing afforded

Table 2. COVID-19 outbreaks in 9 displaced persons' shelters, Thailand–Myanmar border, with cumulative number of cases as of October 31, 2021*

No.	Camp	Date of outbreak start	Date of last detected case	Cumulative no. cases	Remark
1	Umpiem Mai	2020 Nov 19	2020 Nov 19	1	
2	Umpiem Mai	2021 Feb 1	2021 Feb 1	1	
3	Tham Hin	2021 Apr 20	2021 May 28	110	
4	Mae La	2021 Jul 5	2021 Jul 15	3	
5	Umpiem Mai	2021 Jul 7	2021 Jul 12	4	
6	Mae Ra Ma Luang	2021 Jul 30	2021 Oct 31	90	Ongoing outbreak
7	Mae La Oon	2021 Aug 16	2021 Oct 31	198	Ongoing outbreak
8	Mae La	2021 Aug 17	2021 Oct 29	711	Ongoing outbreak
9	Umpiem Mai	2021 Aug 18	2021 Aug 20	4	
10	Tham Hin	2021 Sep 7	2021 Sep 7	1	
11	Ban Don Yang	2021 Sep 10	2021 Sep 10	1	
12	Nupo	2021 Sep 24	2021 Sep 24	1	
13	Umpiem Mai	2021 Oct 6	2021 Oct 31	211	Ongoing outbreak
14	Ban Don Yang	2021 Oct 16	2021 Oct 25	3	
15	Nupo	2021 Oct 26	2021 Oct 31	3	Ongoing outbreak

*For reference, population sizes of each camp are given in Table 1.

camp-based healthcare providers time to plan, recruit and train staff, and bring the enhanced surveillance system into action. During July–October 2021 alone, 11 outbreaks were detected. This number corresponded roughly to the high level of community transmission that was seen across Thailand during that time (Figure 2). In November 2021, several camps were experiencing growing outbreaks. Community resistance to distancing measures, isolation, and testing has been a factor in controlling spread and has been similarly described in other refugee communities (*27*). To build support in this community, risk communication and community engagement activities are ongoing.

A previous modeling paper by Gilman et al. (*28*) identified that the application of control measures, such as efficient isolation of infected persons, use of face masks, and limiting movement of camp residents between sectors, would be effective in limiting COVID-19 transmission. Similar control measures were applied and appeared to have an effect in Tham Hin camp. The outbreak during April–May 2021 started from multiple contacts of an infected person, which nearly overwhelmed the quarantine facilities that had been prepared. Speedy adjustment to the situation and the decision to use house quarantine for close contacts was critical to ensure that existing facilities could accommodate persons who tested positive. Active case finding through systematic screening by camp sections served to identify and stop unknown chains of transmission. Diligent contact tracing, community participation, provision of support to quarantined and isolated persons through food aid, and daily healthcare visits to quarantined households limited transmission; the outbreak was declared over with a total of 110 cases detected after 2 months.

Commercial ATKs were not approved for use in Thailand until July 2021 but were rapidly adopted as an essential tool because of their lower cost, rapid turnaround time, and lack of cold chain requirements. ATKs were particularly helpful because diagnostic laboratories were often distant from the camps, and sample transport and processing required 3–5 days. As an example, a close contact with a positive ATK result could be rapidly isolated and contact tracing could begin while RT-PCR results were pending. False-negative results, however, are commonly experienced with ATK tests because of their lower sensitivity, so RT-PCR testing was still relied upon for confirmation.

The enhanced surveillance system was subject to several limitations. Camp medical staff did not complete comprehensive examination forms for patients seeking care at the ARI clinic, so we could not evaluate whether patients were correctly classified as ARI, ILI, or PUI. Because testing of patients in the ARI clinic was voluntary, uptake varied and the number of tests performed might not accurately reflect the overall incidence of ARI and ILI; some COVID-19 cases could have been missed. Surveillance testing per population was nearly 5-fold greater in Tham Hin camp than in Mae La camp; this difference was related to several factors, including community acceptance of testing.

Similarly, the number of tests performed on persons in travel quarantine might not indicate the total number of persons who returned to a particular camp. Lags in test results and reporting could have caused discrepancies in the total number of COVID-19 cases described in the camps in this study compared with official numbers reported by Thai MOPH. Because ATKs are not as highly sensitive or specific as RT-PCR testing, some COVID-19 cases could have been missed, and the incidence of COVID-19 in the camps might be underestimated.

Despite many humanitarian settings having robust surveillance, more published reports are needed that describe such systems (*29*). A review of the literature covering COVID-19 surveillance found 2 other studies that describe implementation and adaptation to a humanitarian setting, in Yemen and Sudan (*25*,*30*). In Sudan, healthcare providers were trained as rapid response teams (*30*), whereas in Yemen a community-based surveillance system approach was used (*25*). The surveillance system we describe includes elements of community- and healthcare-based surveillance, in which community-based assistants perform contact tracing, identify persons with recent travel history, and refer persons with compatible illness for testing. In addition, our enhanced surveillance system also has an element based in existing clinics, with testing provided for persons experiencing symptoms of ARI and ILI.

COVID-19 surveillance in refugee, migrant, and displaced person populations continues long-term as successive waves of SARS-CoV-2 transmission continue worldwide and vaccine campaigns gradually increase their coverage. Refugees and displaced persons frequently have reduced access to public health services because of language barriers, location in remote areas, and healthcare systems that exclude noncitizens or unofficial residents. Because mobile populations might be more likely to move informally within a country or internationally, establishing surveillance to detect pathogens of international significance and extending national surveillance systems to these groups are vital. The enhanced surveillance developed in displaced persons' shelters on the Thailand–Myanmar border is one such example and has provided a functional solution to this ongoing challenge.

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Leveraging International Influenza Surveillance Systems and Programs during the COVID-19 Pandemic

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A network of global respiratory disease surveillance systems and partnerships has been built over decades as a direct response to the persistent threat of seasonal, zoonotic, and pandemic influenza. These efforts have been spearheaded by the World Health Organization, country ministries of health, the US Centers for Disease Control and Prevention, nongovernmental organizations, academic groups, and others. During the COVID-19 pandemic, the US Centers for Disease Control and Prevention worked closely with ministries of health in partner countries and the World Health Organization to leverage influenza surveillance systems and programs to respond to SARS-CoV-2 transmission. Countries used existing surveillance systems for severe acute respiratory infection and influenza-like illness, respiratory virus laboratory resources, pandemic influenza preparedness plans, and ongoing population-based influenza studies to track, study, and respond to SARS-CoV-2 infections. The incorporation of COVID-19 surveillance into existing influenza sentinel surveillance systems can support continued global surveillance for respiratory viruses with pandemic potential.

The persistent threat of influenza has spurred decades of work to build global surveillance, preparedness, and capacity to respond to seasonal, zoonotic, and pandemic influenza. Activities to support international laboratory and epidemiology capacity building for early detection and response to influenza and other respiratory viruses have been conducted through close collaboration between the World Health Organization (WHO), country ministries of health (MOH), other national health agencies such as the US Centers for Disease Control and Prevention (CDC), nongovernmental organizations (NGOs), academic research groups, and many others. These partnerships helped to prepare countries to respond to seasonal influenza outbreaks, the emergence of human infections with highly pathogenic avian influenza A(H5N1) virus starting in 2004, the 2009 influenza A(H1N1) pandemic (*1*), and the COVID-19 pandemic.

A central component of building global influenza surveillance capacity has been the Global Influenza Surveillance and Response System (GISRS). GISRS, established in 1952 by WHO to monitor circulating influenza virus strains to improve strain selection for seasonal and pandemic influenza vaccines, operates through a network of 148 National Influenza Centres (NICs), 7 Collaborating Centers (CCs), 4 Essential Regulatory Laboratories, and 13 H5 Reference Laboratories (*1*,*2*). Since 1956, the CDC Influenza Division, part of the National Center for Immunization and Respiratory Diseases, has served as a WHO CC for Surveillance, Epidemiology, and Control of Influenza as part of GISRS. In this role, the division has supported global expansion of year-round epidemiologic and virologic surveillance for rapid detection and characterization of seasonal influenza viruses, other respiratory viruses, and other viruses with pandemic potential (*3*). Starting in 2004, the Influenza Division developed an international program with the objective of increasing global contributions to GISRS through the establishment

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of new or expansion of existing national influenza surveillance systems. The division has provided technical and financial assistance to >120 partners in >70 countries to improve influenza prevention and control activities. The Influenza Division established and maintained 5-year cooperative agreements with partner countries and WHO Regional Offices to support influenza surveillance capacity building and pandemic preparedness activities. Moreover, Influenza Division staff have been posted in 17 overseas locations at various times, including at WHO headquarters and Regional Offices, to work closely with public health partners.

On March 11, 2020, WHO made the assessment that COVID-19, the disease caused by SARS-CoV-2 infection, was a pandemic (*4*). In this report, we describe global influenza surveillance systems, pandemic preparedness activities, and partnerships and how these helped the international and country-specific response to the COVID-19 pandemic, focusing on programs and activities supported by the CDC Influenza Division. We also present perspectives about how these programs can continue to support surveillance for influenza, SARS-CoV-2, and other respiratory viruses and bolster preparedness for respiratory viruses with epidemic and pandemic potential.

Leveraging of Influenza Surveillance Infrastructure and Systems for SARS-CoV-2 Surveillance

The Influenza Division's first international program activities in 2004 included supporting the MOH of 9 countries to build or expand their national influenza surveillance systems and pandemic preparedness. By 2018, CDC funding support for influenza surveillance reached >70 countries, in part because of the 2009 H1N1 pandemic response (*5*). Through these activities, WHO, MOH, the Influenza Division, and others at CDC, including the Division of Global Health Protection, Center for Global Health, have defined and standardized severe acute respiratory infection (SARI) and influenza-like illness (ILI) case definitions for respiratory disease surveillance. The Influenza Division assisted in the development of WHO's global surveillance guidelines to standardize how influenza surveillance is conducted across countries and reported to FluNet as part of the GISRS platform (*6*). The division also supported countries as they established sentinel surveillance sites for the identification of persons with influenza or other respiratory virus infections. Along with partners, the Influenza Division provided courses on data analysis, data management, response procedures for respiratory outbreaks, and surveillance system evaluation, and conducted site visits to support surveillance programs and provide technical assistance. With such guidance, many countries increased the number of specimens tested and reported to FluNet; countries that were partnered with the Influenza Division doubled the annual number of specimens tested for influenza viruses and reported to FluNet from 2013 (>500,000 specimens/year) to 2019 (>1 million specimens/year) (*5*). This testing and sentinel surveillance enabled characterization of the seasonality and temporality of influenza and other respiratory viruses, including human coronaviruses, and it equipped countries with the tools to detect disease clusters and community transmission. MOH in several countries subsequently established non–sentinel-based surveillance systems for respiratory viruses, with support from WHO, the Food and Agriculture Organization of the United Nations, CDC, and international NGOs. Thailand and Bangladesh, for example, established event-based surveillance (*7*) for unusual respiratory events in humans, and Bangladesh, Laos, Vietnam, China, and Kenya established zoonotic surveillance in live bird markets for earlier detection of novel respiratory viruses.

As SARS-CoV-2 spread globally, countries used their SARI/ILI sentinel surveillance systems and case definitions to collect and report case data for COVID-19 surveillance. They also used their non–sentinel-based surveillance systems, including event-based surveillance, to further help identify and track COVID-19 community clusters. This capacity to leverage influenza sentinel surveillance systems for COVID-19 was bolstered by the GISRS platform (*8*) and guidance documents that resulted from the WHO Consultations in March and October 2020 focused on adapting influenza sentinel surveillance systems to include COVID-19 (*9*,*10*). Staff from MOH, national health institutes, the European Centre for Disease Prevention and Control, the Influenza Division, and other expert groups participated in these consultations. They contributed to guidance on monitoring COVID-19 through existing influenza sentinel surveillance systems while maintaining influenza surveillance, adapting algorithms to test for both respiratory viruses, and reporting weekly aggregated sentinel surveillance data through the GISRS platform. WHO and the Influenza Division later held trainings on implementing this guidance (*11*). Countries began reporting their SARS-CoV-2 testing data captured through influenza sentinel surveillance to FluNet, which was made publicly available by WHO region (*12*).

A survey administered by CDC found that by May 2020, 82% of Influenza Division partner countries

were using their influenza surveillance systems to identify suspected COVID-19 cases and test for SARS-CoV-2. For example, several countries in Africa with established SARI/ILI surveillance platforms reported using these systems to test for SARS-CoV-2, including Togo, which reported that all its COVID-19–related surveillance activities were conducted using its influenza framework (SARI/ILI sentinel surveillance and routine respiratory disease surveillance systems). Both Mozambique and Nepal used SARI/ILI sentinel surveillance systems to monitor for suspected cases of COVID-19 among persons with a known epidemiologic link or travel history. Jamaica optimized its ILI surveillance to detect suspected COVID-19 clusters as possible signals of community transmission. During the early months of the pandemic, however, MOH mounted national responses with support from WHO and local NGOs and academic and health institutes, in some cases with limited guidance and reagent and protocol distribution from CDC, who was managing the domestic response in the United States. At this stage of the pandemic, the Influenza Division was able to provide the most direct technical assistance to countries supported by field staff. We have summarized milestones and accomplishments of 7 countries where Influenza Division field staff supported local partners in leveraging influenza platforms and integrating SARS-CoV-2 surveillance (*13*–*16*) (Table 1).

Harnessing of Influenza Laboratory Surveillance Infrastructure to Build SARS-CoV-2 Laboratory Surveillance Capacity

GISRS has built international influenza surveillance laboratory capacity that was instrumental in the

Table 1. Milestones and achievements of 7 countries that worked closely with CDC Influenza Division field staff as they integrated SARS-CoV-2 and influenza surveillance*

Date	Milestone or achievement
December 2019	• The WHO country office in China learns of cases of viral pneumonia in the city of Wuhan, China, and notifies the International Health Regulations focal point in the WHO Western Pacific Regional Office on December 31, 2019 (*4*).
January 2020	• Vietnam leverages laboratory capacity built for influenza surveillance to begin testing for SARS-CoV-2 and detects the first case in the country on January 23, 2020. • WHO declares that the COVID-19 outbreak is a Public Health Emergency of International Concern on January 30, 2020 (*4*). • India selects 13 of its Virus Research and Diagnostic Laboratories already equipped to conduct influenza virus testing to start testing for SARS-CoV-2 in 11 states (*13*). • South Africa's NIC at NICD begins testing for SARS-CoV-2 as part of the country's pneumonia and ILI surveillance system.
February 2020	• Thailand starts testing for SARS-CoV-2 using its influenza platform, including its sentinel surveillance systems.
March 2020	• WHO makes the assessment that COVID-19 is a pandemic on March 11, 2020 (*4*). • Laos starts testing for SARS-CoV-2 through its SARI/ILI sentinel surveillance systems. • Bangladesh starts testing for SARS-CoV-2 through its SARI/ILI sentinel surveillance systems. • NICD (South Africa) confirms the country's first case of COVID-19 on March 5, 2020; testing is expanded from the NIC at NICD to the Network for Genomic Surveillance in South Africa, a network of public and private laboratories, academic institutions, and scientists.
April 2020	• Kenya starts testing for SARS-CoV-2 through 8 SARI/ILI sentinel surveillance sites in the country.
July 2020	• Vietnam's severe viral pneumonia surveillance system detects cases from a nosocomial outbreak that leads to the country's second COVID-19 wave (*14*).
December 2020	• Bangladesh enrolls 1,986 case-patients from its SARI sentinel surveillance sites from March–December 2020; 285 (14.3%) are infected with SARS-CoV-2, 175 (8.8%) are infected with influenza virus, and 5 (0.3%) are infected with both respiratory viruses (*15*).
February 2021	• NICD (South Africa) starts receiving requests for SARS-CoV-2 sequencing from other countries in the region and accepts specimens for sequencing from Eswatini, Lesotho, Mauritius, Mozambique, Namibia, and Sudan.
September 2021	• Thailand adds a module of questions to its influenza sentinel surveillance forms to assess influenza and COVID-19 vaccination history in 6 sentinel surveillance sites as part of its Influenza and SARS-CoV-2 Vaccine Effectiveness Network.
November 2021	• On November 24, 2021, NICD and the Network for Genomic Surveillance in South Africa report a new variant of SARS-CoV-2 that was detected from specimens collected on November 14, 2021 in South Africa. • WHO designates B.1.1.529 as Omicron, the fifth variant of concern, on November 26, 2021 (*16*).
March 2022	• Thailand's Influenza and SARS-CoV-2 Vaccine Effectiveness Network reports that of 2,425 specimens collected and tested, 6 (0.2%) are positive for influenza and 573 (23.6%) are positive for SARS-CoV-2; 426 (74.3%) of these SARS-CoV-2–positive specimens are detected during January–March 2022, a period when >90% of sequenced viruses are the Omicron variant. • Kenya reports having enrolled 6,822 SARI/ILI case-patients through its sentinel surveillance system during April 2020–March 2022, of whom 738 (10.8%) test positive for SARS-CoV-2, 628 (9.2%) test positive for influenza, and 63 (0.9%) are co-infected with influenza and SARS-CoV-2.

*CDC, US Centers for Disease Control and Prevention; ILI, influenza-like illness; NIC, National Influenza Centre; NICD, National Institute for Communicable Diseases; SARI, severe acute respiratory infection; WHO, World Health Organization.

response to global infectious disease outbreaks, including the 2009 H1N1 pandemic, 2013 H7N9 outbreak, and COVID-19 pandemic. Influenza Division laboratory teams supported NICs in >120 countries and enhanced laboratory diagnostic capacity through the development of novel assays and proficiency panels, reagent distribution, and technical guidance. WHO and the Influenza Division also worked closely with MOH and other partners, such as the Association of Public Health Laboratories, to support in-depth training to build laboratory capacity and prepare countries to respond to respiratory viruses with epidemic and pandemic potential. In 2017, WHO, the Food and Agriculture Organization of the United Nations, the World Organisation for Animal Health, the Influenza Division, and 150 partners from 12 member states updated global epidemiology and laboratory rapid response trainings for respiratory epidemics; these trainings were held in multiple countries in Asia and the Americas in 2019 before the COVID-19 pandemic. By using these resources, NICs optimized their laboratory capacity to harness influenza diagnostic platforms to test for pandemic- and epidemic-prone respiratory viruses, including Middle East respiratory syndrome coronavirus, respiratory syncytial virus, and more recently, SARS-CoV-2. As a GISRS CC and a participant in WHO's Pandemic Influenza Preparedness Framework (*17*), the Influenza Division also contributed to global respiratory virus genomic sequencing capacity. Staff worked closely with WHO's Global Influenza Programme in developing influenza genomic surveillance recommendations and with GISAID (https://www.gisaid.org), an initiative founded on sharing influenza virus sequencing data, to develop critical sequencing informatics tools and train partners on their use. Partner countries built their genomic sequencing capacity with support from WHO, the Influenza Division, academic institutions, and institutes of health. For example, Chile established next-generation sequencing in collaboration with the Pan American Health Organization (PAHO) and the Influenza Division, a program that is now being used as a pilot for establishing next-generation sequencing laboratory and informatics pipelines in NICs globally.

As COVID-19 spread globally, NICs and public health laboratories rapidly mobilized to test respiratory specimens for SARS-CoV-2 by using influenza laboratory infrastructure, which was then expanded to intermediary, subnational laboratories. A small case study at the end of this section highlights SARS-CoV-2 testing capacity in countries working with the Influenza Division.

As part of its support for the global response to the COVID-19 pandemic, the Influenza Division developed and manufactured a research-only use influenza virus and SARS-CoV-2 (Flu SC2) real-time reverse transcription PCR multiplex assay that enables simultaneous detection of influenza A and B viruses and SARS-CoV-2 (*18*). Influenza Division staff conducted hybrid online and in-person training on this assay to aid users globally, including with partners in the WHO Regional Office for the Eastern Mediterranean and PAHO. The Flu SC2 multiplex assay was distributed globally by the International Reagent Resource (IRR). Originally known as the Influenza Reagent Resource, IRR was established in 2008 by CDC to manufacture, stock, and distribute key reagents and test kits globally and to develop and distribute resources for outbreak responses and the detection of emerging pathogens. Although the program experienced challenges and delays in distributing reagents for SARS-CoV-2 testing during most of 2020, IRR organized global distribution of 1,936 kits of the Flu SC2 multiplex assay to 151 laboratories in 134 countries during October 1, 2020–February 28, 2022, corresponding to >968,000 tests. These assays allowed laboratories to conduct more tests in less time while optimizing the use of important testing materials and facilitating uninterrupted surveillance for both influenza and SARS-CoV-2, even as influenza laboratory staff were reassigned to assist with SARS-CoV-2 testing.

During the COVID-19 pandemic, countries leveraged their influenza platforms and trainings to sequence SARS-CoV-2 and publicly share sequencing data through GISAID. For example, Thailand, which received training on next-generation sequencing from the Influenza Division before the pandemic, received additional support to sequence SARS-CoV-2 and used this platform. Chile used its next-generation sequencing platform to identify novel SARS-CoV-2 variants in the Southern Hemisphere (*19*). CDC also received and sequenced SARS-CoV-2 specimens collected globally using the same staff and infrastructure that routinely monitor influenza viruses for antigenic drift. Laboratory and informatics staff from the Influenza Division comprised ≈75% of CDC's COVID-19 Strain Surveillance and Emerging Variant Team that tracks, sequences, isolates, and antigenically characterizes SARS-CoV-2 variants. Division laboratory staff also developed and performed assays to measure neutralizing activities of sera from SARS-CoV-2–infected or COVID-19 vaccinated persons. These activities helped identify the emergence and spread of SARS-CoV-2 variants of concern and assess correlates of immune protection after natural infection or vaccination. Such activities are anticipated to help with strain selection for future COVID-19 vaccines.

Case Study

Using data extracted from Our World in Data (*20*) and Johns Hopkins University (*21*), we described SARS-CoV-2 testing in low- and middle-income countries (LMICs) to evaluate whether those partnered with the Influenza Division were well-positioned to conduct testing and report data. These data were collected from official publicly available sources, usually published by ministries of health or other government entities (*20*,*21*). Partner countries were defined as LMICs that received CDC funding to support influenza surveillance activities since 2013; we identified 64 partner countries. LMICs were considered to have regular testing data if they reported SARS-CoV-2 testing data (inclusive of reverse transcription PCR and antigen tests) on ≥13% of the days that they reported any COVID-19 data (e.g., confirmed cases and hospitalizations). We selected 13% as a cutoff to approximate weekly (4 times in 30 days) reporting to increase comparability between countries.

Of the 64 LMICs partnered with ID, 41 (64%) regularly reported SARS-CoV-2 testing data by June 2020, with >40 million tests (Table 2). By September 2020, 42 partner LMICs (66%) reported >158 million tests, and by October 2021, 45 (70%) reported >1 billion tests. The scale-up in testing capacity in these countries was accomplished despite major shortages in testing reagents and delays in reagent distribution (22). Median tests per 1,000 persons were highest during January 2020–October 2021 at 240.7 tests/1,000 persons (interquartile range 90.1–424.8 tests/1,000 persons). Median tests per confirmed COVID-19 case were highest during the January 2020–June 2020 start of the pandemic, at 20.9 tests/confirmed case (interquartile range 9.3–34.4 tests/confirmed case).

Use of Influenza Pandemic Preparedness Plans and Trainings for the COVID-19 Response

For years, countries developed pandemic preparedness plans for their national responses (*23*–*25*) and participated in tabletop and simulation exercises on unusual respiratory events and influenza pandemics with WHO and Influenza Division guidance and training. In November 2019, just before the start of the COVID-19 pandemic, Myanmar and the Association of Southeast Asian Nations led a joint tabletop pandemic response exercise with Laos, Cambodia, WHO, and CDC. During 2018–2019, WHO led a multiregional effort to review National Influenza Pandemic Preparedness Plans (NIPPPs) with support from CDC; officials at the WHO Regional Office for the Eastern Mediterranean (*26*) and PAHO held workshops. These pandemic preparedness activities and exercises facilitated cross-sectoral collaboration between healthcare providers, national reference laboratories, emergency operation centers, and pandemic vaccine deployers during the COVID-19 pandemic. Countries were able to use their NIPPPs to quickly develop and operationalize their COVID-19 strategic preparedness and response plans in the face of this new disease and a rapidly evolving epidemiologic climate. In some cases, the national deployment and vaccination plans developed by countries participating in COVAX (*27*), a program co-led by WHO, the Coalition for Epidemic Preparedness Innovations, and Gavi, the Vaccine Alliance, aimed at ensuring equitable COVID-19 vaccine distribution, were adapted from existing approved NIPPPs.

Expansion of Existing Influenza Evaluation Projects to Include COVID-19 Program Evaluations and Studies

During the past decade, MOH engaged in research to better understand influenza virus transmission, epidemic timing, disease and economic burden, and influenza vaccine effectiveness and cost-effectiveness in collaboration with the Influenza Division, other CDC divisions, WHO, and academic research groups. With the global spread of COVID-19, these partnerships were leveraged to collect data about SARS-CoV-2 transmission dynamics and, later, COVID-19 vaccine effectiveness. Research sites in Guatemala, India (*28*), Kenya, Peru, South Africa, and Thailand with CDC staff or collaborating with the agency expanded their influenza evaluation portfolios to engage in COVID-19 projects. Influenza population-based surveillance and

Table 2. Number of SARS-CoV-2 tests and median number of tests per 1,000 persons and per confirmed COVID-19 case among 64 CDC Influenza Division partner LMICs across 3 periods*

Period	No. (%)	Cumulative no. tests†	Median no. tests/1,000 persons (IQR)†	Median no. tests/confirmed case (IQR)†
Jan–Jun 2020	41 (64)	40,092,751	8.2 (3.6–24.6)	20.9 (9.3–34.4)
Jan–Sep 2020	42 (66)	158,319,895	28.4 (11.8–70.1)	11.6 (6.8–24.2)
Jan 2020–Oct 2021	45 (70)	1,051,798,691	240.7 (90.1–424.8)	8.5 (5.7–14.0)

*Partner countries were defined as LMICs that received CDC funding to support influenza surveillance activities since 2013. LMICs were included if they reported SARS-CoV-2 testing data on ≥13% of the days that they reported any COVID-19 data (e.g., confirmed cases and hospitalizations) to approximate 4-times-per-month (4/30 days) reporting. CDC, US Centers for Disease Control and Prevention; IQR, interquartile range; LMICs, low- and middle-income countries.
†Testing data were extracted from ministry of health and other government webpages, and included either reverse transcription PCR tests, antigen tests, or both.

Influenza Division–supported cohort studies in special populations are being used to investigate laboratory-confirmed SARS-CoV-2 incidence, infection risk and mitigating factors, reinfection, and post–COVID-19 conditions among agricultural workers in Guatemala (*29*), pregnant women in Kenya (*30*), older adults in India, and healthcare providers in Peru (*31*). Several of these cohorts are also examining COVID-19 vaccine effectiveness to SARS-CoV-2 variants by dosing schedules. In Thailand, the Ministry of Health and Influenza Division field staff leveraged close partnerships with academic institutions and hospitals to conduct a serosurvey among health care personnel 1 year after the start of the pandemic (*32*) and after COVID-19 vaccination (*33*). The 13-country PAHO Network for the Evaluation of Vaccine Effectiveness in Latin America and the Caribbean, known as REVELAC-I for its acronym in Spanish (*34*), was activated to assess COVID-19 vaccine effectiveness among hospitalized persons in countries such as Paraguay (*35*); CDC supported this work with financial and technical resources.

Leveraging of Influenza Vaccine Partnerships for COVID-19 Vaccine Introduction

Influenza vaccine programs are important for pandemic preparedness (*36*) and helped countries prepare for COVID-19 vaccine introduction. An analysis of the 2009 H1N1 pandemic response, for example, found that countries with influenza vaccination programs before the pandemic were more readily able to receive, distribute, and deliver pandemic influenza vaccines (*36*). Efforts for sustainable, seasonal national vaccination programs have been supported by the Partnership for Influenza Vaccine Introduction (PIVI), which includes the Task Force for Global Health, MOH, the Influenza Division, and other groups (*37*). This partnership has provided technical support to MOH in 17 countries and has enabled the distribution of >4.2 million doses of influenza vaccine since 2013 (*38*). During the COVID-19 pandemic, PIVI partnered with CDC's Global Immunization Division, Center for Global Health, to establish the COVID-19 Implementation Program (CoVIP), whose goal is to support low- and middle-income countries as they administer and evaluate COVID-19 vaccines.

As WHO, MOH, and other international agencies and organizations worked to increase global readiness to implement and evaluate COVID-19 vaccination programs, CoVIP helped >30 partner countries develop workplans to prepare for COVID-19 vaccine rollout and funded all as of August 2021. As part of these activities, the Albania Institute of Public Health and the Armenia National Center for Disease Control used their detailed influenza vaccine distribution microplans for target groups to quickly develop detailed plans for COVID-19 vaccine deployment. CoVIP activities to support partner countries include assistance with safety monitoring, increasing public demand, risk communication, workforce development, data management, and post-introduction and vaccine effectiveness evaluations. Last, PIVI developed a learning agenda to evaluate how existing influenza vaccination platforms for health workers may have facilitated COVID-19 vaccine rollouts.

Conclusion

The epidemiologic and virologic surveillance systems and programs built for influenza during the past 70 years by MOH, WHO, CDC, and many other partners have been critical to the global response to the COVID-19 pandemic. This report based its influenza and COVID-19 programmatic findings on careful review of peer-reviewed publications, publicly available testing data, archival records of timelines, and CDC records to present the value and importance of investments in influenza surveillance and programs for the COVID-19 pandemic response. However, this report is limited because it focuses on CDC's international influenza program through the Influenza Division and its role as partners responded to the COVID-19 pandemic but does not exhaustively cover the work and achievements of other influenza program stakeholders. We do not have comprehensive information about MOH, WHO, NGOs, local academic and health institutes, and funding organizations' COVID-19 pandemic response investments and thus were unable to systematically describe and incorporate their contributions during the pandemic.

As the world adjusts to a long-term strategy for COVID-19 mitigation, the integration of COVID-19 surveillance into existing influenza sentinel surveillance systems and GISRS will facilitate continued global surveillance for respiratory viruses with epidemic and pandemic potential. Staff from MOH, national health institutes, the Influenza Division, and other expert groups contributed to WHO's recent revised interim guidance, End-to-End Integration of SARS-CoV-2 and Influenza Sentinel Surveillance, published in January 2022 (*39*). CDC's Influenza Division will continue to support its partner countries as they implement this end-to-end integration and monitor trends and seasonality of SARS-CoV-2 and influenza viruses through cooperative agreements with countries and WHO Regional Offices, laboratory capacity building efforts, and reagent distribution through IRR. Influenza Division staff are working with WHO to revise SARI/ILI sentinel surveillance

assessment tools to better document and strengthen countries' capacity to monitor SARS-CoV-2 and influenza viruses through existing sentinel sites and national programs. IRR continues to distribute the Flu SC2 multiplex assay globally, and the Influenza Division is working with NICs to develop next-generation sequencing workflows to characterize influenza A, influenza B, and SARS-CoV-2 specimens through timely quality sequencing of representative viruses. Influenza Division laboratory staff and the Association of Public Health Laboratories are working with WHO Regional Offices to conduct trainings with NIC and national influenza laboratory staff on the Flu SC2 multiplex assay and influenza and SARS-CoV-2 next-generation sequencing molecular and informatic pipelines. Finally, the vaccine effectiveness evaluations and epidemiologic investigations that the Influenza Division supports through partnerships with WHO Regional Offices, MOH, academic institutions, Task Force for Global Health, CDC field offices, and other in-country collaborators will continue to build upon enhanced surveillance and genomic sequencing pipelines to help assess COVID-19 vaccine effectiveness to emerging SARS-CoV-2 variants, which MOH can use to help develop national COVID-19 vaccination programs and boosting schedules.

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Incorporating COVID-19 into Acute Febrile Illness Surveillance Systems, Belize, Kenya, Ethiopia, Peru, and Liberia, 2020–2021

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Existing acute febrile illness (AFI) surveillance systems can be leveraged to identify and characterize emerging pathogens, such as SARS-CoV-2, which causes COVID-19. The US Centers for Disease Control and Prevention collaborated with ministries of health and implementing partners in Belize, Ethiopia, Kenya, Liberia, and Peru to adapt AFI surveillance systems to generate COVID-19 response information. Staff at sentinel sites collected epidemiologic data from persons meeting AFI criteria and specimens for SARS-CoV-2 testing. A total of 5,501 patients with AFI were enrolled during March 2020–October 2021; ≥69% underwent SARS-CoV-2 testing. Percentage positivity for SARS-CoV-2 ranged from 4% (87/2,151, Kenya) to 19% (22/115, Ethiopia). We show SARS-CoV-2 testing was successfully integrated into AFI surveillance in 5 low- to middle-income countries to detect COVID-19 within AFI care-seeking populations. AFI surveillance systems can be used to build capacity to detect and respond to both emerging and endemic infectious disease threats.

Acute febrile illness (AFI) is a common clinical syndrome that can be caused by various pathogens, ranging from treatable and vaccine-preventable infectious agents to newly emerging pathogens with pandemic potential (*1*). AFI is characterized by recent onset of fever with or without localizing symptoms, and etiologies can vary depending on the population, region, season, or patient age. Comparable data

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describing the epidemiology and distribution of AFI across countries and regions are limited, particularly among low- and middle-income countries (*2*). In countries with limited laboratory diagnostic testing resources, common causes of fever are challenging to diagnose through clinical assessment alone when localizing symptoms are absent and endemic disease prevalence is unknown. Many low- and middle-income countries struggle to build needed laboratory diagnostic capacity because of resource constraints. Reduced diagnostic capability can lead to inaccurate empirical diagnosis and treatment of emerging infectious and other febrile diseases and encumber both the healthcare system and the population it serves. Management of febrile illness in a primary healthcare clinic can differ from that in a hospital setting in which empiric diagnosis and treatment can be crucial for patients with severe febrile illness or sepsis. Nevertheless, improved knowledge of locally circulating infectious disease etiologies can inform these diagnoses in both healthcare settings. Lack of knowledge of endemic etiologies for AFI can result in delayed diagnoses and treatment and overuse of antimicrobial drugs, which can undermine trust in healthcare systems and governments (*3*).

AFI surveillance is a critical component of a global health strategy and aims to generate data and build capacity to detect and respond to both emerging and endemic infectious disease threats (*4*,*5*). For example, AFI surveillance detected a chikungunya virus outbreak in Puerto Rico in 2014, and the first Zika virus infections in 50 years were identified in Uganda in 2017 through AFI surveillance (*6*,*7*). Through the collection and interpretation of epidemiologic and laboratory data, AFI surveillance data can provide estimates of the occurrence and distribution of disease, inform clinical care practices (including antimicrobial stewardship), and guide prevention measures and public health action. Furthermore, flexible AFI surveillance systems that can adapt to and be leveraged for pathogen-specific needs have been indispensable during the emergence of infectious disease threats, such as Zika virus in the Americas and French Polynesia, yellow fever and Ebola viruses in Africa, and now SARS-CoV-2 worldwide (*8*–*10*).

On March 11, 2020, the World Health Organization (WHO) declared COVID-19 a pandemic (*11*). In response, the US Centers for Disease Control and Prevention (CDC) developed guidance on adapting AFI surveillance systems to integrate SARS-CoV-2 testing into existing or planned AFI activities in various countries (*12*). CDC recommended maintaining the same selection criteria for patients that were used before surveillance integration, which enabled countries to incorporate AFI surveillance systems with minimal disruption. AFI surveillance could be vital for monitoring COVID-19, which can cause fever without localizing symptoms and evade influenza-like illness surveillance if no respiratory symptoms are present (*13*–*17*). We describe how AFI surveillance systems were leveraged to detect and characterize SARS-CoV-2 infections using preliminary data from 5 low- to middle-income countries that incorporated SARS-CoV-2 detection into their AFI surveillance programs.

Materials and Methods

General AFI Surveillance Methods

To select sentinel sites for AFI surveillance, CDC, host governments, and implementing partners considered various factors, including the presence of existing and adaptable data collection platforms, patient volume, known infectious disease hotspots or priority regions, laboratory infrastructure and specimen transport networks, geographic representation, and urban versus rural catchment areas. Surveillance staff members were trained in procedures used for patient screening, consent and enrollment, data collection, and specimen collection and transportation. Staff screened patients with acute fever or a history of acute fever in both outpatient and inpatient settings and enrolled patients who met the AFI case definition and consented to participate in surveillance activities. AFI case definitions were based on pathogen-specific priorities for each country or region. Staff members used questionnaires to collect demographic, clinical, and exposure data from enrolled patients. Epidemiologic data were linked to laboratory data either manually or automatically, depending on the country's data management system, through a unique patient identifier.

Surveillance staff collected whole blood from participants in each country that implemented AFI surveillance. A TaqMan array card that detects multiple targets of both bacterial and viral pathogens from a single sample was developed specifically for AFI surveillance and has been successfully implemented (*18*). This array card, which uses a singleplex microfluidics multiple pathogen PCR detection system, was commonly used to test for pathogens in blood and is not commercially available. CDC partners often use custom versions according to the country's pathogens of interest. In addition, singleplex reverse transcription PCR, multiplex PCR panels, point-of-care rapid testing, or serologic tests were used to identify

specific viral or parasitic pathogens. Depending on the country's protocol and pathogens under surveillance, additional specimens were collected, including respiratory specimens, such as nasopharyngeal, oropharyngeal, and nasal mid-turbinate swab samples, as well as saliva, urine, feces, or eschar samples. CDC and partners selected the list of pathogens for testing according to the pathogens of interest in each country or region, laboratory capabilities, and potential for developing surveillance and laboratory capacity in-country.

COVID-19 Integration

In response to the COVID-19 pandemic, CDC collaborated with partners in different countries to incorporate COVID-19 surveillance into existing or planned AFI surveillance systems. CDC and implementing partners defined how surveillance would be performed and adapted laboratory testing algorithms and case selection criteria, if necessary, to account for respiratory symptoms. COVID-19–specific questions were incorporated into existing questionnaires to ascertain COVID-19–like symptoms, such as shortness of breath, loss of taste, and loss of smell, and COVID-19 vaccination status. Potential exposures were documented, including attendance at large gatherings, contact with anyone suspected of having or confirmed to have COVID-19 or a similar illness, or domestic travel 14 days before symptom occurrence. If respiratory specimens were not collected under the original AFI surveillance protocol, ≥1 specimen was obtained from all consenting patients with AFI.

Country-Specific Methods

The 5 countries evaluated in this study were Belize, Kenya, Ethiopia, Peru, and Liberia. We analyzed AFI and COVID-19 surveillance methods for each country, aggregating AFI surveillance enrollment data and SARS-CoV-2 test results. Methods for AFI surveillance and COVID-19 integration activities varied by country (Table 1).

Each country implemented sentinel surveillance (Table 2). AFI surveillance in Kenya took place specifically at 2 population-based clinics that were essentially sentinel sites but had well-defined catchment areas (*19*,*20*). An inclusion criterion for participation in the AFI surveillance system was a minimum body temperature of 38°C in each country except Liberia, which required a minimum body temperature of 37.5°C. Another inclusion criterion was a history of fever within a set number of days that was either combined with or instead of the minimum required body temperature. Belize was the only country that included afebrile patients if they had ≥2 respiratory symptoms, a history of travel, or other COVID-19 risk factors, or ≥2 gastrointestinal symptoms. All countries except Kenya had an age requirement for participants.

Surveillance site staff collected epidemiologic data by using a combination of electronic and paper-based data collection tools and methods. Platforms, such as REDCap (https://www.project-redcap.org), Epi Info (https://www.cdc.gov/epiinfo), Microsoft Excel and Access (https://www.microsoft.com), or country-specific patient care systems were used for data entry and management. Laboratory staff tested all respiratory specimens collected from consenting participants for SARS-CoV-2 using PCR methods. Liberia was the only country to require a separate verbal agreement for SARS-CoV-2 testing.

Survey activities underwent human subjects review and received approval within their respective countries or institutions. AFI activities also underwent human subjects ethics review by CDC and were conducted in accordance with applicable CDC policy and federal law, including the code of federal regulations (CFR) and US codes (USC) 45 CFR part 46, 21 CFR part 56; 42 USC §241(d); 5 USC §552a; 44 USC §3501 et seq.

For each country, we summarized the information obtained for enrolled AFI surveillance participants during the data collection period and stratified the data by age and sex. CDC did not request or receive any personally identifiable data. The data collection period varied by country; the start date represents the month that COVID-19 surveillance was implemented, and the end date indicates when data were available for analysis in this study. Data collection in each country was ongoing as of June 3, 2022. We calculated the number and percentage of enrolled persons who were tested for SARS-CoV-2; the numbers and percentage of SARS-CoV-2–positive samples were calculated and stratified by age of participants. We used Microsoft Excel version 2102 for all calculations.

Results

The data collection periods in the 5 countries ranged from 4 to 17 months (Table 3). Belize integrated SARS-CoV-2 testing in March 2020, Kenya in May 2020, Ethiopia in February 2021, Peru in February 2021, and Liberia in April 2021. A total of 5,501 patients with AFI were enrolled during the period from initiation of COVID-19 surveillance activities to when data were available for this analysis. Participants who were 15–44 years of age comprised 50% (817/1,627) of enrollees in Belize, 44% (51/115) in Ethiopia, and 66% (228/344) in Peru, whereas 81% (2,507/3,113) of

enrolled patients in Kenya and 47% (141/302) in Liberia were <15 years of age. The sex distribution of participants was approximately equal in Belize (48% male patients, 788/1,627), Kenya (48% male patients, 1,487/3,113), and Peru (52% male patients, 178/344), whereas 43% (131/302) of participants in Liberia were male. In Ethiopia, 57% (65/115) of enrolled patients were male; however, 17% (20/115) of participants in Ethiopia had missing age and sex data.

The percentage of enrolled patients who were tested for SARS-CoV-2 was 84% (1,362/1,627) in Belize, 69% (2,151/3,113) in Kenya, 100% (115/115) in Ethiopia, 97% (334/344) in Peru, and 71% (215/302) in Liberia. Within each age group, >50% of enrolled participants consented to respiratory specimen collection and SARS-CoV-2 testing (Table 3). SARS-CoV-2 percent positivity varied by country. COVID-19 surveillance was integrated with AFI surveillance in early 2020 in Kenya and Belize. Among SARS-CoV-2–tested patients with AFI, samples from 4% (87/2,151) of patients in Kenya and 11% (151/1,362) in Belize were positive for the virus. COVID-19 integration began in early 2021 in Ethiopia, Peru, and Liberia. Among SARS-CoV-2 tested patients with

Table 1. Summary of methods used for COVID-19 incorporation into acute febrile illness surveillance systems in Belize, Kenya, Ethiopia, Peru, and Liberia, 2020–2021*

Category	Belize	Kenya†	Ethiopia	Peru	Liberia
Surveillance start dates					
AFI	2020 Jan	2006 Jan	2021 Feb	2021 Feb	2018 Dec
COVID-19 integration	2020 Mar	2020 May	2021 Feb	2021 Feb	2021 Apr
No. sites	11	2	4‡	5	2
Inclusion criteria					
Age	≥60 d	All ages	≥5 y	>10 y	≥2 y (AFI), ≥5 y (COVID-19)
Documented body temperature or history of fever	Axillary, oral, or rectal T ≥38°C or new fever ≤7 d before exam	Axillary T ≥38°C and ≤5 d of acute fever	Axillary, oral, or rectal T ≥38°C and fever for 2–14 d before exam	Axillary, oral, or rectal T ≥38°C and new fever ≤14 d before exam	Axillary, oral, or rectal T ≥37.5°C or fever ≤7 d before exam
Afebrile patients	≥2 respiratory symptoms and high risk for or suspected SARS-CoV-2 infection or ≥2 GI symptoms	None	None	None	None
Exclusion criteria					
Surveillance protocol procedures	Previously enrolled within the past 7 d or declined follow up for disease outcomes	Previously enrolled	Previously enrolled	None	Previously enrolled within past year
Chief complaint on arrival or during hospitalization	Injury, trauma, or known cause of fever; returning with known cause of fever	Injury or trauma	Injury, trauma, focal infection, localizing symptoms, obstetric- or surgery-related cases	Focal infection or fever onset >24 h after hospitalization (inpatients only)	Injury, trauma, focal infection, returning with known cause of fever
Data use methods§					
Collection	REDCap and paper-based form	Windows-based platform	Paper-based form	REDCap	Paper-based form
Management	REDCap	Microsoft SQL servers	Microsoft Excel	Microsoft Access	Epi Info
Specimens	Blood, NP/OP swabs, feces, eschar swabs	Blood, NP/OP swabs;¶ urine	Blood, NP/OP swabs¶	Blood, nasal MT swabs, saliva	Blood, NP swabs¶
COVID-19 testing methods	Singleplex RT-PCR,# BioFire FilmArray respiratory panel**	RT-PCR#	Singleplex PCR#	CDC COVID-19 assay#††	TaqPath COVID-19 CE-IVD RT-PCR#‡‡

*Data are sorted by COVID-19 integration month. AFI, acute febrile illness; GI, gastrointestinal; MT, mid-turbinate; NP, nasopharyngeal; OP, oropharyngeal; RT-PCR, reverse transcription PCR; T, temperature.
†Data are from Kenya's population-based infectious disease surveillance sites with survey-defined catchment areas.
‡Of 5 designated sites, only 4 were operational because of security issues.
§REDCap (https://www.project-redcap.org); Microsoft Excel, Access, SQL Server, and Windows-based platform (https://www.microsoft.com); Epi Info (https://www.cdc.gov/epiinfo).
¶Additional specimens collected after COVID-19 surveillance integration into regular AFI surveillance activities.
#Tests performed specifically for SARS-CoV-2.
**BioFire (https://www.biofiredx.com).
††2019 nCoV Real-Time RT-PCR Diagnostic Panel, Centers for Disease Control and Prevention (https://www.cdc.gov/coronavirus/2019-ncov/lab/testing.html).
‡‡TaqPath COVID-19 CE-IVD RT-PCR kit, Thermo Fisher Scientific (https://www.thermofisher.com).

Table 2. Surveillance sites for COVID-19 incorporation into acute febrile illness surveillance systems in Belize, Kenya, Ethiopia, Peru, and Liberia, 2020–2021

Category	Belize	Kenya	Ethiopia	Peru	Liberia
City, no. hospitals	Belize City, 3; Corazal,1; Belmopan,1; Orange Walk,1; San Ignacio,1; Dangringa,1; Punta Gorda,1	None	Addis Ababa, 1; Harar, 1; Gonder, 1; Jimma, 1	Iquitos, 2	Monrovia, 1
City, no. clinics	San Pedro, 1; Independence,1	Asembo, 1; Nairobi, 1	None	Iquitos, 4; Mazan, 1	Monrovia, 1

AFI, samples from 19% (22/115) in Ethiopia, 15% (51/334) in Peru, and 12% (25/215) in Liberia were positive for SARS-CoV-2. Participants ≥65 years of age in Belize, Kenya, Ethiopia, and Peru had the highest percentage of SARS-CoV-2 positivity; 19% (18/97) of patients in Belize, 15% (3/20) in Kenya, 40% (8/20) in Ethiopia, and 31% (8/26) in Peru were SARS-CoV-2–positive in this age group. Participants 45–64 years of age had the second highest percentage of SARS-CoV-2 positivity: 18% (38/207) in Belize, 14% (8/56) in Kenya, 27% (6/22) in Ethiopia, and 20% (16/81) in Peru. In Liberia, participants 45–64 years of age had the highest (18% [6/33]) SARS-CoV-2 positivity, and patients ≥65 years of age had the second highest rate, 14% (1/7). In 4 countries, samples from male patients tested positive for SARS-CoV-2 more frequently than did samples from female patients: Belize, 13% (79/632) male patients versus 10% (72/730) female patients; Ethiopia, 25% (16/65) male patients versus 10% (3/30) female patients; Liberia, 13% (12/95) male patients versus 11% (13/120) female patients; and Peru, 20% (35/173) male patients versus 10% (16/161) female patients. In Kenya, samples from ≈4% (46/1,068) male patients and ≈4% (41/1,083) female patients tested positive for SARS-CoV-2.

Discussion

AFI surveillance activities were successfully leveraged for the COVID-19 pandemic in Belize, Kenya, Ethiopia, Peru, and Liberia through the collection of relevant laboratory and epidemiologic data that could then be used to inform each country's response to the disease. Developing a new surveillance system, particularly in a low- to middle-income country, takes a substantial amount of time, planning, resources, and personnel. However, including COVID-19 in planned or existing AFI surveillance systems resulted in an

Table 3. Demographic characteristics of surveillance participants and SARS-CoV-2 testing results after COVID-19 incorporation into acute febrile illness surveillance systems in Belize, Kenya, Ethiopia, Peru, and Liberia, 2020–2021*

Variables	Belize	Kenya	Ethiopia	Peru	Liberia
Data collection period	2020 Mar–2021 Jul	2020 May–2021 Sep	2021 Feb–Aug	2021 Feb–Oct	2021 Apr–Jul
Total no. enrolled patients	1,627	3,113	115	344	302
Sex†					
M	788 (48)	1,487 (48)	65 (57)	178 (52)	131 (43)
F	839 (52)	1,626 (52)	30 (26)	166 (48)	171 (57)
Unknown sex	0	0	20 (17)	0	0
Age groups, y†					
<5–14	473 (29)	2,507 (81)	2 (2)	9 (3)	141 (47)
15–44	817 (50)	502 (16)	51 (44)	228 (66)	113 (37)
45–64	231 (14)	75 (2)	22 (19)	81 (24)	41 (14)
≥65	106 (7)	29 (1)	20 (17)	26 (8)	7 (2)
Unknown age	0	0	20 (17)	0	0
Tested for SARS-CoV-2, y‡					
<5–14	349 (74)	1,734 (69)	2 (100)	9 (100)	90 (64)
15–44	709 (87)	341 (68)	51 (100)	218 (96)	85 (75)
45–64	207 (90)	56 (75)	22 (100)	81 (100)	33 (80)
≥65	97 (92)	20 (69)	20 (100)	26 (100)	7 (100)
Unknown age	0	0	20 (100)	0	0
Total	1,362 (84)	2,151 (69)	115 (100)	334 (97)	215 (71)
SARS-CoV-2 positive, y§					
<5–14	18 (5)	45 (3)	0	0	9 (10)
15–44	77 (11)	31 (9)	5 (10)	27 (12)	9 (11)
45–64	38 (18)	8 (14)	6 (27)	16 (20)	6 (18)
≥65	18 (19)	3 (15)	8 (40)	8 (31)	1 (14)
Unknown age	0	0	3 (15)	0	0
Total	151 (11)	87 (4)	22 (19)	51 (15)	25 (12)

*Participants were enrolled during the indicated periods and sorted by the month data collection began. AFI, acute febrile illness.
†No. (%) participants out of total enrolled.
‡No. (%) enrolled participants who were tested for SARS-CoV-2 in each age group.
§No. (%) tested participants with positive SARS-CoV-2 samples in each age group.

efficient response to an urgent need and increased the ability to build capacity for long-term disease surveillance. Belize and Kenya had existing AFI surveillance systems and were able to rapidly integrate COVID-19 into these systems. Belize integrated COVID-19 within 1 month and Kenya within 2 months after the March 2020 COVID-19 pandemic announcement by WHO. Peru and Ethiopia integrated COVID-19 surveillance during the launch of their AFI surveillance activities in February 2021, and Liberia implemented COVID-19 surveillance in April 2021.

The broad-spectrum AFI syndromic surveillance system complements pathogen-specific surveillance systems. AFI surveillance generally requires participants to have only an acute fever for inclusion, which then allows the detection of a wide variety of pathogens and COVID-19 cases with various clinical manifestations. SARS-CoV-2 infections that were detected through AFI surveillance might have potentially gone undetected if respiratory disease–specific surveillance had been the sole source of case findings.

Our results demonstrate that AFI surveillance can be adapted and leveraged for pandemic monitoring through established laboratory and reporting mechanisms. We found surge capacity testing for SARS-CoV-2 was successful by using existing AFI surveillance specimen collection and testing methods, which was demonstrated by the ≥69% of enrolled AFI participants tested for SARS-CoV-2 in each country. In addition, established AFI surveillance methods enabled collection of descriptive data for participants with COVID-19, including demographic information, potential exposures, and vaccine history. These data could be used to characterize the care-seeking, febrile population affected by COVID-19 in a specific country. Furthermore, the relationships and communication channels that were already established for reporting AFI epidemiologic and laboratory data to public health authorities in each country were used for submission of COVID-19 case data. These data informed case investigations, case management, or contact tracing efforts and contributed to situational awareness and general pandemic tracking. For example, Liberia's COVID-19 cases detected through AFI surveillance were integrated into the country's incident management system and enabled the Montserrado County health team to investigate and manage these cases. The surveillance teams in Kenya routinely shared confirmed case data with county Ministry of Health teams to assist appropriate responses, such as contact tracing, and provided reports and updates to the Ministry of Health and other parties tracking the pandemic. In addition, authorities in Belize used their AFI surveillance data on COVID-19 cases to inform and assist contact tracing efforts.

The WHO COVID-19 Detailed Surveillance Data Dashboard (*21*) shows COVID-19 case, death, and vaccination data reported worldwide through official communications and is supplemented with official data taken from ministry of health websites of different countries (*22*). We aimed to compare the test positivity rates from the WHO COVID-19 dashboard with the SARS-CoV-2 percent positivity in the AFI surveillance populations reported in this study. However, because of a lack of test volume data for some relevant weeks, we were only able to compare these statistics for Ethiopia. We divided the total number of COVID-19 cases reported on the dashboard for Ethiopia by the total number of persons tested for SARS-CoV-2 during February–August 2021 (Ethiopia's AFI data collection time frame). The national test positivity rate reported by the WHO dashboard was 12%, which was below the 19% found in the AFI surveillance time frame. This difference is consistent with the types of populations that were surveyed. Most AFI surveillance participants described in this study were from a care-seeking population with acute symptomatic illness, which potentially yielded a higher proportion of SARS-CoV-2–positive samples. Hospitalized patients likely had more serious symptoms and a higher probability of SARS-CoV-2 infection than patients in outpatient clinics (*16*,*17*). Other factors, such as the level of community transmission and access to care, can also influence the percent positivity. As the COVID-19 pandemic evolves, the percentage of positive cases is expected to change depending on circulating variants, levels of immunity, and vaccination status in different communities.

Surveillance staff reported logistical and administrative challenges that affected their surveillance activities. Staff in Ethiopia encountered unexpected funding constraints and procurement issues that negatively affected sample collection supplies and limited AFI surveillance expansion to additional sites and testing for additional pathogens. Staff in Belize, Peru, and Liberia experienced shortages of nasopharyngeal swabs. Staff in Liberia borrowed swabs from the national reference laboratory, whereas surveillance staff in Peru switched to nasal mid-turbinate swabs. Peru experienced widespread nosocomial SARS-CoV-2 transmission, leading to treatment deferment for many patients with mild and moderate disease severity. Belize encountered a substantial decrease in participant enrollment in

their AFI surveillance throughout all 11 healthcare facilities because of a strict government lockdown at the beginning of the pandemic. In addition, Belize, Kenya, and Peru reported issues with procuring personal protective equipment for use by facility staff.

The first limitation of our study is that harmonizing data from projects with slightly different methods created some challenges. Differences in inclusion and exclusion criteria and laboratory testing platforms made inter-country comparisons difficult; however, local circumstances and testing capacity often made these differences unavoidable. Furthermore, different conditions in each country made it impractical to restrict data to a specific period; thus, we showed all available data. Second, health facility–based sentinel surveillance was used rather than population-based surveillance, which limited the findings to the healthcare-seeking population. However, implementers selected sentinel sites that were broadly representative of their country's care-seeking population. For example, Belize used most of the nation's clinical sites, which comprehensively captured a high proportion of their care-seeking population. Third, sex and age data were missing in some cases, limiting the interpretation of some findings. In Ethiopia, sex and age data were missing for 17% of enrollees, although project staff were still able to estimate overall SARS-CoV-2 percentage positivity because 100% of participants consented to SARS-CoV-2 testing. Last, some enrolled patients might have had asymptomatic SARS-CoV-2 infection concurrent with another febrile illness, although this possibility is unlikely.

Molecular SARS-CoV-2 testing and genomic sequencing methods have promoted ongoing surveillance of COVID-19. In Peru, Belize, and Kenya, genomic sequencing is being used to track SARS-CoV-2 variants. Collection of COVID-19 data through AFI surveillance continues to evolve in all 5 countries included in our study. Those data offer possibilities for analyses of single-site trends, incorporation of additional testing methods (such as SARS-CoV-2 serologic tests), and identification of emerging variants and co-infections. Other descriptive and statistical analyses can also be performed by using demographic, clinical, epidemiologic, and laboratory testing data.

In conclusion, through examination of preliminary data from Belize, Ethiopia, Kenya, Liberia, and Peru, we have shown that SARS-CoV-2 testing can be integrated successfully into AFI surveillance systems. We reported SARS-CoV-2 percent positivity data among care-seeking AFI surveillance populations and demonstrated the utility of leveraging existing AFI surveillance systems for COVID-19 pandemic responses or pathogen-specific needs. Integrating pathogens, such as SARS-CoV-2, into existing surveillance systems builds capacity to prevent, detect, and respond to both emerging and endemic infectious disease threats in low- to middle-income countries.

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Extending and Strengthening Routine DHIS2 Surveillance Systems for COVID-19 Responses in Sierra Leone, Sri Lanka, and Uganda

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The COVID-19 pandemic challenged countries to protect their populations from this emerging disease. One aspect of that challenge was to rapidly modify national surveillance systems or create new systems that would effectively detect new cases of COVID-19. Fifty-five countries leveraged past investments in District Health Information Software version 2 (DHIS2) to quickly adapt their national public health surveillance systems for COVID-19 case reporting and response activities. We provide background on DHIS2 and describe case studies from Sierra Leone, Sri Lanka, and Uganda to illustrate how the DHIS2 platform, its community of practice, long-term capacity building, and local autonomy enabled countries to establish an effective COVID-19 response. With these case studies, we provide valuable insights and recommendations for strategies that can be used for national electronic disease surveillance platforms to detect new and emerging pathogens and respond to public health emergencies.

In the aftermath of the 2014 Ebola outbreak in West Africa, ministries of health in the region proposed building resilient health systems capable of responding to routine health challenges and public health emergencies (*1*). In the same year, the Global Health Securities Agenda (GHSA, https://ghsa2024.org) was established to strengthen capacities to prevent, detect, and respond to public health threats (*2*). Improving reporting completeness and timeliness via electronic surveillance systems is a key tactic of the GHSA to ensure real-time data is used to target prevention activities, detect threats early, and plan response measures for disease outbreaks and public health emergencies (*3*). This report examines how 3 countries built on past investments in routine health information systems to respond to the COVID-19 pandemic.

Before the COVID-19 pandemic, many low- and middle-income countries had made substantial investments in scaling up their national health management information systems (*4*). Those efforts were often bolstered by financing from multilateral agencies or global funds, such as the Global Fund, Gavi Alliance, World Bank, and GHSA, along with US bilateral initiatives, such as the President's Malaria Initiative and President's Emergency Plan for AIDS Relief. In 2015, the US Centers for Disease Control and Prevention provided funds for the core District Health Information Software version 2 (DHIS2, https://dhis2.org) platform. DHIS2 is a free, open-source software platform that enables users to create data collection forms, indicators, and data visualizations. DHIS2 provides dashboard platforms to enhance capabilities for aggregate and case-based disease surveillance and learning in early adopter countries, such as Uganda and Sierra Leone (Figures 1, 2). Investments in DHIS2 resulted in functional improvements for generating predictive disease thresholds according to previously reported data and creating outbreak alerts from the system via email, short message services, or other means. During 2016–2018, dedicated regional training academies for designing DHIS2-based disease surveillance were created in Africa and Asia to enhance uptake and use of these functional improvements.

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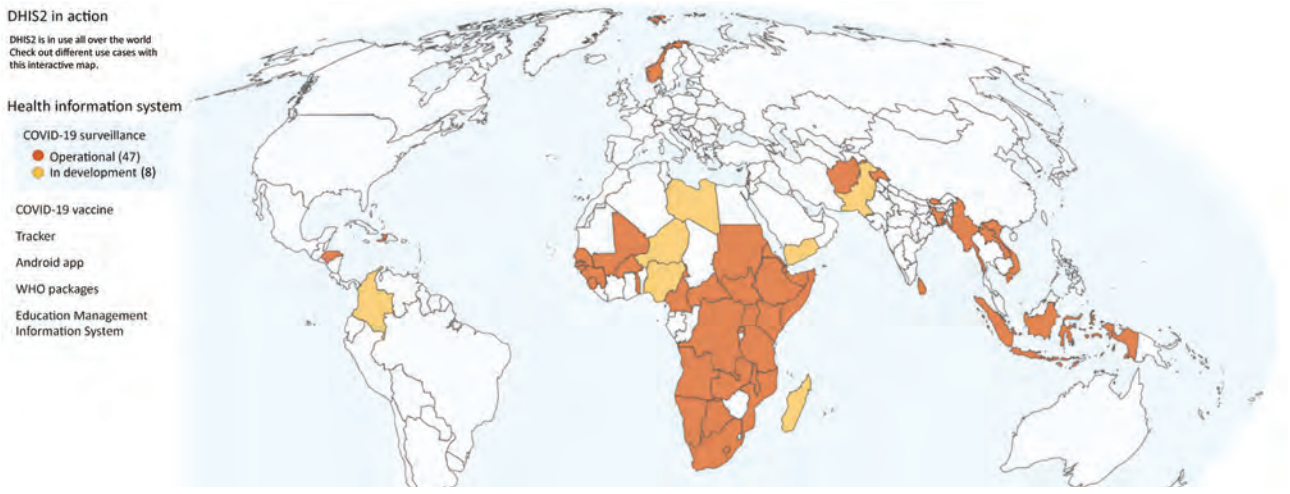

Figure 1. Countries using the District Health Information Software version 2 (DHIS2, https://dhis2.org) platform for COVID-19 surveillance, as described in review of extending and strengthening routine DHIS2 surveillance systems for COVID-19 responses in Sierra Leone, Sri Lanka, and Uganda. The online map (https://dhis2.org/in-action, cited 2022 Sep 8) is interactive and indicates which countries have DHIS2 operational or in development for COVID-19 surveillance in the country's health management information system. Surveillance can include case-based surveillance, contact tracing, port of entry screening, hospital stay monitoring, call center data, and exposure risk assessment.

By the end of 2019, a total of 25 countries worldwide had adopted DHIS2 as the national surveillance platform. Surveillance often began by including weekly aggregate electronic reports to the Integrated Disease Surveillance and Response (IDSR) or a similar framework for priority disease monitoring in their national health management information systems. The gradual scaling and decentralization of electronic reporting for priority diseases down to the primary healthcare level is an effort that generally takes countries years to fully achieve. Many countries began these efforts to scale up electronic reporting well before the COVID-19 pandemic, leveraging the existing DHIS2 platform at the health facility level for routine reporting in their health management information system. By 2020, each ministry of health (MOH) in >55 countries worldwide had established national DHIS2 platforms.

DHIS2 was already established globally before the COVID-19 pandemic and had extensive support structures and a growing global ecosystem of users and developers, conferences, discussion forums, and financial and technical partners. A key lesson learned from the information and communications technology response to the 2014 Ebola epidemic, reinforced during the COVID-19 pandemic, was the benefit of using existing technologies and digital infrastructure in-country to rapidly respond to an emergency. Heeding this lesson, countries including Sri Lanka, Uganda, and Sierra Leone began to adapt and configure their existing DHIS2-based systems to meet the new data collection and analysis needs for COVID-19 without establishing new parallel systems. By October 2021, a total of 55 countries had leveraged their DHIS2-based information systems to support COVID-19 detection, prevention, and response measures, including vaccinations.

This report discusses how prior investments in DHIS2-based surveillance systems by Sri Lanka, Sierra Leone, and Uganda enabled each country to rapidly respond and adapt their existing DHIS2 systems to meet the needs of the COVID-19 pandemic. Whereas emergency response measures may require innovation and novel approaches, this report shows how local innovation and self-reliance can be deployed quickly and effectively and complement existing systems and infrastructures. Furthermore, we show how local capacity and technological innovation can co-exist within existing institutionalized, national-scale deployment of DHIS2. These countries were selected because they illustrate successful outcomes of integrating emergency surveillance for COVID-19 within existing disease surveillance systems. Challenges and occasional setbacks associated with building resilient health information systems still remain. Challenges and tensions related to DHIS2 use have been reported (*5*–*7*).

Case Studies

Sierra Leone

Sierra Leone established DHIS2 as a national routine health information system in 2008. Concurrently, they adopted technical guidelines to implement the

IDSR framework developed by the World Health Organization (WHO) Regional Office for Africa (*8*) and began comprehensive public health surveillance and response systems for priority diseases, conditions, and events at all levels of the health system. In 2016, the Sierra Leone Ministry of Health and Sanitation (MOHS), in partnership with the US Centers for Disease Control and Prevention, WHO, and e-Health Africa, began a transition from paper-based to electronic reporting of weekly aggregate IDSR data for 26 reportable diseases in public health facilities using DHIS2. National rollout was completed during 2018–2019 (*9*). Building on the success of the electronic reporting of aggregate data, the MOHS developed an electronic case-based disease surveillance (eCBDS) system for reporting individual cases from healthcare facilities to a centralized data repository. The eCBDS system was tested in 4 of 16 districts during 2018–2019 for 20 of 26 reportable epidemic-prone diseases.

Acute respiratory infection is 1 of 20 conditions being reported through the eCBDS; this condition was updated to incorporate WHO-recommended variables for COVID-19 in February 2020. By leveraging the existing electronic IDSR (eISDR) system infrastructure that included smart mobile devices, other means of accessing the internet, and trained healthcare workers, the MOHS was able to rapidly launch an integrated eCBDS reporting module for COVID-19 and other notifiable diseases in all remaining districts and healthcare facilities. To cope with fast-spreading COVID-19 and the increasing need to report data from across the country, the MOHS, with support from multiple partners, used a 3-tiered approach for eCBDS system training in the remaining districts. The tiers consisted of training the trainers at the national level, who then trained district staff, who then trained healthcare facility personnel.

In addition to case-level data reporting, eCBDS operations were enhanced to support contact tracing, quarantine monitoring, and international travel monitoring for COVID-19. The system was further expanded to integrate COVID-19 vaccination programs that included an electronic immunization registry of all persons who received vaccines. The ability to track due dates for second vaccine doses and send vaccination reminders through short message services to all eligible persons with mobile phones was also incorporated in the system. A COVID-19 vaccine adverse events reporting module was added. Platform adaptability and flexibility enabled the vaccination and surveillance data to be captured in the same system, which promoted planning for and distribution of COVID-19 vaccines. The Sierra Leone National COVID-19 Emergency Response Centre has strengthened governance of the eCBDS system since mid-2021 to ensure that useful data from various data systems and tools can be easily integrated into the eCBDS system in an emergency.

Sri Lanka

DHIS2 was introduced in Sri Lanka in 2011 and widely used by several national health programs at the start of the COVID-19 pandemic. Before reports of COVID-19 in Sri Lanka, senior representatives at the MOH discussed the need to collect data at points

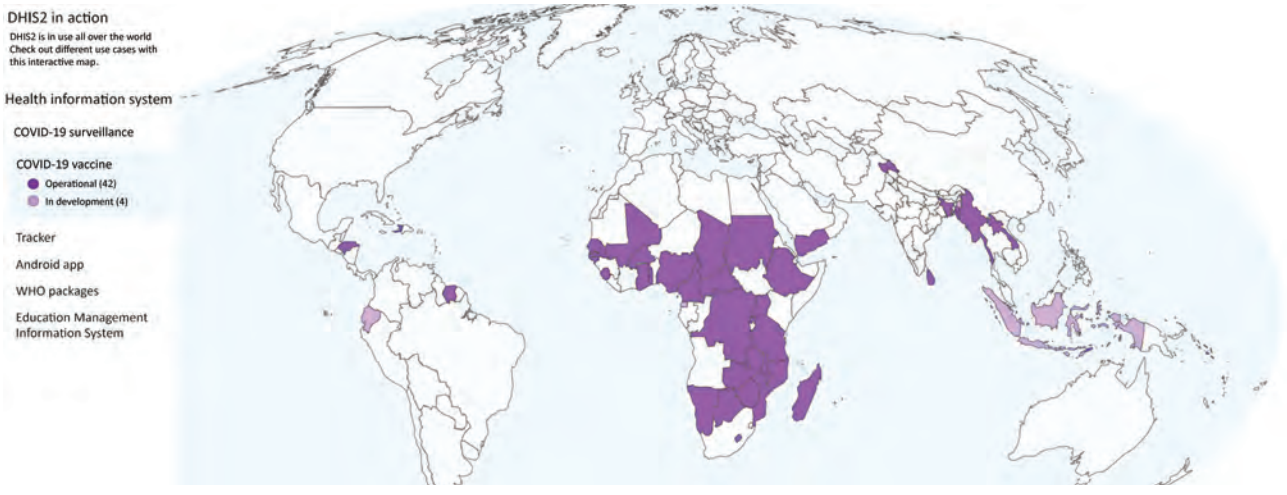

Figure 2. Countries using the District Health Information Software version 2 (DHIS2, https://dhis2.org) platform to monitor COVID-19 vaccination status, as described in review of extending and strengthening routine DHIS2 surveillance systems for COVID-19 responses in Sierra Leone, Sri Lanka, and Uganda. The online map (https://dhis2.org/in-action, cited 2022 Sep 8) is interactive and indicates which countries have DHIS2 operational or in development to monitor COVID-19 vaccination status in the country's health management information system. Monitoring can include tracking electronic immunization registries, vaccine stock management, the Android Capture application, and electronic certifications.

of entry (POE) from travelers arriving from countries with known COVID-19 transmission as part of a prevention strategy. The Health Information Systems Program (HISP) Sri Lanka, the DHIS2 implementation group supporting the MOH, modified DHIS2 in 2 days to register all international travelers arriving through airports and actively monitor them for 14 days for potential signs or symptoms of COVID-19 infection. The director general of health services approved modifications to the system, and Sri Lanka began using DHIS2 for COVID-19 surveillance; data were added to the system beginning in January 2020 (*10*). By early February 2020, POE screening was fully functional at all airports in Sri Lanka, which enabled the country to temporarily maintain open air borders to tourists while monitoring COVID-19 globally and within the country.

Sri Lanka's Information Communication Technology Agency (ICTA) was already experienced with hosting and supporting DHIS2; however, additional human resources were required to implement DHIS2 at POE and quarantine centers. The human resource gap was addressed by using a large pool of medical doctors who had completed a government sponsored master's degree program in information systems and had previous experience with DHIS2. However, the need for an integrated system for all COVID-19 case reporting and surveillance data in the country quickly became apparent. Integration required new applications and DHIS2 functionalities; however, the HISP and ICTA lacked developer resources for those changes. The ICTA announced a hackathon on Twitter and recruited 25 volunteer developers, most from Sri Lanka; the University of Oslo (UiO) also loaned a DHIS2 core developer. UiO recognized that local innovations needed in Sri Lanka would likely be required in other countries. Therefore, the core developer was intended to support the development team in Sri Lanka to produce generic applications and functionality that could also be used in other countries.

Within 2 weeks, the team of developers created a customized data capture application for POE and contact tracing data, an analytics application for COVID-19 case relationships, and an interoperability solution for exchanging data with Sri Lanka's immigration information system. Sri Lanka also introduced a hospital bed tracking component to the COVID-19 system, permitting facility users to quickly enter and update available intensive care unit and non–intensive care unit beds. This component was invaluable in locating available hospital beds for COVID-19 patients, which enabled planning and allocation of patient flow, including to other facilities.

On January 28, 2021, Sri Lanka launched a further expansion of its COVID-19 data systems in DHIS2. Expansion included a national-scale electronic immunization registry for COVID-19, vaccine stock monitoring at vaccination sites, real-time monitoring dashboards, and interoperability with Digital Infrastructure for Vaccination Open Credentialing (DIVOC, https://divoc.digit.org) software to generate digital vaccine certificates. Interoperability solutions were used to preregister a large proportion of the population in the COVID-19 electronic immunization registry according to existing citizen registries. Government stakeholders reported that monitoring real-time vaccination rates across the country was particularly effective and contributed to rapid planning for distributing vaccine stock, which often arrived sporadically in the country with little information about vaccine quantity, type, or expiration dates. As of December 2021, a total of 19,147,151 persons in Sri Lanka were enrolled in the country's DHIS2-based electronic immunization registry.

Uganda

Uganda established DHIS2 as a national eIDSR system for notifiable diseases in 2013; the system included case-based reporting linked to case investigation and laboratory data for some priority diseases. At the onset of the COVID-19 pandemic, the Uganda MOH incorporated WHO-recommended data variables for COVID-19 case-based surveillance into the existing DHIS2-based eIDSR system with support from HISP Uganda.

Uganda is a hub for overland trade routes among Kenya, Tanzania, Rwanda, Democratic Republic of the Congo, and South Sudan. Continuous and essential flow of goods, especially petroleum, occurs through 60 official border crossings. Truck drivers transiting Uganda from surrounding countries elevated the risk for COVID-19 spread and faced crowded, long waits at Uganda's borders. In response, HISP Uganda developed a new POE module within the eIDSR system to screen, test, and clear persons entering Uganda at all 60 formal border crossings. Using the DHIS2 Android Capture application, screeners at the border collected a traveler's personal details and travel history simultaneously with specimen collection. Test samples were processed at the POE. Upon receipt of a negative test, travel clearance was provided in the form of a printed paper pass with the traveler's photo and a quick response (QR) code. As truck drivers and passengers traveled through Uganda, they were required to present their paper passes at different checkpoints where QR codes were scanned, and the POE system automatically updated the GPS

location. Truck occupants were periodically retested at checkpoints. If a driver or passenger tested positive at a checkpoint, contact tracers were able to follow up and analyze the patient's travel history by using geographic information system tools within DHIS2.

Global DHIS2 Community Response

Local innovation and extension of national DHIS2 systems, coordinated by UiO, inspired the development of products and guidance for DHIS2 use for COVID-19 surveillance, prevention, and response activities in 55 countries across Asia, Africa, Europe, and Latin America. HISP Sri Lanka's POE module was shared alongside a suite of configuration packages and implementation tools for COVID-19 case-based surveillance, contact tracing, situation reports, and dashboards, following WHO technical guidance and recommendations for data collection, case definitions, and analysis. A customizable COVID-19 case-based surveillance module was made available to the global community. The design was predicated on Uganda's and Sierra Leone's existing DHIS2 configurations. Routine integrated case-based disease surveillance and functional requirements were identified by a global surveillance advisory group convened by WHO with support from the Gavi Alliance in 2019 for vaccine-preventable diseases. Most countries that deployed DHIS2 for COVID-19 surveillance, prevention, and response already had existing national DHIS2-based systems for some health programs. Chad, Mauritius, and Suriname adopted DHIS2 during the pandemic response. Similarly, DHIS2 developers worked closely in real-time with users to respond to emerging functional requirements, such as improved QR scanning functionality in the DHIS2 Android app and new data visualization parameters for tracking epidemic curves on dashboards.

Effects of local innovations and custom DHIS2 apps extended beyond their countries of origin and the COVID-19 pandemic. Innovations were shared in real-time through online communities of practice, webinars, informal social media chat groups among implementers and developers, and other channels to accelerate progress in other countries. Developers of the COVID-19 contact tracing app in Sri Lanka later partnered with a developer in Guinea to extend app functionality to visualize temporal transmission chains in a cluster of Ebola cases in Guinea in February 2021. HISP Mozambique used the same technology and adapted Uganda's approach to establish a similar mobile phone integrated POE system in Mozambique and Guinea Bissau. By November 2021, dozens of countries had used QR code scanning for COVID-19 surveillance and vaccine certificates, barcode scanning for stock management and parcel tracking, and for tracking school attendance in Mozambique and The Gambia.

Discussion

Prior investments in electronic disease surveillance systems provided a solid foundation for low- and middle-income countries to respond to the emerging data management needs for COVID-19. Through these case studies, several factors were identified that enabled rapid COVID-19 surveillance: flexible, open-source technology; communities with a strong ethos of sharing; and long-term capacity building.

The DHIS2 software is free and open source and can be customized or configured according to local requirements and adapted to changing circumstances. These features were evidenced during the pandemic by Sri Lanka's innovative web apps for analyzing chains of transmission (*11*), Uganda's extension of the DHIS2 Android Capture app to generate and read QR travel passes (*12*), and Sierra Leone's rapid eCBDS configuration updates that enabled COVID-19 reporting.

Using a generic, extendable platform approach, software investments in one country can be shared, customized, reused, and ultimately translated to add substantial value in another country. Sri Lanka distributed their custom apps globally through an online DHIS2 app hub, and Uganda worked closely with DHIS2 developers to add needed functionality to the core software. In both cases, new software functionalities for COVID-19 pandemic response measures were rapidly made available to countries worldwide through continuous innovation by a diverse network of implementers, users, and developers. Developers engaged in the COVID-19 response reported that they felt a responsibility to develop generic, open-source platform extensions so that the broader DHIS2 community could benefit from their innovations, especially during a global crisis (*13*).

An inclusive and participatory community of practice enables innovations to be shared, shaped, adjusted, and improved, while also building knowledge across geographic and organizational boundaries. Sri Lanka relied on participation from independent, volunteer Sri Lanka-based developers, existing networks of master's program alumni, and a core DHIS2 developer to create and implement novel solutions. Existing community channels have been used during the COVID-19 pandemic to assist with real-time learning and sharing, such as the community of practice web portal (https://community.dhis2.org), Health Data Collaborative (https://www.healthdatacollaborative.org)

webinar series, Digital Square (https://digitalsquare.org/covid19), and the DHIS2 annual conference (https://thedac2020.sched.com). Those efforts enabled countries to learn about emerging practices, adapt solutions, make improvements, and engage with the community through the same channels.

Investments in global goods require an adequate investment in local capacity to implement and sustain these products. The UiO has supported capacity building for 3 decades by contributing to online self-study training modules, regional DHIS2 training academies, master's and doctoral programs in low- and middle-income countries, and international exchange.

In Sri Lanka, staff with skills and experience with DHIS2 were critical for development of new COVID-19 modules and providing training for their use. Degree programs at the University of Colombo in Sri Lanka expose students to the DHIS2 platform, who can then be quickly trained on the POE module. In Uganda, a strong domestic community around DHIS2 provided the necessary capacity to develop new apps. In Sierra Leone, the institutionalization of the eCBDS and investments in governance enabled a more coherent, integrated information system supporting many aspects of the COVID-19 emergency. DHIS2-based systems around the world are not COVID-specific; rather, most are integrated health information systems that exhibit flexibility to adapt to emerging diseases and public health threats. DHIS2 can bring data together across programs for powerful analysis and use. Timely deployment of electronic surveillance systems for COVID-19 was the result of decades of decentralizing capacity to govern and manage national data systems, designing and configuring systems responsive to users' needs, and implementing interoperable systems that achieved MOH data analysis requirements. This process illustrates the importance of system strengthening in nonemergency periods to support the needs during a public health emergency.

Countries with existing integrated case-based disease surveillance systems, such as Uganda and Sierra Leone, were able to quickly add new variables, data collection forms, and visualizations to their DHIS2 configurations. They also streamlined data collection from facilities with minimal efforts in training and rollout to meet the new COVID-19 requirements. Those countries immediately benefitted from existing electronic disease surveillance system coverage, and reporting occurred at the facility level in most districts. Local innovations were disseminated rapidly through the global community. For example, Sri Lanka pioneered the use of DHIS2 to integrate POE screening into their national surveillance system. Rather than establishing a new disease reporting system for each emerging new disease, existing systems and workflows can be modified quickly to meet new programmatic requirements.

Long-term investments in strengthening health systems contributed to core capacities for data management, information system design, and administration within different MOHs, enabling national HISP teams to rapidly modify existing electronic surveillance systems. In countries where COVID-19 surveillance data were integrated into a national system at the onset of the pandemic, key stakeholders indicated there were streamlined data flows and trust in DHIS2 as a surveillance data source. COVID-19 response funding contributed to strengthening the overall national electronic disease surveillance system in countries where COVID-19 surveillance was integrated into an existing system. In this report, we provide valuable insights and recommendations for strategies that can be used to prepare national electronic disease surveillance platforms to detect and respond to new and emerging pathogens and public health emergencies.

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Scrapie

[skra'pe]

Scrapie is a fatal neurodegenerative disease of sheep and goats that was the first of a group of spongiform encephalopathies to be reported (1732 in England) and the first whose transmissibility was demonstrated by Cuille and Chelle in 1936. The name resulted because most affected sheep develop pruritis and compulsively scratch their hides against fixed objects. Like other transmissible spongiform encephalopathies, scrapie is associated with an alteration in conformation of a normal neural cell glycoprotein, the prion protein. The scrapie agent was first described as a prion (and the term coined) by Stanley Prusiner in 1982, work for which he received the Nobel Prize in 1997.

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Leveraging PEPFAR-Supported Health Information Systems for COVID-19 Pandemic Response

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Since 2003, the US President's Emergency Plan for AIDS Relief (PEPFAR) has supported implementation and maintenance of health information systems for HIV/AIDS and related diseases, such as tuberculosis, in numerous countries. As the COVID-19 pandemic emerged, several countries conducted rapid assessments and enhanced existing PEPFAR-funded HIV and national health information systems to support COVID-19 surveillance data collection, analysis, visualization, and reporting needs. We describe efforts at the US Centers for Disease Control and Prevention (CDC) headquarters in Atlanta, Georgia, USA, and CDC country offices that enhanced existing health information systems in support COVID-19 pandemic response. We describe CDC activities in Haiti as an illustration of efforts in PEPFAR countries. We also describe how investments used to establish and maintain standards-based health information systems in resource-constrained settings can have positive effects on health systems beyond their original scope.

Since its creation in 2003, the US President's Emergency Plan for AIDS Relief (PEPFAR) has funded and supported development, implementation, and expansion of capabilities, and maintenance of health infrastructure, including health information systems, for HIV/AIDS and related diseases, such as tuberculosis (TB), in numerous countries (*1*). When the COVID-19 pandemic emerged, several PEPFAR countries were already extensively using health information systems for managing, reporting, and visualizing the burden of HIV/AIDS and TB among their populations.

As with any public health emergency response, the COVID-19 pandemic response required accurate, standards-based, and timely public health data for optimal national prevention, detection, and response efforts (*2*–*5*). Robust health information systems and digital health tools provide reliable data to clinical and public health decision makers and can decrease the time from disease detection to response at the patient and national levels (*6*,*7*). Integrated, standards-based health information systems can add value to national public health emergency response by reducing redundant efforts, thus increasing efficiency, which is especially useful in resource-constrained settings (*8*,*9*).

As the COVID-19 pandemic progressed in many PEPFAR-supported countries, the PEPFAR Technical Guidance in Context of COVID-19 Pandemic publications provided strategic direction for leveraging PEPFAR investments for the pandemic response (*10*,*11*). PEPFAR-funded PCR platforms for HIV viral load testing, and related laboratory information systems, were used for SARS-CoV-2 confirmatory testing (*12*,*13*). HIV and SARS-CoV-2 testing integration occurred on both centralized high-throughput PCR instruments and decentralized point-of-care and near–point-of-care devices (*14*).

When the COVID-19 pandemic emerged, several PEPFAR-supported countries assessed the surveillance

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data and visualization needs of the national response (*14*,*15*). These countries rapidly assessed existing PEPFAR-funded HIV/AIDS, TB, and national health information systems and evaluated how these extensive systems could support COVID-19 surveillance data collection, analysis, visualization, and reporting needs. PEPFAR stakeholders recognized that existing standards-based, PEPFAR-funded components of their national health information systems could be enhanced to provide timely, high-quality data for national COVID-19 public health decision makers.

We describe how investments to establish and maintain standards-based health information systems for HIV/AIDS and TB in resource-constrained settings can have broader effects on the health system. Beyond their original scope, these systems can be leveraged to meet data needs for additional or emerging public health threats (*2*). We describe the methods and findings of rapid landscape assessments conducted by project teams at the US Centers for Disease Control and Prevention (CDC) headquarters in Atlanta, Georgia, USA and the CDC country office in Haiti, a PEPFAR-supported country with a long history of health information system investments. In addition, we describe results from the implementation, enhancement, and use of existing PEPFAR-supported national health information systems, electronic medical records (EMRs), and laboratory information systems for surveillance in support of the COVID-19 pandemic response in Haiti. We also discuss the centrally developed health information systems solutions designed and developed at CDC to potentially support COVID-19 surveillance requirements in select PEPFAR countries.

Methods

CDC, CDC Haiti, and PEPFAR Overview

At CDC, we coordinated efforts with CDC country offices and worked with respective ministries of health in some PEPFAR countries to enhance HIV/AIDS and TB health information systems and the policies, capacities, and relationships to support COVID-19 surveillance (*15*). Our strategy was to leverage existing PEPFAR and national digital health investments to support needs beyond the initially funded diseases. Over the years, PEPFAR investments have helped countries develop a health information exchange, national data repository, and patient identity management systems. Additional central investments include an open-source EMR system, called Open Medical Record System (OpenMRS, https://wiki.openmrs.org) and the OpenMRS HIV Reference Implementation (OHRI) package to specifically support HIV/AIDS electronic medical record keeping and reporting. Technical enhancement and customization of existing PEPFAR health information systems were coordinated and funded by CDC by leveraging ongoing efforts of the Technical Assistance Platform (TAP). TAP is a central mechanism that enables PEPFAR and national health information system stakeholders to come together as the Global Informatics Collaborative (GIC) (Figure 1).

Building informatics-savvy health organizations is critical for tracking PEPFAR's epidemic control goals. Information-savvy health organizations can obtain, effectively use, and securely exchange information electronically to improve public health practice and population health outcomes (*16*). Informatics-savvy health organizations have 3 core capabilities: an organization

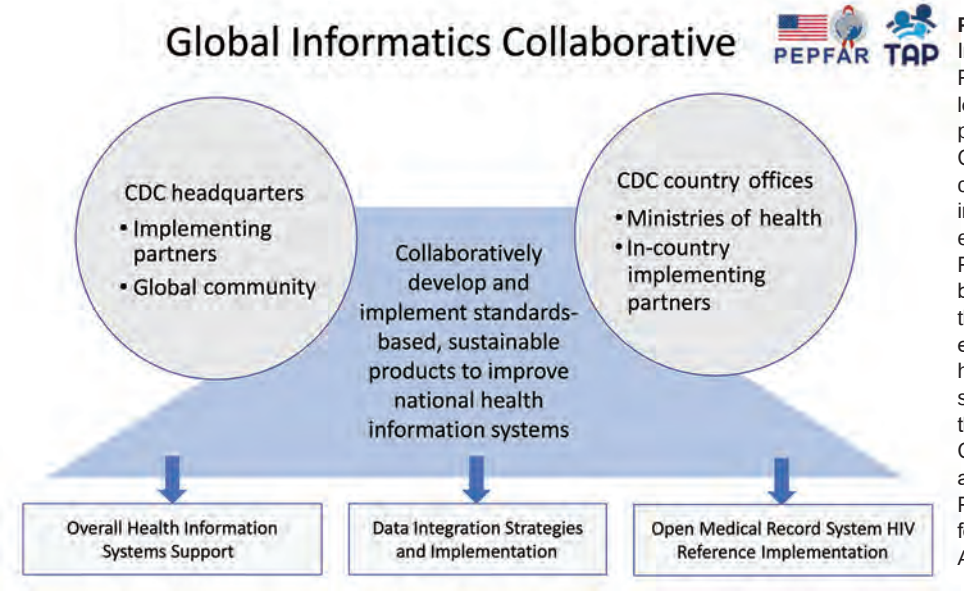

Figure 1. Elements of the Global Informatics Collaborative of PEPFAR-supported systems leveraged for COVID-19 pandemic response. The US CDC headquarters project team coordinated work across 3 implementing partners. Partners enhanced and customized existing PEPFAR health information systems by leveraging ongoing efforts of the TAP, a central mechanism that enables PEPFAR and national health information systems stakeholders to come together as the Global Informatics Collaborative. CDC, Centers for Disease Control and Prevention; PEPFAR, US President's Emergency Plan for AIDS Relief; TAP, Technical Assistance Platform.

wide informatics vision, policy, and governance; a skilled workforce; and effective information systems (Figure 2). GIC partners strategically collaborate to develop sustainable information system solutions and interventions that enable the CDC-based team to guide and assist country efforts. TAP technical areas support development of informatics-savvy health organizations in each of its 3 pillars: TAP policies and health information system governance support the vision, policy, and governance pillar; TAP workforce capacity efforts support the skilled workforce pillar; and TAP data integration strategies and implementation and OHRI support the effective information systems pillar.

CDC staff in Haiti have been working with the country's ministry of public health and population, Ministère de la Santé Publique et de la Population (MSPP), to strengthen public health systems by focusing on laboratory, workforce development, and health information systems (Figure 3). These cross-cutting domains are supported by leveraging several ongoing disease elimination and eradication initiatives, including initiatives for HIV/AIDS prevention and treatment, TB control, malaria elimination, lymphatic filariasis elimination, and cholera elimination. Haiti used this integrated approach and PEPFAR seed investments to establish a sophisticated HIV/AIDS health information system suite that has a central data repository that can be customized for other disease surveillance and emergency response efforts. We summarize CDC Atlanta and CDC Haiti country office experiences by outlining methods and findings from rapid assessments of existing PEPFAR and national COVID-19 surveillance health information systems.

CDC Atlanta

In 2021, the COVID-19 project team conducted rapid desktop landscape assessments of health information systems in Haiti and 4 PEPFAR countries in Africa by using online resources and knowledge of the countries' health information systems through past and ongoing work. In addition, we examined activities around the 3 core TAP technical areas: data integration strategies and implementation to study surveillance data exchange; OHRI for EMR and laboratory information systems implementations and requirements; and overall health information system support to review policies, governance, and workforce capacity.

Summary Assessment Findings for PEPFAR Countries

All 5 study countries have implemented EMRs for HIV clinical case management. In addition, all 5 countries have laboratory information systems for HIV laboratory data management; HIV dashboards for reporting; and some form of centralized data storage at the national level for a subset of health data (e.g., HIV, COVID-19, or other reportable diseases) for supporting clinical care and public health surveillance data exchange (*15*). PEPFAR countries also deployed various digital surveillance solutions as part of the COVID-19 response, such as COVID-19 surveillance data entry systems and dashboards. In addition, most PEPFAR countries were using PEPFAR-funded laboratory infrastructure for COVID-19 testing of HIV patients and the general population.

We learned that PEPFAR-supported EMRs were not widely used for COVID-19 surveillance of HIV patients in the study countries. COVID-19 outpatient and inpatient care were usually provided at government-designated care units or private healthcare facilities that do not share health records with HIV care facilities. The failure to longitudinally share medical records is multifactorial. COVID-19 EMRs, where available, were usually standalone systems that lacked the ability to interact with national interoperability platforms to enable data exchange in support of clinical decision making (*14*). Therefore, clinicians at most COVID-19 care units did not have access to HIV-related patient risk factor information.

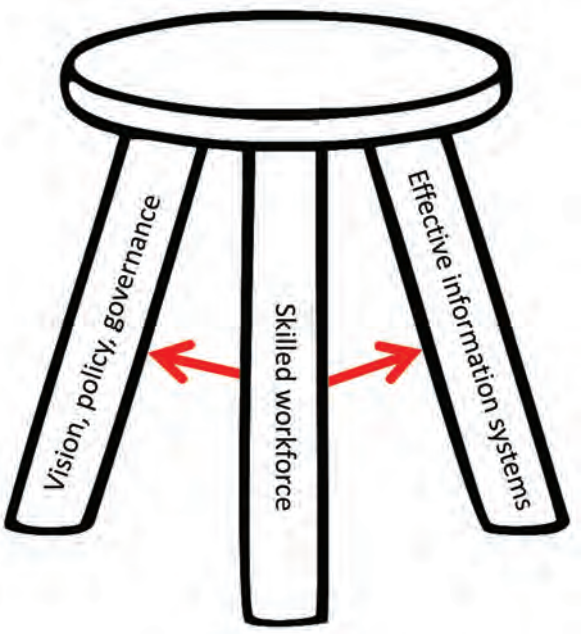

Figure 2. Core pillars of the US President's Emergency Plan for AIDS Relief–supported informatics-savvy health organizations leveraged for COVID-19 pandemic response. The 3 pillars of an information-savvy health organization are supported by Technical Assistance Platform technical areas.

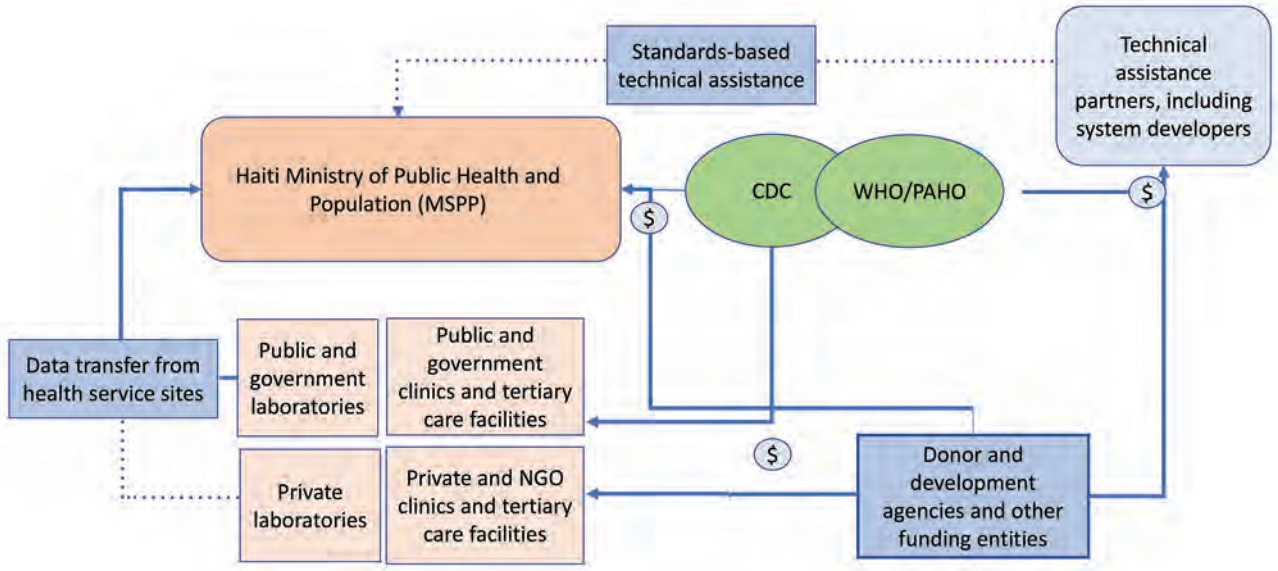

Figure 3. Collaborating stakeholders and beneficiaries of US President's Emergency Plan for AIDS Relief–supported health information systems leveraged for COVID-19 pandemic response, Haiti. Funding supported Haiti's ministry of public health and population, Ministère de la Santé Publique et de la Population (MSPP). Dollar signs denote health information systems–specific investments. Dotted lines indicate episodic or sporadic technical assistance and other inputs into the MSPP. Solid lines indicate structured technical assistance and other inputs into the MSPP's systems. CDC, Centers for Disease Control and Prevention; NGO, nongovernmental organization; PAHO, Pan-American Health Organization; WHO, World Health Organization.

In addition, direct exchange of COVID-19 laboratory test requests and results between EMR and laboratory information systems at a facility or through a national data repository was challenging because of gaps in system linkage and health information exchange capabilities.

Countries are exploring ways to mainstream COVID-19 clinical care (*17*), including COVID-19 care of HIV patients at PEPFAR clinics. Mainstream or longitudinal care could enable use of PEPFAR EMRs for COVID-19 outpatient assessment, surveillance, and management, including vaccination, as well as monitoring the COVID-19 burden among HIV patients. In addition, existing PEPFAR health information systems, specifically OpenMRS, laboratory information system, and country leadership support for standards-based health information exchanges provide the opportunity for leveraging PEPFAR investments to support COVID-19 surveillance (*14*). We shared assessment findings with PEPFAR countries and discussed priorities to define specific projects to address each country's needs.

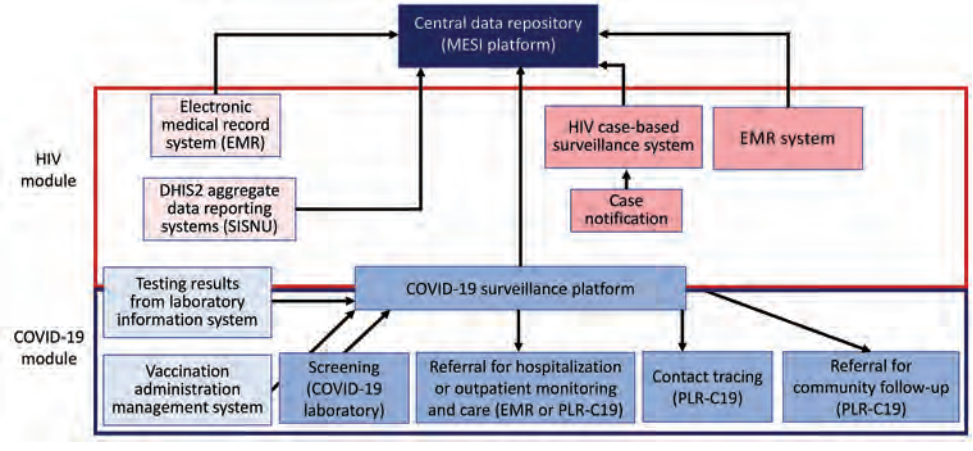

Figure 4. US President's Emergency Plan for AIDS Relief–supported health information suite leveraged for COVID-19 pandemic response, Haiti. The system was built on the nation's existing monitoring and evaluation platform, MESI. Red indicates existing HIV systems; blue indicates COVID-19 systems. SISNU is a DHIS2 (https://dhis2.org) hub for aggregate case reporting by disease and geography. C19, COVID-19; EMR, electronic medical record; MESI, Monitoring, Évaluation et Surveillance Intégreé; PEPFAR, US President's Emergency Plan for AIDS Relief; PLR, Patient Locator and Retention mobile phone application; SISNU, Systeme d'Information Sanitaire Unique.

CDC Haiti

To support COVID-19 surveillance, MSPP reviewed Haiti's existing information systems. Haiti uses 2 central data repositories for infectious disease reporting: the national monitoring and evaluation platform, Monitoring, Évaluation et Surveillance Intégré (MESI), a national monitoring system that serves as the data hub for HIV case-based surveillance information systems; and Systeme d'Information Sanitaire Unique, a DHIS2-based (https://dhis2.org) hub for aggregate case reporting by disease and geography.

MESI Platform Applications and Data Flow

The MESI platform serves as a central repository for patient records coming from facilities that use iSante/iSantePlus (OpenMRS-based EMR), which is used by >90% of health facilities supported by PEPFAR. The other 10% of health facilities use a customized in-house EMR and an EMR built on OpenMRS, from which data are transformed and uploaded into the MESI platform for data merging and removal of duplicate information. EMR data are pushed to the MESI central repository by using a network secure file transfer protocol. The data are then concatenated and cleaned, patient data merged, and duplicate data removed for a single record per person within the final dataset.

MESI interfaces with 3 community-level applications, generating additional patient-level data accessible on smartphones, tablets, and desktop devices.

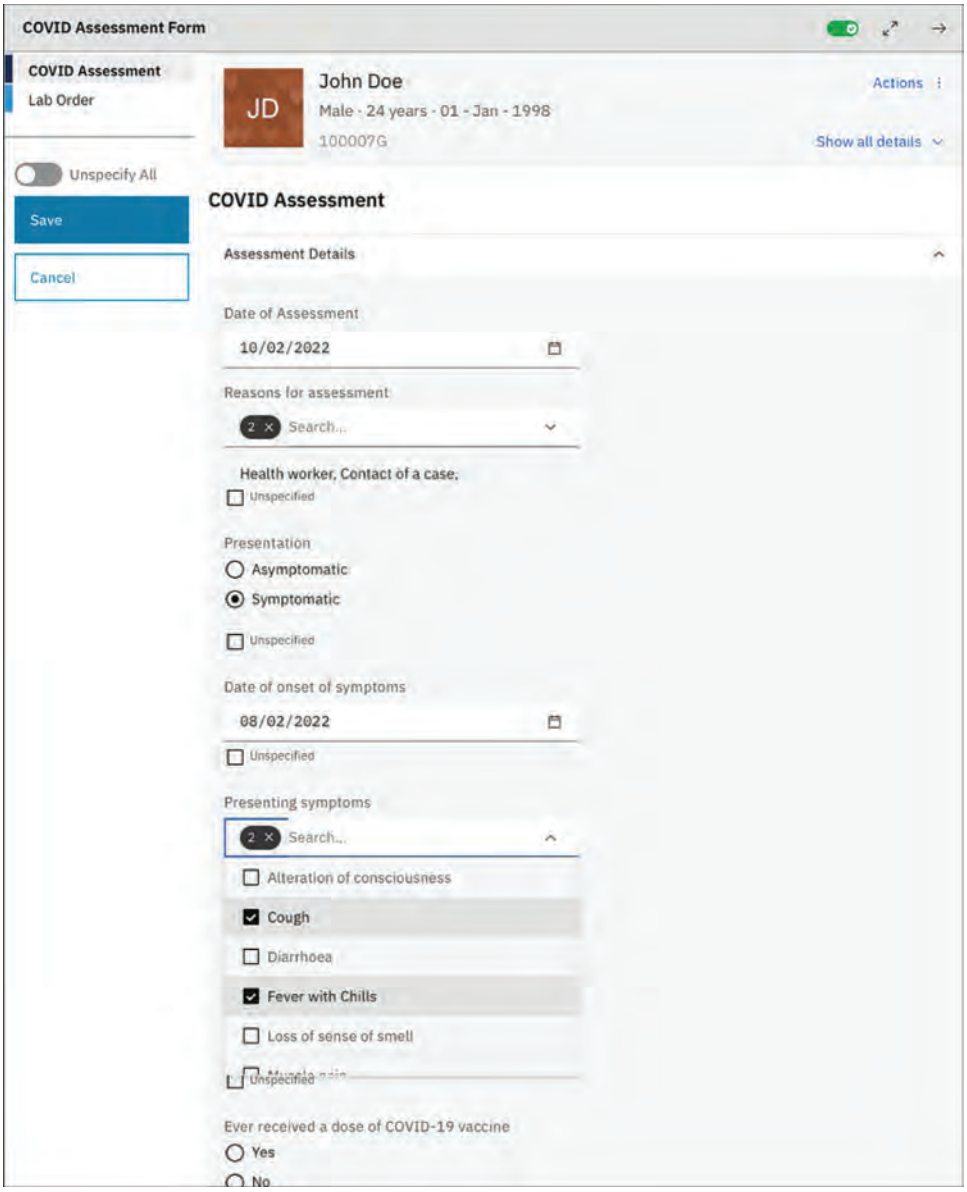

Figure 5. Example of COVID-19 pandemic response patient management and surveillance package developed from US President's Emergency Plan for AIDS Relief (PEPFAR)–supported systems leveraged for COVID-19 pandemic response. The open medical record system HIV reference implementation (OHRI) platform is based on requirements from some PEPFAR countries. The COVID-19 system developed at the US Centers for Disease Control and Prevention leveraged the OHRI platform, already developed and being adapted by some PEPFAR countries.

Table 1. COVID-19 surveillance indicators leveraged from PEPFAR-supported systems during the COVID-19 pandemic response

Key indicators
No. persons screened
No. persons screened but not tested
No. tests without results
No. confirmed cases
No. confirmed cases hospitalized
No. confirmed cases followed at home
No. confirmed cases who recovered
No. confirmed cases who died
Time interval between confirmation and linkage to care

*PEPFAR, United States President's Emergency Plan for AIDS Relief.

One application for tracking and tracing HIV patients and their contacts was leveraged for COVID-19 contact tracing during the pandemic response. Community health workers, Field Epidemiology Training Program graduates and residents, and some health facility managerial staff use a mobile application to routinely upload community data into the MESI platform. The mobile application has geolocation for locating persons and relational functionalities to link cases to their exposed contacts, which were critical components of the COVID-19 systems model in Haiti (Figure 4).

Implementations and Results

CDC Atlanta

The CDC Atlanta team studied assessment findings to identify generic national COVID-19 surveillance needs and develop requirements for a new CDC-based generic TAP product or enhancements for existing products. The team identified technical developments that could enhance PEPFAR health information systems to support COVID-19 surveillance data capture and exchange between EMR and laboratory information systems and to visualize clinical and laboratory data (*15*). The project team developed plans for enhancements by leveraging health information system strengths identified during these assessments. System enhancements were made to existing clinical and laboratory dataflows, including COVID-19 clinical data capture and laboratory request form submission within the EMR, transmission of laboratory results to EMR, and surveillance case reporting from the EMR. We developed the architecture and data entry forms for the COVID-19 package within OHRI based on OpenMRS 3.0 framework

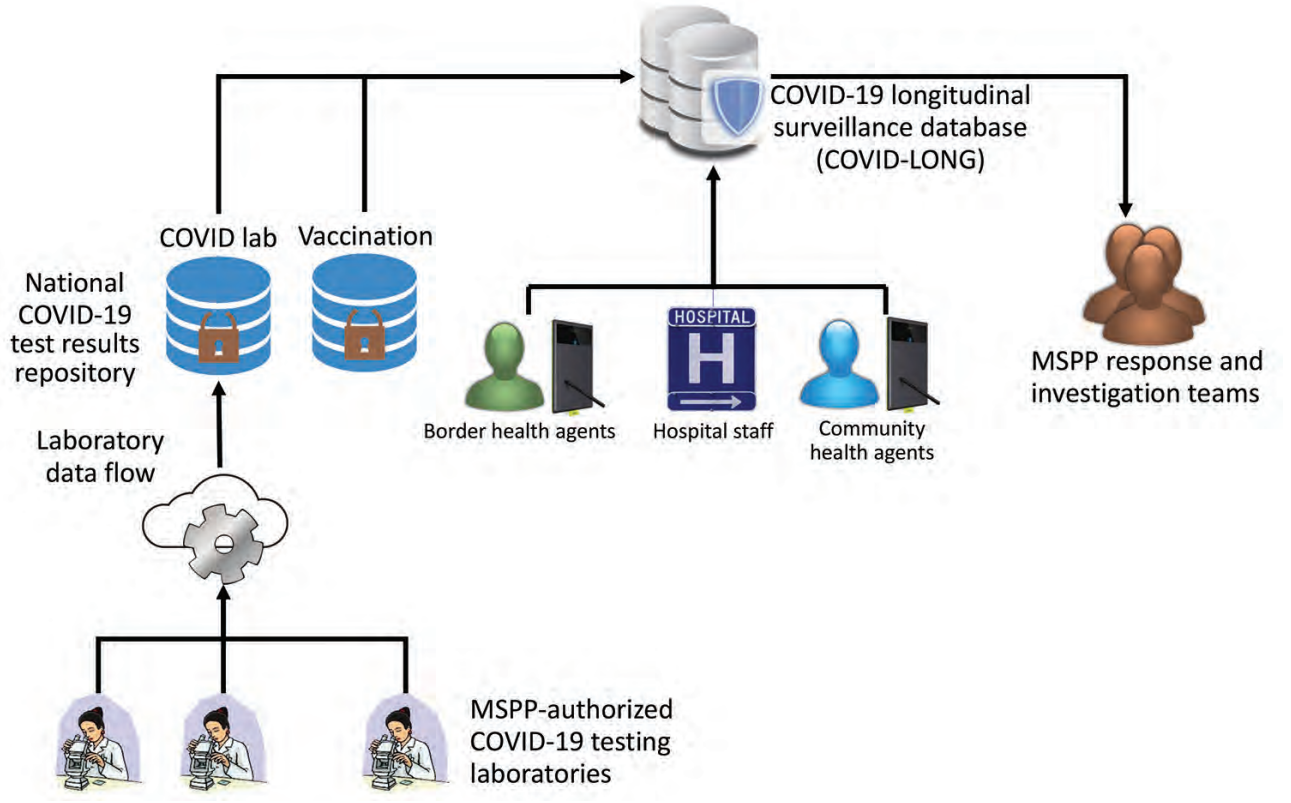

Figure 6. Dataflow of COVID-LONG system developed from US President's Emergency Plan for AIDS Relief–supported HIV surveillance systems and used for COVID-19 pandemic response, Haiti. Testing laboratories, vaccination sites, hospitals, community, and border health facility agents uploaded data to the web-based system that was accessible by MSPP staff. COVID Lab, national dashboard of COVID-19 laboratory testing in Haiti; COVID-LONG, COVID-19 longitudinal surveillance database; MSPP, Ministère de la Santé Publique et de la Population.

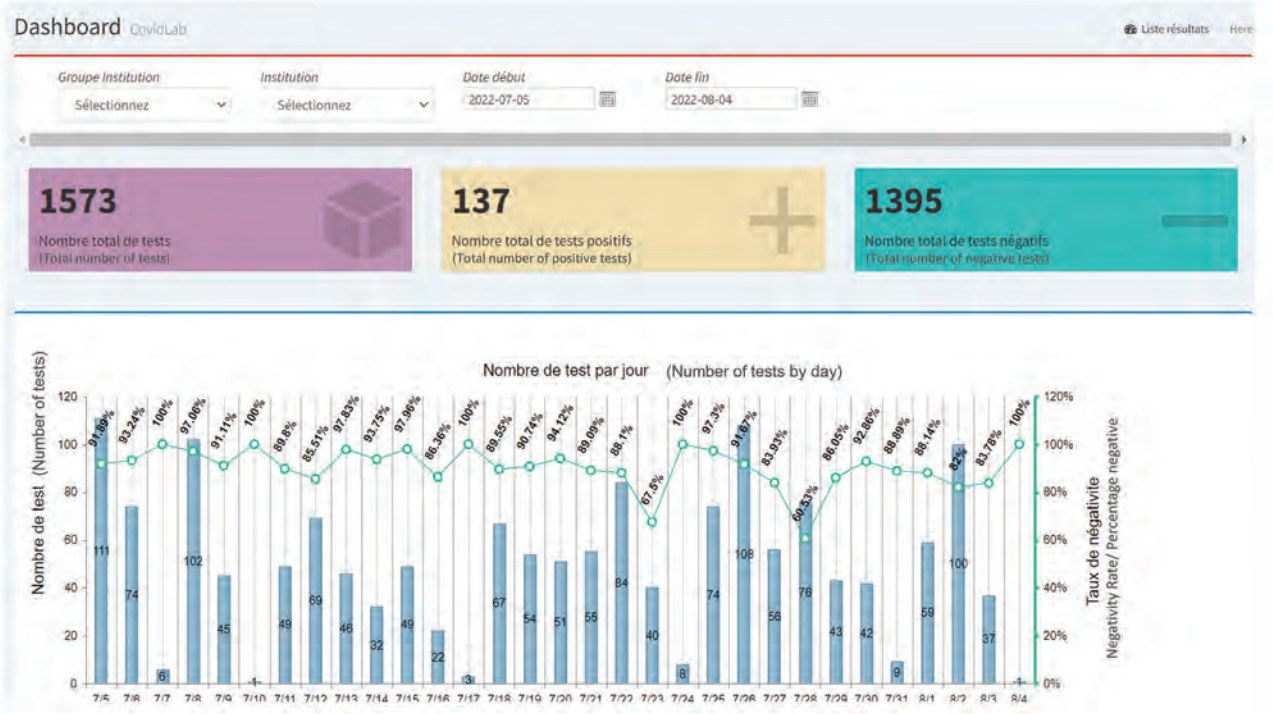

Figure 7. Surveillance dashboard database built from US President's Emergency Plan for AIDS Relief–supported systems leveraged for COVID-19 pandemic response, Haiti. A screenshot from the COVID-19 interactive dashboard from Haiti COVID-19 surveillance database shows a COVID-19 histogram tracking the number of COVID-19–positive cases per day on the top row and positivity rates of total reported COVID-19 tests on the bottom row.

(Figure 5) and deployed it in a technical demonstration environment. The architecture used unique patient identifiers or client registries to assist with health information exchange. After ongoing testing, the open-source products were available to the GIC for country-specific customization and in-country implementation through CDC support to local resources.

CDC Haiti

Haiti used PEPFAR-funded HIV systems for healthcare facilities and for community-based COVID-19 case management and selected their DHIS2-based system for the COVID-19 vaccine registry. Haiti leveraged an existing interoperability solution for data sharing via a health information exchange across the 2 hubs, ensuring capacity for seamless and timely COVID-19 reporting.

Using US Coronavirus Aid, Relief, and Economic Security (CARES) Act (P.L.116–136) funding to enhance existing systems and develop new information systems, some PEPFAR systems were replicated for COVID-19 surveillance, and a laboratory component was added. Previously collected paper-based COVID-19 data were retrospectively entered into the system, and subsequent newly identified cases and their contacts were entered in real time. The system included a dashboard with process and outcome indicators (Table 1). The system enabled custom analyses and data disaggregation by demographic and clinical variables and grouped results by index case for all reported and entered contacts (Figure 6).

COVID-19 Testing System

By September 30, 2021, the COVID-19 testing system contained 216,015 entries and 15 variables across 31 MSPP-approved testing sites. The system reported 14,711 positive test results, representing 65% of cumulatively reported cases. These data reflect a policy gap in mandatory laboratory reporting for class one notifiable diseases, especially novel etiologic agents.

COVID-19 Clinical Surveillance System

The COVID-19 surveillance system contained 22,431 positive cases, representing 94% of cumulatively reported cases. This surveillance database also contained 375 recorded deaths among persons with a positive COVID-19 test result, and 209 reported deaths among persons who did not have a documented COVID-19 test or result. The total deaths recorded in the COVID-19 surveillance database

Table 2. COVID-19 response support leveraged from PEPFAR investments

Program area	CDC headquarters	CDC Haiti office
Clinical case management	OHRI enhanced by developing a COVID-19 module for case management and surveillance at healthcare facilities	PEPFAR-funded HIV systems were used for healthcare facilities and community-based COVID-19 case management.
Surveillance	Enhanced national health information exchange model was used to link electronic systems for COVID-19 case confirmation and case management	Existing interoperability solutions were leveraged for data sharing via a health information exchange across 2 national COVID-19 data hubs
Laboratory	Automated exchange functionality was developed for COVID-19 testing requests and results between EMR and local laboratory information systems directly at a facility or through a national data repository	PEPFAR systems were replicated for COVID-19 surveillance, and a laboratory component was added for COVID-19 laboratory data flow
Dashboard	Dashboard requirements were developed for specific indicators, such as the number of persons living with HIV who were hospitalized for COVID-19	COVID-19 surveillance dashboard was built by leveraging the HIV dashboard used to track patient retention in HIV care

*CDC, US Centers for Disease Control and Prevention; EMR, electronic medical record; OHRI, Open medical record system HIV reference implementation; PEPFAR, United States President's Emergency Plan for AIDS Relief.

represented 85% of cumulative reported COVID-19 deaths in the country. Forty deaths were reported among cases with a negative test result, and 19 of these persons were reported contacts of an index case. The system reported 594 exposure contacts from 407 confirmed index cases and an additional 156 reported exposure contacts from persons with negative or missing test results.

Utility of the COVID-19 Information Systems for Response Monitoring

Despite challenges with data completeness and reporting gaps (largely from the private laboratory network), the COVID-19 health information system provided critical data for national COVID-19 decision-making. The dashboard showed the number of positive cases per day and positivity rates of total reported COVID-19 tests (Figure 7). This dashboard was built by leveraging the HIV dashboard used to track patient retention in HIV care. On the basis of positivity rates, the dashboard data assisted staff and decision makers with supply management for COVID-19 testing commodities and allocation of therapeutic treatment and human resources. When the data were disaggregated by department, staff and decision makers were able to allocate resources by geographic area. As the dashboard's effectiveness became evident, we observed a 31% increase in system use over 90 days.

Table 3. Enabling factors of informatics-savvy health organizations leveraged by CDC headquarters and CDC country offices for COVID-19 pandemic response*

Pillars and supporting functions
Pillar 1. Vision, policy, and governance
Acceptance by country leadership
Ownership by host country governments
Timely stakeholder engagement to maximize uptake and utility
Collaboration among implementing partners and alignment of various stakeholders' priorities, activities, and plans
Use of existing standards-based data systems for routine health service delivery and surveillance
Assured confidentiality and trust for new, name-based data systems, specifically for novel infections and other highly stigmatized conditions
Central coordination of health information system investments
Pillar 2. Skilled workforce
Local capacity building for systems development
Use of existing investments in easily customizable health information systems solutions built on open-source platforms ensured the availability of local technical capacity
Availability of strong technical capabilities within the country
Pillar 3. Effective information systems
Investments in interoperability solutions to facilitate health information exchange and integrate data across systems and disease programs
Existing investments in flexible and scalable IT infrastructure
Use of existing standards-based open-source electronic medical record platforms

*CDC, US Centers for Disease Control and Prevention.

Discussion

The COVID-19 pandemic response required rapid availability of surveillance data, which necessitated multisectoral response efforts and internal and external stakeholder participation. Setting up a new health information system for any disease takes considerable effort and time and involves high-level strengths and needs assessments, requirement development, resource allocation, technical development, pilot testing, training, and implementation. We describe efforts in a PEPFAR-supported country and concurrent CDC Atlanta work for technical enhancements of existing standards-based PEPFAR health information systems after rapid landscape assessments of system strengths and needs. Our approach was consistent with principles for digital development (*18*), including rapid and cost-effective implementation; data standardization, integration, and reporting; and local sustainability and community support (*18*).

PEPFAR and national investments enabled some countries to allocate resources to expand or enhance existing health information systems to rapidly support the national COVID-19 response, which improved

the timeliness and usefulness of data for decision making. PEPFAR health information system enhancements and new products supported COVID-19 clinical case management, surveillance, laboratory results, and dashboards (Table 2).

Enhanced reporting reduced time needed to make data available. Timeliness of data improved decision making capacity for resource allocation, identification of hot spots, and other transmission factors for mitigation measures. Enhanced reporting also enabled surveillance for new variants and other factors affecting virus transmission. In addition, enhanced reporting enabled validation of novel diagnostic tools, instruments, and treatment efficacy and monitoring of response outcomes at the system and patient levels.

The COVID-19 project team at CDC Atlanta incorporated COVID-19 surveillance requirements into the existing TAP product planning to develop the OHRI–COVID-19 module and health information exchange architecture design. The team developed this module to enable integrated COVID-19 surveillance for HIV patients in PEPFAR countries. As countries move toward mainstream COVID-19 care, the team has been testing various implementation use cases. One use case would enable COVID-19 surveillance for HIV patients by implementing OHRI–COVID-19 module in healthcare facilities where PEPFAR EMRs currently are used only for HIV patients. A second use case would conduct COVID-19 surveillance for all patients by implementing the OHRI–COVID-19 module in healthcare facilities where PEPFAR EMRs are being used for all patients.

Despite challenges with implementing mandated reporting, by showing the usefulness of the testing and surveillance databases, CDC Haiti secured support from the MSPP minister and the broader government of Haiti via the President's Commission on SARS-CoV-2 Co-Chairs. As Haiti's sole government-mandated health authority, MSPP has responsibility for implementing and ensuring internationally acceptable standards for health data and the health information systems through which the data are collected, stored, managed, accessed, and used (*19*). Leveraging PEPFAR-funded flexible, adaptable, and customizable health information systems enabled MSPP to build on centrally warehoused data infrastructure for the COVID-19 response, in keeping with internationally acceptable standards. Although the experience provided evidence for health policy reform, particularly for peripheral systems out of compliance, emerging challenges with timeliness and completeness of data entry compromised the usefulness of warehoused SARS-CoV-2 data at the system's initiation. In addition, challenges during the transition from paper-based forms to electronic data entry created a lag in cumulative reporting.

We learned that several factors enabled success in CDC Haiti and CDC Atlanta work. Haiti had high level decision-makers actively engaged in the project and the local health ministry served as a de facto International Standards Organization, which reinforced CDC Haiti and World Health Organization defined standards for data systems. The health ministry's lack of official International Standards Organization status did impede its ability to ensure comparable standards for privately owned and implemented health information systems. MSPP already had standards-based health information systems in place and had technically skilled staff to use the systems and implement changes.

In conclusion, accurate and timely COVID-19 surveillance data were needed to understand COVID-19 epidemiology for HIV patients and determine how to manage the pandemic, based on models similar to those used for HIV (*5*). CDC's efforts to enhance PEPFAR-supported information systems during the COVID-19 pandemic included expanding HIV and TB EMRs for COVID-19 case management, vaccination, surveillance, and case reporting; enhancing surveillance through reporting of laboratory test results; strengthening national data repository to facilitate data exchange for enhanced surveillance; and improving dashboards for decision makers. The use and enhancement of existing PEPFAR health information systems for COVID-19 response showed that investing in establishing and maintaining health information systems in resource-constrained settings can positively impact health systems beyond the original scope (Table 3).

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Contribution of PEPFAR-Supported HIV and TB Molecular Diagnostic Networks to COVID-19 Testing Preparedness in 16 Countries

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The US President's Emergency Plan for AIDS Relief (PEPFAR) supports molecular HIV and tuberculosis diagnostic networks and information management systems in low- and middle-income countries. We describe how national programs leveraged these PEPFAR-supported laboratory resources for SARS-CoV-2 testing during the COVID-19 pandemic. We sent a spreadsheet template consisting of 46 indicators for assessing the use of PEPFAR-supported diagnostic networks for COVID-19 pandemic response activities during April 1, 2020, to March 31, 2021, to 27 PEPFAR-supported countries or regions. A total of 109 PEPFAR-supported centralized HIV viral load and early infant diagnosis laboratories and 138 decentralized HN and TB sites reported performing SARS-CoV-2 testing in 16 countries. Together, these sites contributed to >3.4 million SARS-CoV-2 tests during the 1-year period. Our findings illustrate that PEPFAR-supported diagnostic networks provided a wide range of resources to respond to emergency COVID-19 diagnostic testing in 16 low- and middle-income countries.

Since its inception in 2003, the US President's Emergency Plan for AIDS Relief (PEPFAR) program has supported >50 countries in their ongoing response to the global HIV and AIDS epidemic, including 22 countries with ongoing HIV and tuberculosis (TB) coepidemics (*1*). PEPFAR has routinely supported molecular HIV and TB public health laboratory systems and diagnostic networks in low- and middle-income countries (LMICs) to promote patient access to quality clinical testing services and associated care.

SARS-CoV-2, the causative agent of COVID-19, first emerged from China in late 2019 and subsequently spread across the globe. COVID-19 was officially characterized as a pandemic by the World Health Organization on March 11, 2020 (*2*). PEPFAR was quick to respond to this public health emergency and provided the first PEPFAR technical guidance in the context of the COVID-19 pandemic in March 2020 (*3*). That guidance included recommendations on continuity of essential HIV and TB services while ensuring a safe healthcare environment for clients and staff, as well as guidance on the use of PEPFAR-supported resources such as diagnostic networks for the COVID-19 response (*3*).

At the beginning of the epidemic, availability of quality test materials and testing sites was scarce, especially in LMICs (*4*). As SARS-CoV-2 assays became available in LMICs, PEPFAR-supported countries developed and implemented individualized testing strategies that used existing laboratory infrastructure, national laboratory strategic plans, laboratory documentation, standard operating procedures,

instrumentation, sample referral networks, supply chain systems, and human resource and technical capacity to perform SARS-CoV-2 testing. These testing strategies were unique to each country and had to balance the SARS-CoV-2 and existing diagnostic testing needs with the availability of reagents and capacity of laboratories to perform the necessary testing within an appropriate timeframe. To achieve the necessary balance, countries used high-throughput centralized laboratories that can test a large number of specimens or lower-throughput decentralized laboratories that are often closer to the point of patient care. We therefore sought to identify and describe the range and quantity of existing centralized and decentralized PEPFAR-supported public health laboratory resources used in response to the COVID-19 pandemic.

Methods

Study Design

We designed a retrospective and cross-sectional study by using an information-gathering tool based on Excel (Microsoft, https://www.microsoft.com) to quantify the use of PEPFAR-supported diagnostic networks in LMICs for the COVID-19 response during April 1, 2020–March 31, 2021. We defined a PEPFAR-supported laboratory as a laboratory directly receiving any of the following: infrastructure support or upgrades; molecular testing instrumentation, maintenance, or both; HIV viral load (VL), HIV early infant diagnosis (EID), or TB commodities; human resource or training support; and quality assurance or remote or in-country technical assistance from the PEPFAR program. We identified 3 main use categories: centralized HIV VL and EID instrumentation for SARS-CoV-2 molecular testing; PEPFAR-supported laboratory information systems (LISs) for SARS-CoV-2 laboratory data management; and decentralized HIV VL, HIV EID, and TB instrumentation and resources for SARS-CoV-2 molecular testing on Cepheid GeneXpert instruments (Cepheid, https://www.cepheid.com). We sent the Microsoft Excel tool electronically as an open request to CDC PEPFAR laboratory advisors from 24 countries and 3 regions across the Americas, Africa, and Asia. Data were collected through CDC in-country laboratory advisors during June–August 2021 and verified for completion and quality by CDC headquarters staff in Atlanta, Georgia, USA. This activity was reviewed by CDC and was conducted consistent with applicable federal law and CDC policy. We obtained national SARS-CoV-2 testing volumes from Our World in Data, a publicly available database (*5*).

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Centralized and Decentralized Testing

We defined centralized laboratories as those with high-throughput testing platforms routinely used for HIV VL and EID testing that could also be used for SARS-CoV-2 molecular testing (*6*–*11*). Such platforms included the Abbott m2000 and Alinity M System (Abbott Molecular, https://www.abbott.com), the Roche cobas 6800 and cobas 8800 Systems (Roche Diagnostics, https://diagnostics.roche.com), and the Hologic Panther System (https://www.hologic.com). Decentralized testing sites were defined as those equipped with Cepheid GeneXpert instruments of any modular capacity directly or indirectly supported by the PEPFAR program for TB testing, HIV VL, HIV EID testing, or all of these. We collected country-specific aggregate data on the number of PEPFAR-supported centralized and decentralized laboratories; the number of these laboratories performing SARS-CoV-2 testing; the number of instruments; the volumes of HIV VL and EID, TB, and SARS-CoV-2 testing at centralized and decentralized laboratories; and the use of PEPFAR-supported testing staff, laboratory documentation, training or training materials, commodities and supplies, and LISs or diagnostic connectivity solutions for centralized and decentralized SARS-CoV-2 testing.

Laboratory Information Systems

We defined PEPFAR support for a LIS as support for the development, implementation, or maintenance of a LIS. We counted only countries using the adapted PEPFAR-supported LIS for managing SARS-CoV-2 specimens in the laboratory as having implemented the system. We defined the implementation date as the month and year that the first laboratory began recording specimens in the LIS. Countries also reported on the primary format in which the LIS returns results to the clinic and how data from the LIS are shared with the COVID-19 surveillance system.

Data Analysis

We analyzed and visualized completed tools by using Microsoft Power BI Desktop version 2.96.701.0 (August 2021). Descriptive analyses were conducted by CDC staff at headquarters after verification of data.

Results

Overview of PEPFAR Laboratory Support for COVID-19

Sixteen PEPFAR-supported countries responded to the survey, including the Dominican Republic and 15 countries from sub-Saharan Africa. (Table 1). This geographic distribution is fairly representative of the PEPFAR laboratory program, with most support focused in sub-Saharan Africa. All 16 countries reported using the PEPFAR-supported centralized and decentralized laboratories or laboratory resources for SARS-CoV-2 testing, and 11 reported using a PEPFAR-supported HIV VL and EID LIS for SARS-CoV-2 (Kenya used >1 LIS) (Table 1). Of the 11 countries or regions that did not provide data, 4 did not respond to the request, 2 declined to participate because PEPFAR resources were not being used for SARS-CoV-2 testing during the study period, and the remaining 5 could not provide data within the requested timeframe.

Table 1. Types of PEPFAR-supported laboratory systems used by 16 countries in their response to the COVID-19 pandemic, April 1, 2020–March 31, 2021*

Country	Centralized resources	Decentralized resources	Laboratory information system
No. (%) countries implementing	16 (100)	16 (100)	11 (73)
Eswatini	✓	✓	✓
Kenya	✓	✓	✓
Lesotho	✓	✓	✓
Malawi	✓	✓	✓
Mozambique	✓	✓	✓
South Sudan	✓	✓	✓
Uganda	✓	✓	✓
Zambia	✓	✓	✓
Nigeria	✓	✓	✓
Namibia	✓	✓	✓
Zimbabwe	✓	✓	✓
Angola	✓	✓	No data
Cameroon	✓	✓	–
Dominican Republic	✓	✓	–
Ethiopia	✓	✓	–
Democratic Republic of the Congo	✓	✓	–

*PEPFAR, US President's Emergency Plan for AIDS Relief; ✓, use of network component reported; –, network component was not used.

Table 2. PEPFAR-supported centralized VL and EID laboratories and instruments used for SARS-CoV-2 testing in 16 countries in their response to the COVID-19 pandemic, April 1, 2020–March 31, 2021*

Country	No. PEPFAR laboratories	No. (%) PEPFAR laboratories conducting SARS-CoV-2 testing	No. instruments	No. HIV VL and EID tests conducted in PEPFAR laboratories†	No. SARS-CoV-2 tests conducted in PEPFAR laboratories	No. SARS-CoV-2 tests conducted nationally (*5*)	% SARS-CoV-2 tests performed at PEPFAR laboratories‡
Angola	2	2 (100)	2	NA	No data	NA	NA
Cameroon	13	10 (77)	7	NA	No data	NA	NA
DR	4	1 (25)	1	26,930	588,736	1,176,196§	50
DRC	6	5 (83)	2	176,249	5,565	No data	NA
Eswatini	4	1 (25)	1	NA	No data	NA	NA
Ethiopia	20	15 (75)	15	325,276	630,119	2,355,880¶	27
Kenya	10	8 (80)	25	1,348,294	401,402	571,413#	70
Lesotho	6	3 (50)	0	189,631	47,006	No data	NA
Malawi	11	11 (100)	18	580,578	113,738	56,987¶	200
Mozambique	16	5 (31)	5	1,061,555	378,029	472,224#	80
Namibia	8	4 (50)	3	NA	No data	NA	NA
Nigeria	12	4 (33)	10	1,987,452	208,317	702,055§	30
South Sudan	1	0 (0)	0	NA	0	NA	NA
Uganda	1	1 (100)	11	1,459,010	279,176	851,514§	33
Zambia	24	24 (100)	10	1,025,000	600,000	1,218,207¶	49
Zimbabwe	15	15 (100)	11	650,423	89,504	428,121#	21
Total	153	109 (71)	121	8,830,398	3,341,592	7,832,597	42

*DR, Dominican Republic; DRC, Democratic Republic of Congo; EID, early infant diagnosis; NA, not applicable; PEPFAR, US President's Emergency Plan for AIDS Relief; VL, viral load.
†Number of HIV VL and EID and national SARS-CoV-2 tests are only shown for those countries reporting SARS-CoV-2 testing volumes in PEPFAR-supported laboratories. For countries not reporting SARS-CoV-2 testing volumes in PEPFAR-supported laboratories, HIV VL and EID and national SARS-CoV-2 test numbers are listed as NA.
‡ Percentage of SARS-CoV-2 tests performed at PEPFAR-supported laboratories was only calculated for countries with data available for both PEPFAR and national SARS-CoV-2 testing numbers. For countries without both PEPFAR and national SARS-CoV-2 testing numbers available, % of SARS-CoV-2 tests performed at PEPFAR laboratories is listed as NA.
§National SARS-CoV-2 test numbers represent the number of PCR tests.
¶Test type for national SARS-CoV-2 test numbers was uncited or listed as unclear.
#National SARS-CoV-2 test numbers represent the number of PCR and antigen tests.

Centralized Testing

Of the 16 countries that responded, 15 countries reported using PEPFAR centralized VL and EID laboratories for SARS-CoV-2 testing and 1 country (South Sudan) reported no use of those resources (Table 2). Of the 14 countries that reported a date for SARS-CoV-2 test initiation, 8 reported testing for SARS-CoV-2 by April 2020. Five countries (Angola, Malawi, Uganda, Zambia, and Zimbabwe) used 100% of their PEPFAR-supported centralized testing laboratories for SARS-CoV-2 testing (Table 2). Four countries (Democratic Republic of the Congo, Kenya, Cameroon, and Ethiopia) adapted 75%–90% of centralized laboratories for SARS-CoV-2 testing (Table 2). Four countries (Lesotho, Namibia, Nigeria, and Mozambique) used 30%–50% of their PEPFAR-supported centralized laboratories for SARS-CoV-2 testing, and 2 countries (Dominican Republic and Eswatini) used 25% of their centralized laboratories (Table 2). Across the 16 countries, a total of 109 (71%) PEPFAR-supported centralized VL and EID laboratories conducted SARS-CoV-2 testing on 121 centralized VL and EID instruments during the reporting period (Table 2).

Of the 15 countries reporting SARS-CoV-2 testing at PEPFAR-supported centralized VL and EID laboratories, 11 reported SARS-CoV-2 testing volumes. In these 11 countries, a total of 3,341,592 SARS-CoV-2 tests were performed in PEPFAR-supported centralized VL and EID laboratories during the 12-month reporting period and accounted for 42% of the national testing volumes in these countries according to a publicly available database (*5*) (Table 2). Three countries (Ethiopia, Zambia, and Dominican Republic) performed >500,000 SARS-CoV-2 tests using PEPFAR-supported laboratories during the study period, contributing to 27% (Ethiopia), 49% (Zambia), and 50% (Dominican Republic) of the national testing volumes (Table 2). These countries also had the highest proportion of SARS-CoV-2 tests performed in PEPFAR-supported centralized laboratories compared with HIV VL and EID testing ranging from 96% in the Dominican Republic to 37% in Zambia (Table 2). Four countries (Kenya, Mozambique, Uganda, and Nigeria) performed ≈208,000–402,000 SARS-CoV-2 tests during the reporting period, contributing to 70% (Kenya), 80% (Mozambique), 33% (Uganda), and 30% (Nigeria) of the national SARS-CoV-2 testing volume (Table 2). These countries also performed >1 million HIV VL and EID tests each (Table 2). Angola, Cameroon, Eswatini, Namibia, and South Sudan did not report SARS-CoV-2 test volumes.

Thus far, we have described the contribution of physical laboratory space and instrumentation to SARS-CoV-2 testing in PEPFAR-supported centralized laboratories. We assessed additional categories of centralized laboratory support provided by PEPFAR and whether they were used for SARS-CoV-2 testing (Table 3). Of the 16 countries, 14 reported using laboratory documentation for SARS-CoV-2 testing, 13 reported using testing staff, 12 reported using the specimen referral network, and 10 countries each reported using PEPFAR-supported laboratory training materials (Table 3). Three countries that reported no use of PEPFAR testing staff to conduct SARS-CoV-2 testing indicated that trained ministry of health staff conducted the testing in these laboratories. Although it was not requested, a few countries provided additional information on PEPFAR resources contributing to SARS-CoV-2 external quality-assurance programs.

Decentralized Testing

As with centralized HIV molecular testing instrumentation, modular GeneXpert near-point-of-care systems are designed for multi-disease testing. By March 31, 2021, five countries had not introduced the Xpert Xpress SARS-CoV-2 assay into their networks, in part because of disruptions in the availability of GeneXpert testing services (Angola) or national implementation plans prioritizing high-volume centralized testing strategies or test implementation at sites outside the PEPFAR-supported network (Ethiopia, Kenya, Uganda, and Cameroon) (Table 4). The remaining 11 countries reported integration of SARS-CoV-2 into GeneXpert-based TB or TB and HIV services across a total of 138 (7.1%) PEPFAR-supported decentralized molecular sites (Table 4). Of note, decentralized SARS-CoV-2 testing was not reported in any country until June 2020 likely because of the reasons stated previously.

Although the number of PEPFAR-supported GeneXpert laboratories varied by country, South Sudan (17/17 [100%]), Dominican Republic (7/11 [64%]), Malawi (35/89 [39%]), Zimbabwe (33/122 [27%]), and the Democratic Republic of the Congo (2/18 [11%]) reported the highest proportion of PEPFAR-supported decentralized instruments used for SARS-CoV-2 testing (Table 4). The remaining countries used <10% of their PEPFAR-supported decentralized networks for SARS-CoV-2 (Table 4). As expected, the proportion of GeneXpert network use generally correlated with network size; the highest proportion of instruments used was reported by countries with ≤125 instruments, whereas lower proportions were reported by countries supporting larger networks, such as Nigeria, Zambia, Ethiopia, and Uganda (250–400 instruments) (Table 4).

Of the 11 countries that introduced SARS-CoV-2 testing at PEPFAR-supported GeneXpert sites, 9 reported testing volumes for TB and SARS-CoV-2, of which 7 also indicated the provision of GeneXpert-based HIV VL or EID testing services and reported combined HIV-specific testing volumes (Table 4). The highest SARS-CoV-2 testing volumes were reported from Nigeria (39,902 tests), Zambia (27,000

Table 3. Use of PEPFAR-supported centralized viral load and early infant diagnosis diagnostic networks for SARS-CoV-2 testing in 16 countries in their response to the COVID-19 pandemic, April 1, 2020–March 31, 2021*

Country	Testing staff	Laboratory documentation	Training materials	Specimen referral networks
No. (%) countries implementing	13 (81)	14 (93)	10 (67)	12 (75)
Kenya	✓	✓	✓	✓
Malawi	✓	✓	✓	✓
Mozambique	✓	✓	✓	✓
Namibia	✓	✓	✓	✓
Nigeria	✓	✓	✓	✓
South Sudan†	✓	✓	✓	✓
Zimbabwe	✓	✓	✓	✓
Cameroon	✓	No data	No data	✓
Democratic Republic of Congo	✓	✓	✓	–
Uganda	✓	✓	–	✓
Lesotho	✓	✓	–	✓
Zambia	✓	✓	–	✓
Angola	–	✓	✓	–
Dominican Republic	–	✓	✓	–
Eswatini	–	✓	–	✓
Ethiopia	✓	–	–	–

*PEPFAR, US President's Emergency Plan for AIDS Relief; ✓, use of network component reported; –, network component was not used.
†Did not report utilizing PEPFAR-supported centralized viral load and early infant diagnosis laboratories for SARS-CoV-2 testing.

Table 4. PEPFAR-supported decentralized laboratories and instruments used for SARS-CoV-2 testing in 16 countries in their response to the COVID-19 pandemic, April 1, 2020–March 31, 2021*

Country	No. PEPFAR sites	No. (%) PEPFAR sites conducting SARS-CoV-2 testing	No. TB tests conducted in PEPFAR sites†	No. HIV VL and EID tests conducted in PEPFAR sites†	No. SARS-CoV-2 tests conducted in PEPFAR sites	No. SARS-CoV-2 tests conducted nationally	% SARS-CoV-2 tests performed at PEPFAR sites‡
Angola	4	0 (0)	NA	NA	No data	NA	NA
Cameroon	13	0 (0)	NA	NA	No data	NA	NA
DR	11	7 (64)	18,519	3,133	1,240	1,176,196§	0.1
DRC	18	2 (11)	NA	NA	No data	No data	NA
Eswatini	32	1 (3)	18,243	1,196	873	No data	NA
Ethiopia	280	0 (0)	NA	NA	No data	NA	NA
Kenya	158	0 (0)	NA	NA	No data	NA	NA
Lesotho	33	3 (9)	19,596	15,046	21,946	No data	NA
Malawi	89	35 (39)	33,450	43,602	10,482	56,987¶	18.4
Mozambique	161	6 (4)	159,685	0	10,332	472,224#	2.2
Namibia	45	4 (9)	NA	NA	No data	NA	NA
Nigeria	400	27 (7)	56,183	0	39,902	702,055§	5.7
South Sudan	17	17 (100)	4,024**	1,081**	2,931**	41,171¶	7.1
Uganda	250	0 (0)	NA	NA	No data	NA	NA
Zambia	300	3 (1)	150,000	6,000	27,000	1,218,207¶	2.2
Zimbabwe	122	33 (27)	8,326	1,247	9,976	428,121#	2.3
Total	1,933	138 (7.1)	468,026	71,305	124,682	4,094,961	2.5

*DR, Dominican Republic; DRC, Democratic Republic of Congo; EID, early infant diagnosis; NA, not applicable; PEPFAR, US President's Emergency Plan for AIDS Relief; VL, viral load.
†Number of HIV VL and EID and national SARS-CoV-2 tests are only shown for those countries reporting SARS-CoV-2 testing volumes in PEPFAR-supported laboratories. For countries not reporting SARS-CoV-2 testing volumes in PEPFAR-supported laboratories, HIV VL and EID and national SARS-CoV-2 test numbers are listed as NA.
‡Percentage of SARS-CoV-2 tests performed at PEPFAR-supported laboratories was only calculated for countries with data available for both PEPFAR and national SARS-CoV-2 testing numbers. For countries without both PEPFAR and national SARS-CoV-2 testing numbers available, % of SARS-CoV-2 tests performed at PEPFAR laboratories is listed as NA.
§National SARS-CoV-2 test numbers represent the number of PCR tests.
¶Test type for national SARS-CoV-2 test numbers was uncited or listed as unclear.
#National SARS-CoV-2 test numbers represent the number of PCR and antigen tests.
**Testing numbers reported in South Sudan PEPFAR laboratories represent the period October 2020–March 2021.

tests), and Lesotho (21,946 tests), followed by Malawi (10,482 tests), Mozambique (10,332 tests), and Zimbabwe (9,976 tests), whereas the lowest testing volumes were reported from Dominican Republic (1,240) and Eswatini (873) (Table 4). Similarly, South Sudan reported a low testing volume for the portion of the reporting period for which testing data were available (2,931 tests during October 2020–March 2021) (Table 4). Because of lower instrument throughput, PEPFAR-supported decentralized sites contributed to a small percentage of the national SARS-CoV-2 testing volumes (2.5%) in the countries with data available (Table 4). Of note, most (6/8 [75%]) of reporting countries completed more TB tests than HIV or SARS-CoV-2 tests during the pandemic period, ranging from 43% to 94% of testing by country conducted during the reporting period (Table 4). Only Malawi and Lesotho indicated higher volumes of HIV tests (50% in Malawi) and SARS-CoV-2 tests (39% in Lesotho) than either other disease (Table 4), which is in agreement with published reports of reduced TB service use and case notifications in these countries during a period of HIV or SARS-CoV-2 Xpert test scale-up (*12*,*13*). Overall, PEPFAR supported the completion of >664,000 TB, HIV, and SARS-CoV-2 Xpert tests across the 9 reporting countries during the study period.

In addition to the use of GeneXpert instruments and Xpert cartridges at PEPFAR-supported testing sites, 12 of 16 reporting countries reported additional use of other components of the PEPFAR-supported diagnostic network for implementation of the Xpert Xpress SARS-CoV-2 molecular test (Table 5). Support for testing staff to conduct SARS-CoV-2 tests was reported by all 11 countries, followed closely by the use of laboratory documentation to record Xpert Xpress SARS-CoV-2 testing data and trainings or training materials for new or existing site staff (10/12 [83%]) (Table 5). Commodities required for safe and accurate Xpert Xpress SARS-CoV-2 testing were also provided in 8 (67%) countries and included, but were not limited to, personal protective equipment, waste management materials, testing consumables and supplies, and Xpert Check calibration cartridges (Table 5). In addition, 7 countries reported using the PEPFAR-supported diagnostic connectivity solutions to track or report Xpert Xpress SARS-CoV-2 test results to healthcare providers or disease surveillance programs (Table 5). Of note, nearly all the countries that implemented SARS-CoV-2 GeneXpert testing at PEPFAR-supported sites used ≥4 of the 5 network support components; testing in Eswatini, Lesotho, and Zimbabwe were supported with all

listed components by the end of the reporting period (Table 5). Uganda did not report use of PEPFAR-supported GeneXpert sites for SARS-CoV-2 testing but did report use of PEPFAR-supported connectivity solutions (Table 5).

LISs

LISs help to manage specimens and workflows within the laboratory and are critical for ensuring efficient laboratory testing and reporting in high-throughput laboratories. As stated, of the 16 countries reporting data, 11 reported having adapted and implemented the existing PEPFAR-supported LIS (or LISs, as in Kenya) for managing SARS-CoV-2 testing (Table 1) in 121 centralized and decentralized laboratories (Table 6). Reasons for countries reporting not adapting a PEPFAR-supported LIS included implementation of the PEPFAR-supported LIS after the reporting period and use of a non–PEPFAR-supported LIS. The time to adapt the LIS for SARS-CoV-2 testing ranged from March to December 2020; nine of the 11 countries reported the system having been implemented by the end of June 2020 (Table 6). We categorized the type of LISs that were adapted and found that 5 countries (Namibia, Eswatini, Zambia, Lesotho, and Mozambique) adapted a commercial LIS, 2 countries (Uganda and Nigeria) adapted a custom-built LIS, 1 country (Kenya) adapted a mix of commercial and custom-built LISs, and 3 countries (Malawi, Zimbabwe, and South Sudan) adapted open-source LIS solutions (Table 6).

One benefit of an LIS is the ability to return results to the clinic through a paperless route and thus decrease the turnaround time for this segment of laboratory testing. Nine (82%) of the 11 countries using a PEPFAR-supported LIS for SARS-CoV-2 testing returned results through electronic means (8 countries) or through SMS (1 country), whereas 2 (18%) countries reported returning results through a paper system. We should note that these means of result return represent the primary format and that several countries reported using various methods on the basis of the capacity of the health facilities receiving the results.

In addition to returning results efficiently, LISs are also used for surveillance purposes by providing the number and (potentially) demographic information of patients or samples tested and the results of those tests. All 11 countries reported that the LIS contributed to COVID-19 surveillance; 4 (36%) 11 of countries reporting exporting data from the LIS directly (1 country) or indirectly (3 countries) to an electronic medical record or surveillance system, and 6/11 (55%) described exporting data from the LIS in bulk for surveillance purposes. The remaining country reported manual entry of results from an LIS to the surveillance system.

Discussion

Worldwide, more COVID-19 cases were documented in the first 5 months of 2021 than in all of 2020 (*5*). Many PEPFAR-supported countries experienced multiple waves of infections. Although challenges facing LMICs in battling the ongoing COVID-19 pandemic are numerous (*14*), existing PEPFAR-supported diagnostic networks and ongoing laboratory strengthening activities enabled several countries to effectively respond to emergency SARS-CoV-2 testing demands in a timely manner.

SARS-CoV-2 testing volumes on PEPFAR-supported centralized and decentralized molecular

Table 5. Use of PEPFAR-supported decentralized diagnostic networks for SARS-CoV-2 testing in 12 countries in their response to the COVID-19 pandemic, April 1, 2020–March 31, 2021*

Country	Testing staff	Laboratory documentation	Training materials	Commodities	Connectivity
No. (%) countries implementing	11 (92)	10 (83)	10 (83)	8 (67)	7 (58)
Eswatini	✓	✓	✓	✓	✓
Lesotho	✓	✓	✓	✓	✓
Zimbabwe	✓	✓	✓	✓	✓
Democratic Republic of the Congo	✓	✓	✓	✓	–
Dominican Republic	✓	✓	✓	✓	–
Nigeria	✓	✓	✓	✓	–
South Sudan	✓	✓	✓	✓	–
Malawi	✓	✓	✓	–	✓
Zambia	✓	✓	–	✓	✓
Namibia	✓	✓	✓	–	–
Mozambique	✓	–	✓	–	✓
Uganda†	–	–	–	–	✓

*PEPFAR, US President's Emergency Plan for AIDS Relief; ✓, use of network component reported; –, network component was not used.
†Uganda did not report using PEPFAR-supported decentralized laboratories for SARS-CoV-2 testing.

Table 6. Summary of PEPFAR-supported LISs adapted for SARS-CoV-2 testing in 11 countries in their response to the COVID-19 pandemic, April 1, 2020–March 31, 2021*

Country	No. PEPFAR-supported laboratories with a SARS-CoV-2 LIS†	LIS category	Month and year the SARS-CoV-2 LIS was implemented in first laboratory
Namibia	39	Commercial	Mar 2020
Mozambique	16	Commercial	Mar 2020
Eswatini	2	Commercial	Apr 2020
Zambia	24	Commercial	Apr 2020
Nigeria	4	Custom-built	Apr 2020
Uganda	3	Custom-built	May 2020
Malawi	5	Open-source	Jun 2020
Zimbabwe	15	Open-source	Jun 2020
Kenya	8	Commercial and custom-built	Jun 2020
Lesotho	3	Commercial	Dec 2020
South Sudan	2	Open-source	Dec 2020
Total	121		

*LIS, laboratory information system; PEPFAR, US President's Emergency Plan for AIDS Relief.
†Number of PEPFAR-supported laboratories with a SARS-CoV-2 LIS includes centralized and decentralized laboratories.

instruments were dependent on each country's individualized COVID-19 testing strategy, which considered many factors, including instrument capacity, availability of SARS-CoV-2 molecular test kits, reagents and consumables, availability of trained staff, and total testing need for all diseases on each instrument or in each laboratory. Furthermore, centralized and decentralized testing offer unique benefits; centralized testing offers higher testing volumes, and decentralized testing offers increased testing access nearer to the patient. For those reasons, laboratory use and testing volumes between countries or laboratory types cannot be meaningfully compared; however, our findings demonstrate that existing PEPFAR-supported centralized and decentralized diagnostic networks contributed to SARS-CoV-2 testing in all countries reporting data and to 43% of national testing volumes reported in a publicly available database (Tables 2, 4) (*5*). This contribution was potentially even higher given that PEPFAR testing data were limited to molecular tests and the testing data for several countries in the database included antigen testing or did not specify the type of test reported (*5*). We should note that SARS-CoV-2 testing in PEPFAR-supported countries and laboratories was probably limited by a global shortage of molecular reagents and test kits that disproportionately affected automated molecular platforms and LMICs (*4*,*15*). Furthermore, PEPFAR only supports closed platforms for molecular testing, and our study therefore did not investigate the use of open platforms for SARS-CoV-2 testing, which were commonly used across LMICs, particularly early in the pandemic. Nevertheless, the PEPFAR-supported contributions to national SARS-CoV-2 testing volumes are substantial and illustrate that PEPFAR-supported laboratory strengthening efforts in LMIC are not only beneficial for HIV- and TB-related programs and services but can have a broader public health benefit.

SARS-CoV-2 testing was performed at PEPFAR-supported centralized and decentralized molecular laboratories in addition to routine HIV VL, HIV EID, and TB testing. For most countries, apart from Ethiopia and the Dominican Republic, SARS-CoV-2 testing accounted for <50% of total centralized and decentralized SARS-CoV-2, HIV VL and EID, and TB testing volumes (Tables 2, 4). Diagnostic networks in LMICs have historically been implemented in a siloed, program-specific manner (*16*), resulting in parallel networks operating or managed by different entities. With the availability of molecular platforms, which can test for multiple diseases, and a need for more sustainable and efficient networks, countries are exploring how to integrate these parallel networks and use instruments to test for several diseases. Data for HIV and TB testing trends before the COVID-19 pandemic were not collected in this study and thus the effect of integration of SARS-CoV-2 on existing test cannot be directly assessed; however, the use of existing laboratories, instrumentation, and sample transport networks within these PEPFAR-supported countries for SARS-CoV-2 testing demonstrates the feasibility of diagnostic network integration. Although diseases and testing needs will differ by country, the process of assessing the existing network infrastructure and capacity and determining how to meet the cumulative testing demand is the same across all countries. Lessons learned from cross-disease resource sharing between TB, HIV, and COVID-19 in these countries and others can guide future models for integrated, patient-centered service delivery.

The variety of categories and types of LISs adapted for SARS-CoV-2 testing in PEPFAR-supported countries illustrate the diversity of the

PEPFAR LIS portfolio and the versatility of information system maintenance and support. The diversity of the systems in place is indicative of country-led efforts in LIS selection and implementation. Each of the categories of LISs (commercial, custom built, or open-source) require a different level of upfront and recurring costs to implement and maintain, yet each category was successfully adapted and implemented for SARS-CoV-2 testing in PEPFAR-supported countries (Table 6). These data demonstrate that the countries had, or quickly acquired, the necessary technical and financial support to update their LISs to respond to a global pandemic.

The first limitation of our study is that our analysis is limited to the countries that reported data and thus cannot be extrapolated to the entire PEPFAR program, given that the decision to participate or not provide complete data could have been biased by the level of PEPFAR resources used for SARS-CoV-2. In addition, the reported scope of laboratory resources used by these 16 countries is limited to molecular diagnostic networks and only the resources supported by PEPFAR. Although PEPFAR-supported diagnostic networks are extensive, they are not nationally representative and do not include other disease program laboratory services that were similarly adapted for SARS-CoV-2 molecular testing during the initial year of the COVID-19 pandemic. Furthermore, the level of PEPFAR support for each of the countries varies, and thus the countries cannot be compared to each other. Our analysis might also be limited by the quality of the data reported. Although data were reported in line with the indicators to the best of the individual or country team's knowledge, reporting errors may have occurred. Nonetheless, our data demonstrate the resiliency of laboratory systems strengthened through PEPFAR and how quickly these systems were able to adapt to accommodate testing for SARS-CoV-2.

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A Nationally Representative Survey of COVID-19 in Pakistan, 2021–2022

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We conducted 4,863 mobile phone and 1,715 face-to-face interviews of adults ≥18 years residing in Pakistan during June 2021–January 2022 that focused on opinions and practices related to COVID-19. Of those surveyed, 26.3% thought COVID-19 was inevitable, and 16.8% had tested for COVID-19. Survey participants who considered COVID-19 an inevitability shared such traits as urban residency, concerns about COVID-19, and belief that the virus is a serious medical threat. Survey respondents who had undergone COVID-19 testing shared similarities regarding employment status, education, mental health screening, and the consideration of COVID-19 as an inevitable disease. From this survey, we modeled suspected and confirmed COVID-19 cases and found nearly 3 times as many suspected and confirmed COVID-19 cases than had been reported. Our research also suggested undertesting for COVID-19 even in the presence of COVID-19 symptoms. Further research might help uncover the reasons behind undertesting and underreporting of COVID-19 in Pakistan.

The novel coronavirus SARS-CoV-2 was characterized as a pandemic by the World Health Organization on March 11, 2020 (*1*), after its discovery in Wuhan, China, in December 2019. The first case of COVID-19 in Pakistan was reported on February 26, 2020, with the government declaring an outbreak the same day (*2*–*5*). As of December 31, 2021, there were >1,290,000 confirmed COVID-19 cases and 28,909 COVID-19–related deaths in Pakistan (*6*).

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Given the relatively young median age in Pakistan of 23 years, fewer cases of severe disease have been reported in Pakistan than in other countries, which is consistent with previously observed findings of decreased disease severity among younger persons (*7*). Pakistan is especially vulnerable to COVID-19 spread because of the country's high population density and average household size of 6.4 persons (*8*). Sixty-two percent of residents live in rural areas with inadequate or inaccessible healthcare facilities, and many others are reluctant to access health services (*9*,*10*). Although Pakistan has infection control and prevention guidelines, including those specific to COVID-19, these guidelines were not uniformly implemented in public healthcare settings before or during COVID-19, which might have perpetuated public distrust of the healthcare system and reluctance of residents to use health services (*11*–*14*).

Administration of COVID-19 vaccines in Pakistan began in February 2021, and by December 31, 2021, a total of 31.3% of the population had completed a fully primary vaccination series, and another 11.7% were partially vaccinated. However, only those ≥12 years of age were eligible for vaccination (*15*). Although vaccination is a critical prevention measure, nonpharmaceutical interventions to prevent the spread of COVID-19 also are critical to ensure that the healthcare system is not overwhelmed during surges. Challenges to Pakistan's vaccine program include scarcity of pediatric doses, introduction of booster doses, and lower efficacy of 2-dose vaccine regimens (*15*,*16*).

Individual prevention behaviors, such as physical distancing and mask wearing, can lead to decreases in the sickness and death rates related to COVID-19 (*17*,*18*). It is therefore important to understand the willingness of residents to engage in these behaviors to maximize the safety of the population. Previous studies have shown that personal perceived risk regarding COVID-19 during the pandemic varies based

on such factors as demographics, physical health, anxiety about COVID-19, and knowing someone who had contracted COVID-19 (*19*,*20*). Perceived risk is an important factor for engagement in prevention behaviors (*21*). Understanding perceived risk across different groups—and how perceived risk translates to behavior—can inform policy and interventions.

Two years into the pandemic, mitigation policies and the social and emotional toll of the pandemic have left many populations weary (*22*). Because COVID-19 will remain a threat for the foreseeable future, it is important to understand its effect on society and the willingness of persons to continue engaging in prevention measures. Vaccination rates are stagnating in many countries, and immunity (natural and vaccine-derived) wanes over time. Waning immunity could leave persons vulnerable to future infection. Pandemic fatigue may also affect willingness to get tested for COVID-19, especially for those who have already been infected or vaccinated or who have seen others get infected and experience only mild symptoms. Testing remains important for detection of COVID-19 cases to facilitate isolation of infected persons and for surveillance purposes (*23*). Delays in testing can result in continued transmission; it is important therefore to understand factors that influence a person's decision to test (*24*).

As of December 31, 2021, Pakistan ranked 102nd out of 132 countries for administered COVID-19 tests per million persons, suggesting that the number of cases reported and, in turn, the number of COVID-19–associated deaths are underestimated (*6*,*25*). We conducted a survey in Pakistan to gather nationally and provincially representative data about the knowledge and attitudes of residents regarding COVID-19 and how they are responding to the pandemic. In addition, we estimated the number of COVID-19 suspected and confirmed cases. We hope that our data will help to inform evidence-based policies and programs in Pakistan.

Materials and Methods

Study Design and Setting

We conducted a national cross-sectional, 2-stage, cluster survey in all 4 provinces of Pakistan (Punjab, Sindh, Kyber Pakhtunkhwa, and Balochistan), as well as other territories (Gilgit Baltistan, Azad Jamu, and Kashmir), using mobile phone and face-to-face interviews. Mobile phone interviews were conducted from June 29, 2021, through August 16, 2021. Face-to-face interviews were conducted from December 8, 2021, through January 11, 2022. Funding delays caused the gap of approximately 4 months between the end of the mobile phone survey and the beginning of the face-to-face survey.

We determined eligibility criteria based on such chief factors as age ≥18 years, ability to speak Urdu, Pashto, or Sindhi, and willingness to provide verbal consent. The duration of interviews was ≈15 minutes for mobile phone interviews and ≈25 minutes for face-to-face interviews. We conducted the mobile phone interviews with the intent of mitigating the spread of SARS-CoV-2 throughout the country. Recognizing that mobile phone ownership is not universal in Pakistan, we carried out face-to-face interviews to supplement those conducted by mobile phone and reach underrepresented populations, such as women, those living in rural areas without mobile phone service, and persons at lower socio-economic status and thus less likely to own mobile phones.

We selected mobile phone interviewees using random digit dialing. We randomly selected phone numbers from a national repository of registered mobile phone numbers based on the proportion of market share held by mobile phone providers. If no answer, we made 3 callback attempts. Estimating a response rate of 5%, we selected 120,000 phone numbers to reach the target sample size of 4,980. Once we reached the target sample size, we stopped conducting interviews. We selected participants for the face-to-face survey using a 2-stage, stratified, cluster sampling design. In the first stage, we selected 132 primary sampling units (PSUs) from 2 strata using the 2017 census, with probability proportionate to size (*8*). The PSUs were urban census blocks and villages. In the second stage, we divided the PSUs into 4 parts with equal numbers of households. We conducted interviews using a modified Kish Grid approach to select 1 of the 4 quadrants from which households were sampled (*26*). The interviewer went to the center of the segment and randomly selected a household and then went to every fifth household using a right-hand rule. If there was >1 eligible respondent in a household, we randomly selected 1 using the Kish Grid method. We estimated the sample size for face-to-face interviews as 1,320, a number that we determined would supplement the mobile phone interviews and be large enough to be representative in terms of sex, province, age, language, education, and occupation at national and subnational levels.

Study Instrument

We developed a questionnaire comprised of 9 modules: demographics, COVID-19 history, knowledge, attitudes, behavior, mental health, violence, the effect

of COVID-19, and COVID-19 sources of information. We used the Patient Health Questionnaire 4 scale to categorize mental health status into normal (score of 0–2), mild (3–5), moderate (6–8), and severe (9–12) (*27*). A score of higher than normal indicates anxiety and depression.

Data and Analysis

We conducted descriptive analysis to calculate the frequency and percentage of demographic information, behaviors, and perceptions. This primary analysis focused on 2 correlates: 1) belief that it is impossible to avoid contracting COVID-19 (referred to as "COVID-19 is inevitable"); and 2) history of testing for COVID-19. We also estimated the number of suspected and confirmed cases. We defined confirmed cases as someone who had a laboratory-confirmed positive COVID-19 test, and we defined suspected cases as someone who was not tested for COVID-19 but experienced COVID-19 symptoms, including new loss of taste or smell or any 3 of these symptoms: fever, cough, headache, general weakness or fatigue, sore muscles, sore throat, loss of appetite, diarrhea, and difficulty breathing.

We constructed survey weights by iteratively poststratifying the sample on educational attainment, occupation, province, rural/urban, and sex. We obtained population proportions for the poststratifications from census data (*8*). When calculating population proportions from the rate at which an event occurs in the households of the respondents, we further weighted inversely by household size, because members of large households would be overrepresented in the sample otherwise.

We conducted logistic regression to assess correlates of believing that contracting COVID-19 was inevitable and history of ever testing for COVID-19. We included variables with an association of $p<0.1$ on bivariate analysis in the multivariate model. We conducted statistical analysis in Stata version 16.0 (StataCorp LLC, https://www.stata.com) and R version 4.1.1 (The R Project for Statistical Computing, https://www.r-project.org) (*28*,*29*).

Ethics Approval

The International Research Force Pakistan institutional review board reviewed and approved the survey protocol. This activity was reviewed by US Centers for Disease Control and Prevention and was conducted consistent with applicable federal law and Centers for Disease Control and Prevention policy (see e.g., 45 C.F.R. part 46.102(l)(2), 21 C.F.R. part 56; 42 U.S.C. §241(d); 5 U.S.C. §552a; 44 U.S.C. §3501 et seq.). All participants provided verbal consent. Participants were able to end the survey at any time for any reason.

Results

We conducted phone interviews with 4,863 persons (response rate 20%, 4,863/24,315) and face-to-face interviews with 1,715 persons (response rate 70%, 1,715/,2450), for a total of 6,578 interviews. The median age of participants was 32 years. After weighting the data, we split the population roughly equally, 50.6% women and 49.4% men (Table 1, https://wwwnc.cdc.gov/EID/article/28/13/22-0728-T1.htm). Geographically, 35.4% lived in rural areas and 64.6% lived in urban areas. Approximately half (49.9%) completed less than primary education, 19.8% primary and middle, 23.2% secondary and high, and 7.1% graduate and postgraduate. Approximately half (50.3%) were employed, 40.7% were female homemakers, and 9.1% were not working. In terms of income (thresholds were originally set in Pakistan rupees and converted to US dollars [USD]), 35.8% did not earn any money, 49.9% earned <$163 USD per month, 8.3% earned $163–$208 USD per month, and 5.9% earned >$208 USD monthly. The percentage who earned money is notably higher than those who were employed, which might be because some persons work in the informal sector and do not consider themselves to be employed.

Mental health challenges were common; 36.9% of the weighted study population screened positive for mild anxiety and depression, 12.7% for moderate, and 5.3% for severe. Nearly half (49.9%) were not worried about COVID-19, 24.3% were a little worried, 3.7% were moderately worried, and 22.2% were very worried. There were 52.1% who noted that life was more stressful since the start of the pandemic because of additional caregiving or work responsibilities.

Most (75.9%) of the weighted study population thought COVID-19 was a serious health issue, and 26.3% thought contracting COVID-19 was inevitable. Men (32%) were more likely than women (21.2%) to think contracting COVID-19 was inevitable. Urban residents (31.4%) were more likely than rural residents (23.5%) to think contracting COVID-19 was inevitable. Of those who thought COVID-19 was inevitable, 36.6% had tested for COVID-19 and 24.2% had not. Of those respondents who thought COVID-19 was inevitable, almost one-third (29.2%) thought COVID-19 was serious compared with those who did not (17.7%). Among those respondents who thought COVID-19 was inevitable, 19.4% felt this made them less willing to avoid it, and 61.7% were more willing to try avoiding it (data not shown).

Fewer than 1 in 5 study participants (16.8%) had ever tested for COVID-19, with a higher proportion of men (22.1%) than women (11.7%) having tested. Testing was most common among those with the highest levels of income or education. One quarter (25.7%) of those earning >$208 USD per month had tested for COVID-19 compared with 12.4% of those who did not earn money. Similarly, 27.2% of those with a graduate or postgraduate degree had tested for COVID-19, compared with 13.9% of those with less than primary education. History of testing for COVID-19 was more common among those who thought getting COVID-19 was inevitable (23.6%) compared with those who thought it was not (14.6%). History of testing for COVID-19 also was more common for those with no anxiety or depression (18.6%) compared with those with severe anxiety or depression (13.0%). Of those who tested for COVID-19, 39.4% did so because they felt unwell, 14.8% because it was required for work, 12.7% because they were in close contact with someone with COVID-19, and 7.9% because it was required for school. Among those who tested for COVID-19, 71.8% tested once, 22.9% tested twice, and 5.3% tested 3–5 times.

In multivariate analysis, thinking COVID-19 was inevitable was associated with thinking it was a serious health issue (adjusted odds ratio [aOR] 1.7, 95% CI 1.2–2.4) (Table 2, https://wwwnc.cdc.gov/EID/article/28/13/22-0728-T2.htm). People living in rural areas were less likely to think COVID-19 was inevitable than urban residents (aOR 0.7, 95% CI 0.6–0.8). Thinking COVID-19 was inevitable was not associated with mask wearing, physical distancing, handwashing, or avoiding nonessential shopping, domestic travel, or public transport.

From the testing of correlates of having tested for COVID-19, those with a graduate or postgraduate degree were more likely to have tested for COVID-19 (aOR 1.5, 95% CI 1.1–2.2) compared with those with less than primary education (Table 2). Female homemakers (aOR 0.6, 95% CI 0.3–0.9) were less likely to have tested than women who were employed. Testing for COVID-19 was not associated with mask wearing, physical distancing, handwashing, or avoiding nonessential shopping, domestic travel, or public transport.

We estimated the cumulative number of suspected and confirmed cases of COVID-19. Among household members of study participants, there were 316 confirmed cases, 856 suspected and confirmed cases, 24 caregiver deaths, and 2 children who were orphaned because of the virus (Table 3). Adjusting for Pakistan's population, we estimated 1,518,000 (95% CI 880,000–2,156,000) confirmed cases and 4,180,000 (95% CI 3,256,000–5,192,000) suspected and confirmed cases.

Discussion

Our nationally representative COVID-19 survey in Pakistan explores views on the inevitability of contracting COVID-19, gauges public tendency to seek out testing, and estimates the number of COVID-19 cases. Compared with those living in rural areas, urban residents were more likely to think COVID-19 was inevitable. Completion of a graduate degree, being employed, and screening positive for anxiety and depression were associated with having tested for COVID-19. Our estimates of the number of confirmed cases were 17.7% higher than official estimates of confirmed cases: 1,518,000 compared with 1,290,000. Our estimates of suspected cases were nearly 3 times as high as official estimates: 4,180,000 compared with 1,290,000 (*6*).

Although the initial spread of COVID-19 in Pakistan was first recognized in urban areas, incidence in rural areas was equal to that in urban areas (*30*). Nonetheless, we found that rural residents were less likely than urban residents to consider COVID-19 inevitable. It is possible that residents in rural areas are more likely to live in less densely populated settings or work outside, scenarios where physical distancing is more easily accomplished and transmission is less likely (*31*). Feeling that COVID-19 is inevitable was not associated with practicing prevention behaviors (e.g., indoor mask wearing, maintaining physical distancing, handwashing, avoiding nonessential shopping, domestic travel, and taking public transportation) suggests there are opportunities to promote and support prevention behaviors even among those resigned to getting COVID-19.

Attitudes about the seriousness of COVID-19 as a health issue were related to attitudes about its inevitability; those who thought it was a serious health issue were more likely to think they would inevitably contract COVID-19. An April 2021 convenience survey in Peshawar, Pakistan, found that 66% of persons

Table 3. Survey-based estimates of confirmed and suspected COVID-19 cases, Pakistan, 2021–2022

COVID-19 cases	No.	Illness rate (95% CI)	No. cases/100,000 population	Total estimated no. cases (95% CI)
Confirmed cases	316	0.0069 (0.0040–0.0098)	690	1,518,000 (880,000–2,156,000)
Suspected and confirmed cases	856	0.0192 (0.0148–0.0236)	1,900	4,180,000 (3,256,000–5,192,000)

thought COVID-19 was a serious health issue (*32*). We found 75.9% of persons thought it was a serious health issue. As more persons become infected with SARS-CoV-2 and more know someone who became seriously ill or died, it is possible that more persons may also think the disease is serious. This situation could change, however, with the arrival of new variants, such as Omicron, that may result in less severe illness (*33*). The Delta variant, which was more transmissible than previous variants but induced the same level of disease severity, arrived in Pakistan after the mobile phone survey but before completion of the face-to-face survey (*34*).

Testing is a critical tool for both COVID-19 surveillance and mitigation. More than 1 year into the pandemic, less than one fifth of Pakistan's population (16.8%) had been tested for COVID-19. Education level and employment status were significantly associated with having tested for COVID-19; those with graduate or postgraduate degrees and those who were employed were more likely to have tested than those with less than a primary education or who were not working. Although ≈70% of Pakistan residents access health care at private health facilities, both education and employment status were associated with accessing health care at private health facilities in Pakistan (*35*). As of March 7, 2022, a total of 82% of the 239 COVID-19 testing sites in Pakistan were in private or mixed public-private health facilities (*36*). COVID-19 testing is free of charge at public health facilities, but there is a cost to test at private health facilities. Assuming therefore that residents with higher socioeconomic status would be more likely to have tested for COVID-19, reported testing results might provide an incomplete picture of COVID-19 incidence and, consequently, deaths, and are likely not reflective of the entire population.

Increasing testing likely requires increasing both supply and demand in Pakistan. Although three quarters felt that COVID-19 was a serious health issue, a national survey conducted in March 2021 found that 28% of persons surveyed would do nothing if they had COVID-19 symptoms, 27% would isolate at home, 18% would treat themselves, 14% would get tested, and 6% would go to a clinic (*37*). Those data suggest that although people consider COVID-19 a serious health issue, they may think it is a serious health issue for others and not for themselves, making them inclined to avoid confirming their illness and not seek necessary treatment. Determining whether people understand their own risks for severe illness from COVID-19 and why they avoid getting tested for COVID-19 would help to inform COVID-19 policy making. Possible reasons could be that testing facilities are far or busy. One of the main barriers to accessing public healthcare services in Pakistan is the long wait times, as well as cost (*38*).

Overall, we found that COVID-19 prevention behaviors of mask wearing, physical distancing, handwashing, and avoiding nonessential shopping, domestic travel and public transit were not associated with thinking COVID-19 is inevitable or getting tested for COVID-19. Messaging about how these behaviors can help to protect family and friends might help to encourage people to engage in them.

Our estimates of suspected and confirmed cases are nearly 3 times higher than the number of officially confirmed cases, highlighting the low availability, access, and uptake of COVID-19 testing. Such a disparity in regard to the incidence of COVID-19 in Pakistan also suggests a more substantial loss of caregivers and indicates that the impact of the COVID-19 pandemic on families might be underestimated.

Responses to our survey were self-reported, so there is some risk for inaccurate responses because of recall bias or other reasons. Some participants completed the survey using a mobile phone and others provided responses in face-to-face interviews, which could also bias responses. Because of funding delays, there was a gap of approximately 4 months between the end of the mobile phone survey and beginning of the face-to-face survey. Incidence was much higher during the mobile phone survey than the face-to-face survey, which might have influenced responses because persons might be more likely to engage in mitigation measures when cases are high. Conversely, the face-to-face survey happened later, when pandemic fatigue might have begun to emerge across the population, possibly leading residents to relax mitigation behaviors. Emergence of the Delta variant during that time could also have influenced responses.

We determined that most people in Pakistan engage in prevention behaviors and consider COVID-19 a serious health issue. Unfortunately, our survey of Pakistan residents also demonstrated that there is substantial undertesting and thus underreporting of COVID-19 incidence and deaths. Further research is needed to understand why so few persons are getting tested and to determine whether they truly understand the risk of COVID-19 to themselves and to those around them.

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etymologia revisited

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Falciparum

[fal-'sɪ-pə-rəm]

From the Latin *falx* or *falci* (sickle or scythe-shaped) and *parum* (like or equal to another) or *parere* (to bring forth or bear). The species *falciparum* in the genus *Plasmodium* is the parasite that causes malignant tertian malaria in humans.

There were many terms suggested for this parasite, such as *Ematozoo falciforme* by Antolisei and Angelini in 1890 and *Haemotozoon falciforme* by Thayer and Hewetson in 1895, because of its sickle-shaped gametocytes, the sexual stage of falciparum parasites. However, the term *falciparum*, suggested by William Henry Welch in 1897, was eventually accepted. In 1954, P*lasmodium falciparum* (previously *Laverania malariae*) was approved by International Commission on Zoological Nomenclature.

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SARS-CoV-2 Prevalence in Malawi Based on Data from Survey of Communities and Health Workers in 5 High-Burden Districts, October 2020

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To determine early COVID-19 burden in Malawi, we conducted a multistage cluster survey in 5 districts. During October–December 2020, we recruited 5,010 community members (median age 32 years, interquartile range 21–43 years) and 1,021 health facility staff (HFS) (median age 35 years, interquartile range 28–43 years). Real-time PCR–confirmed SARS-CoV-2 infection prevalence was 0.3% (95% CI 0.2%–0.5%) among community and 0.5% (95% CI 0.1%–1.2%) among HFS participants; seroprevalence was 7.8% (95% CI 6.3%–9.6%) among community and 9.7% (95% CI 6.4%–14.5%) among HFS participants. Most seropositive community (84.7%) and HFS (76.0%) participants were asymptomatic. Seroprevalence was higher among urban community (12.6% versus 3.1%) and HFS (14.5% versus 7.4%) than among rural community participants. Cumulative infection findings 113-fold higher from this survey than national statistics (486,771 versus 4,319) and predominantly asymptomatic infections highlight a need to identify alternative surveillance approaches and predictors of severe disease to inform national response.

The first 3 SARS-CoV-2 infections in Malawi were confirmed on April 2, 2020, using real-time PCR (rPCR) (*1*). Facility-based national surveillance data and national statistics indicated that the number of new infections with SARS-CoV-2, the virus that causes COVID-19, rose rapidly in June 2020 and peaked in mid-July at 192 cases/day before declining to a 7-day moving average of 2–6 cases/day in October 2020 (Appendix, https://wwwnc.cdc.gov/EID/article/28/13/21-2348-App1.pdf). Daily test average positivity declined from 17.5% in July to 2.7% by October 2020.

The national COVID-19 surveillance and response in Malawi, like those of most public health systems in Africa, relies on routine facility-based surveillance data sent from district and regional health offices, which presents several challenges. First, without a reliable denominator for estimating key epidemiologic parameters, the source population is poorly defined. Second, a substantial proportion of the infected population who are asymptomatic or mildly ill might not seek treatment at health facilities and might thus remain undetected (*2*–*4*). Third, because of low availability of reagents and low investment in the healthcare system, low capacity for SARS-CoV-2 testing limits diagnosis (*5*). In addition,

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some community members might avoid COVID-19 tests because of negative perceptions about the disease or healthcare system (*6*).

Apart from information from small surveys in urban areas (M.B. Chibwana, unpub. data, https://www.medrxiv.org/content/10.1101/2020.07.30.20164970v3), the extent of COVID-19 spread and associated demographic and clinical characteristics has remained undescribed in Malawi, making it difficult to interpret morbidity and mortality data and obstructing evidence-informed predictive modeling and planning. We therefore conducted a healthcare facility and population-based survey to determine viral and antibody prevalence and risk factors for SARS-CoV-2 infection in 5 districts of Malawi.

Methods

Study Design and Study Population

During October 14–December 8, 2020, we conducted a cross-sectional survey in 3 districts with urban centers (Lilongwe, Blantyre, and Mzimba North) and in 2 predominantly rural districts (Karonga and Mangochi) (Figure 1) from among the 28 districts in Malawi. The 5 districts selected for the survey were categorized as high-risk areas for SARS-CoV-2 infections because of high population density, high volume of travelers to and from high-risk countries, or both. At the beginning of the survey, Lilongwe district had reported 49 cases/100,000 population, Blantyre 151/100,000 population, Mzimba North 101/100,000 population, Karonga 22/100,000, and Mangochi 12/100,000 population (Appendix).

The survey population was composed of community members ≥10 years of age and health facility staff (HFS) ≥18 years of age. Participants ≥18 years of age provided written consent to be included in the survey; participants <18 years of age provided personal assent and consent from a guardian. All HFS—frontline healthcare workers and support and administrative staff from primary, secondary, and tertiary facilities—were eligible for the survey if they consented.

Sample Size and Sampling Method

The target sample size for community participants from each district was ≤1,620 from 540 households, ≤8,100 participants from 2,700 households overall. We based sample size targets on several assumptions about general population participants: 6% of the surveyed population would test rPCR positive on the basis of a rPCR positivity rate from national surveillance data of 6%–6.5% in early to mid-June 2020 (Appendix); ±10% precision for the 95% CI for the rPCR-confirmed SARS-CoV-2 infection prevalence; an arbitrary design effect of 1.3; response rate of 96%; and 1% of sampled households with fewer than the targeted number of participants. For HFS, the total sample size was 1,600 assuming rPCR-confirmed SARS-CoV-2 infection prevalence of 12% (*7*), ±15% precision for the 95% CI, an arbitrary design effect of 1.2, and expected response rate of 95%.

For community participants, we used a 3-stage cluster sampling approach to randomly select 27 (16 rural and 11 urban) enumeration areas (EAs) using probability proportional to size of EA in each district. Four sampled EAs were noncooperative because of misconceptions about COVID-19 and were replaced by reserve EAs also randomly selected using probability proportional to size. From the selected EAs, we used a simple random sampling approach using random number tables to sample 20 households per EA from the 2018 national census household listing obtained from the Malawi National Statistics Office. We entered names and ages of all household members to an electronic tablet using an OpenDataKit (ODK; https://getodk.org) mobile application. Using a command programmed in the ODK form in the tablet, we randomly selected a maximum of 3 names from among household members ≥10 years of age to participate. For households with <3 household members ≥10 years of age, we selected all age-eligible members to participate.

We included 40 facilities for the HFS survey. In each district, we first selected the largest facility, a secondary or tertiary hospital, to maximize the number of included HFS, then used probability proportional to size sampling for an additional 7 primary or secondary care facilities in each district (Appendix). We used the same approach to list and sample HFS using the ODK program command to select 400 HFS per district in Blantyre, Lilongwe, and Mzimba North and 200 per district from Karonga and Mangochi. We sampled more HFS from facilities in urban than predominantly rural districts because they have more staff. In facilities where the number of HFS was less than or equal to the target sample size, we included all staff.

Community Sensitization and Data Collection

A trained survey team met with community leaders including district commissioners, district councilors, chiefs, and subchiefs. Community members were mobilized through meetings coordinated with village navigators, community health workers, and the survey team. Public address systems were used to transmit messages about the survey to the community. At

health facilities, we briefed the district health officer and participating health facility managers before they conducted sensitization meetings with HFS.

Study staff equipped with required personal protective equipment visited sampled households and health facilities to obtain informed consent and enroll participants. We collected data using an electronic questionnaire on an ODK platform and sent them to a server hosted at the Malawi Central Health Surveillance Unit. We collected information on sociodemographics, international travel, gatherings attended, contact with rPCR-confirmed SARS-CoV-2–infected persons, self-reported underlying health conditions, and signs and symptoms of influenza-like illness or severe acute respiratory illness in the previous 6 months.

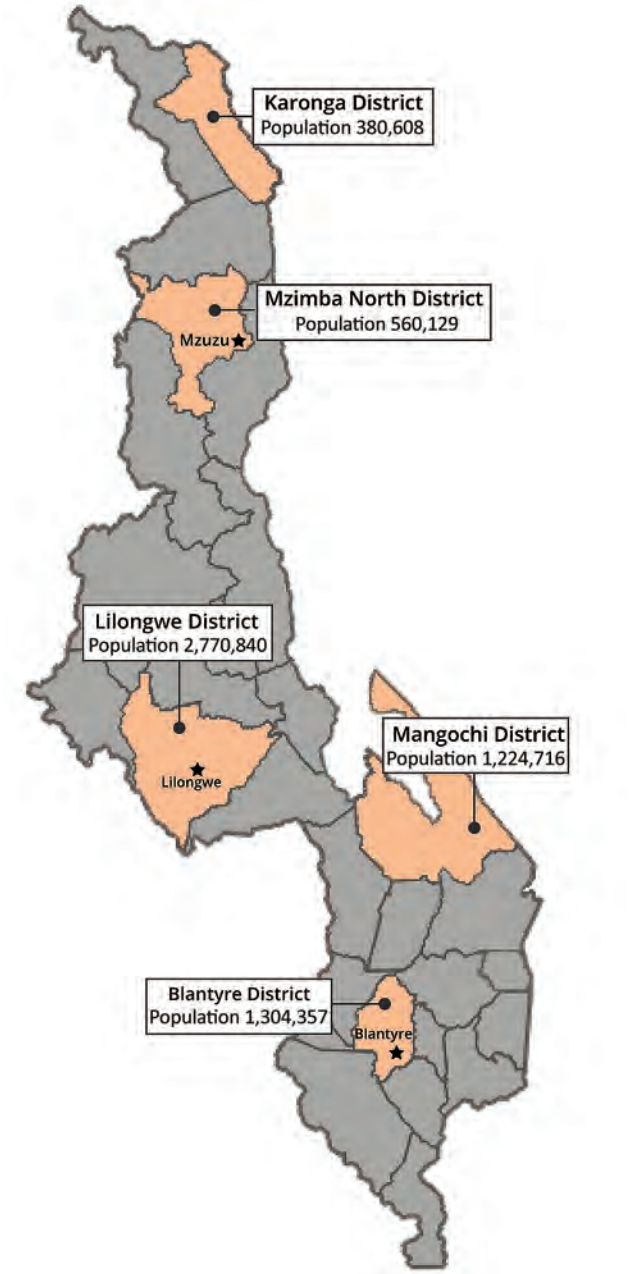

Figure 1. Locations and populations of districts included in study of SARS-CoV-2 infection in Malawi, 2020.

Laboratory Procedures

We collected nasopharyngeal swabs and blood specimens and transported them to testing laboratories under cold chain processes and stored them in cryovials in a −80°C freezer until they were analyzed. Nasopharyngeal specimens were tested in government laboratories for SARS-CoV-2 RNA using rPCR for the RdRp (RNA-dependent RNA polymerase) and N (nucleocapsid) genes using the Abbott RealTime SARS-CoV-2 Assay (Abbott Molecular Inc., https://www.molecular.abbott). Serum specimens were analyzed using the Wantai SARS-CoV-2 Ab ELISA (https://www.fda.gov/media/140030/download) for qualitative detection of total antibodies (IgG and IgM) to SARS-CoV-2, a 2-step incubation antigen sandwich enzyme immunoassay kit using polystyrene microwell strips precoated with recombinant SARS-CoV-2 receptor-binding domain (RBD) antigen. The manufacturer-reported performance characteristics for the Wantai test were 96.7% (95% CI: 83.3%–99.4%) sensitivity and 97.5% (CI: 91.3%–99.3%) specificity. We calculated the ratio between absorbance and cutoff points for each specimen; ratios <0.9 indicated specimens were SARS-CoV-2–negative, ratios >1.1 positive, and ratios 0.9–1.1 borderline. All specimens with initial positive or borderline results were retested using the same assay before final determination of status. If initial and retest results did not match, we used a EUROIMMUN SARS-CoV-2 IgA and IgG assay test kit (https://www.euroimmun.com) for verification.

Data Analysis

The primary outcomes we used to define infection positivity were any positive test result for either SARS-CoV-2 RNA from an rPCR test or SARS-CoV-2 RBD total antibodies from the Wantai ELISA test. Other outcomes included self-reported influenza-like illness and severe acute respiratory illness signs and symptoms for those with a positive primary outcome. Independent variables in the analysis included age, sex, location, highest level of education, occupation, self-reported underlying medical conditions, and reported high risk for contact with SARS-CoV-2. We performed all statistical analyses using Stata software version 14.1 (https://www.stata.com). We calculated sampling weights for community participants on the basis of

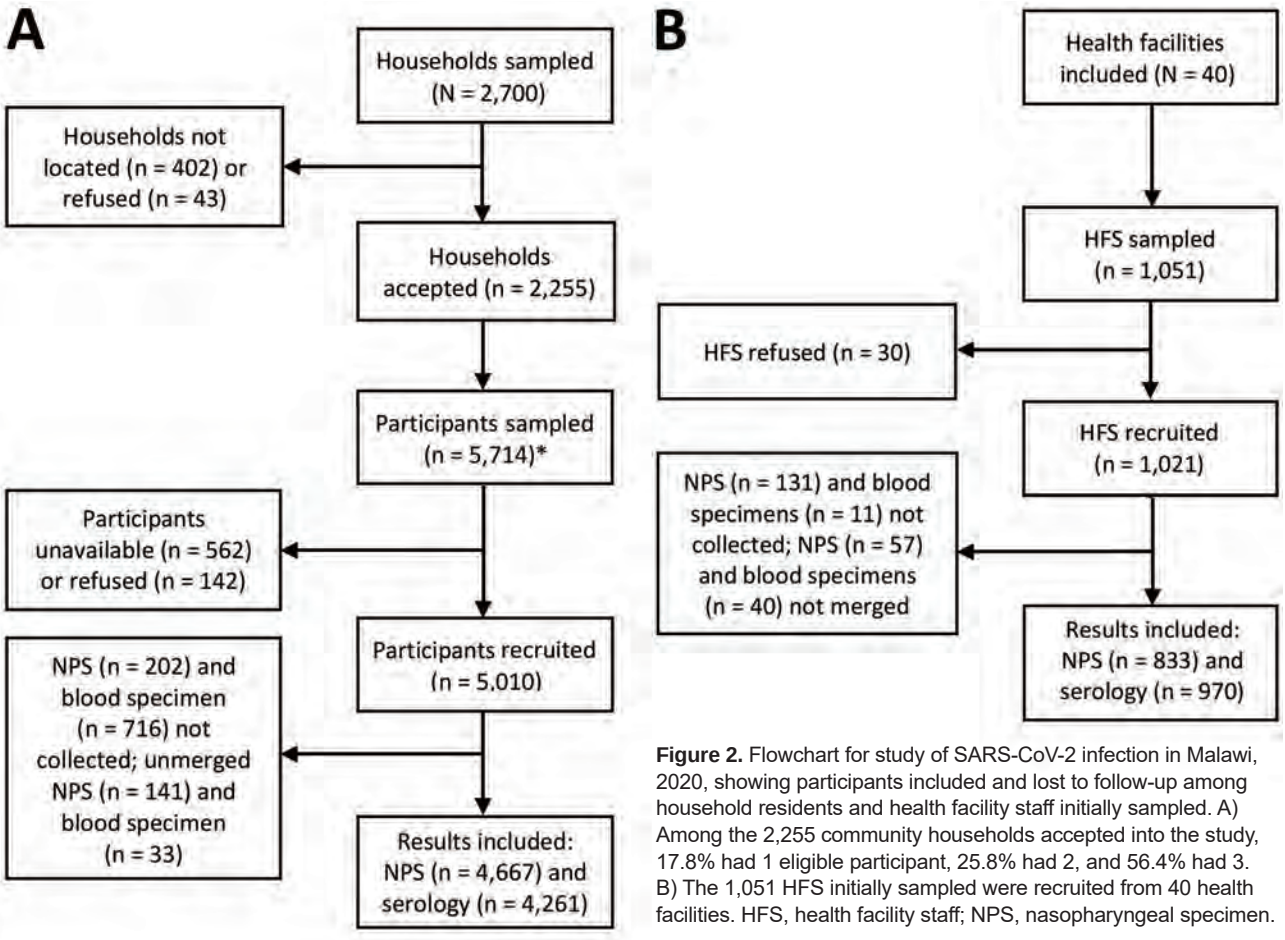

Figure 2. Flowchart for study of SARS-CoV-2 infection in Malawi, 2020, showing participants included and lost to follow-up among household residents and health facility staff initially sampled. A) Among the 2,255 community households accepted into the study, 17.8% had 1 eligible participant, 25.8% had 2, and 56.4% had 3. B) The 1,051 HFS initially sampled were recruited from 40 health facilities. HFS, health facility staff; NPS, nasopharyngeal specimen.

the 2018 Malawi population and housing census (*7*) and for HFS, on the basis of the 2019 Malawi Harmonized Health Facility Assessment (*8*). We used Svy commands in Stata to calculate proportions to account for the complex survey design and incorporate sampling weights to address unequal selection probability within districts. We calculated SARS-CoV-2 infection prevalence with 95% CIs. We used adjusted seroprevalence results to estimate the number of SARS-CoV-2 infections in the 5 districts. We used bivariate logistic regression analysis to calculate crude odds ratios (ORs) and multivariable logistic regression analysis to calculate adjusted odds ratios (aORs) with 95% CIs. In the multivariable analysis, we included age and sex and variables statistically significant at $p<0.05$ during bivariate regression.

The National Health Sciences Research Committee (NHSRC) in Malawi, as the engaged institution, reviewed and approved the protocol. The US Centers for Disease Control and University of Washington provided a nonresearch determination under Code of Federal Regulations, Common Rule (45 CFR 46.102(l)(2). Sampled persons provided verbal consent or assent to participate after understanding the purpose, procedures, risks and benefits of the study. We ensured that data were collected in a private area and electronic data access was password-controlled.

Results

Participant Recruitment and Data Collection

We chose 2,700 households to sample, from which we did not locate 402 (14.9%) and 43 (1.6%) refused to participate (Figure 2, panel A). Among the 2,255 households that consented, 983 had <3 eligible persons in the household. Overall, we sampled 5,714 household members and enrolled 5,010 (87.7%). Among the community participants enrolled, 4,667/5,010 provided nasopharyngeal and 4,261/5,010 blood specimens with results available for analysis. For HFS, we sampled 1,051 and enrolled 1,021 (97.1%) (Figure 2, panel B). Among samples taken from enrolled participants, 833/1,021 provided nasopharyngeal and 970/1,021 blood specimens with results available for analysis.

Participant Characteristics

Weighted proportions of 63.4% of community participants and 52.5% of HFS were women (Table 1). Median age was 32 years (interquartile range 21–43 years) among community participants and 35 years (interquartile range 28–4 years) among HFS. Among community participants, 53.3% had primary and 29.0% had secondary education; among HFS, most of them nurses, 58.9% had secondary education and 36.5% had tertiary education (Appendix). Overall, 46.0% of community participants reported being unemployed. The largest proportion of both community and HFS participants were from Mzimba North. Among community participants 49.5% and among HFS 64.7% were from urban settings. An underlying medical condition was reported by 23.9% of HFS and 11.2% of community participants.

Prevalence of rPCR-Confirmed SARS-CoV-2 Infection

Of 4,667 specimens collected from community participants that were tested for SARS-CoV-2 by rPCR, 14 (0.3%, 95% CI 0.2%–0.5%) were positive. The prevalence was highest among community participants ≥50 years of age (0.5%, 95% CI 0.1%–1.3%). No

Table 1. Characteristics of participants in survey of SARS-CoV-2 prevalence in Malawi, October 2020*

Characteristic	Community participants, n = 4,261		Health facility staff, n = 970		Total, N = 5,231
	No. (%)	Weighted proportion (95% CI)	No. (%)	Weighted proportion (95% CI)	
Sex					
M	1,524 (35.8)	36.6 (32.8–40.6)	428 (44.1)	47.5 (39–56)	1,952
F	2,737 (64.2)	63.4 (59.4–67.2)	542 (55.9)	52.5 (44–61)	3,279
Age, y					
10–19	982 (23.0)	20.1 (18.0–22.4)	8 (0.8)	0.4 (0.1–1.5)	990
20–29	1,085 (25.5)	23.8 (21.9–25.8)	291 (30.0)	20.0 (14.8–26.3)	1,376
30–39	887 (20.8)	21.7 (19.4–24.3)	335 (34.5)	38.7 (33.1–44.6)	1,222
40–49	626 (14.7)	16.8 (15.1–18.7)	236 (24.3)	25.9 (22.6–29.5)	862
≥50	681 (16)	17.5 (15.5–19.8)	100 (10.3)	15.0 (9.6–22.6)	781
District					
Blantyre	535 (12.6)	16.0 (13.0–19.6)	163 (16.8)	15.1 (7.9–27.0)	698
Karonga	1,092 (25.6)	8.5 (7.2–10.1)	132 (13.6)	19.9 (11.5–32.1)	1,224
Lilongwe	560 (13.1)	37.8 (29.9–46.5)	216 (22.3)	23.6 (17.8–30.5)	776
Mangochi	937 (22.0)	23.9 (19.8–28.6)	191 (19.7)	9.5 (7.2–12.4)	1,128
Mzimba North	1,137 (26.7)	13.7 (11.4–16.4)	268 (27.6)	31.9 (22.6–42.9)	1,405
Location type					
Rural	1,505 (35.3)	50.5 (38.3–62.5)	406 (41.9)	35.2 (32.1–38.2)	1,911
Urban	2,756 (64.7)	49.5 (37.5–61.6)	564 (58.1)	64.7 (61.6–67.7)	3,320
Household size, categorical					
1–2	500 (11.7)	15.1 (11.5–19.6)	241 (24.8)	23.5 (17.7–30.5)	741
3–4	1,888 (44.3)	44.1 (41.1–47.1)	331 (34.1)	34.5 (29.4–40.1)	2,219
≥5	1,872 (43.9)	40.8 (36.9–44.8)	398 (41.0)	42.0 (36.0–48.1)	2,270
Education†					
No education	339 (8.0)	12.8 (8.8–18.2)	0	0	339
Primary	2,138 (50.5)	53.3 (48.0–58.5)	51 (5.3)	4.6 (2.5–8.4)	2,189
Secondary	15,250 (35.9)	29.0 (25.0–33.4)	485 (50.0)	58.9 (51.5–66.0)	2,005
Tertiary/postsecondary	237 (5.6)	4.9 (3.7–6.5)	434 (44.7)	36.5 (29.3–44.3)	671
Occupation					
Student	950 (22.3)	18.5 (16.4–20.8)	NA	NA	950
Unemployed	1,704 (40.0)	46.0 (40.8–51.2)	NA	NA	1,704
Employed, HFS	30 (0.7)	0.98 (0.7–1.4)	970	970	65
Employed, non-HFS	275 (6.5)	0.54 (0.3–0.9)	NA	NA	30
Retired	65 (1.5)	7.0 (5.4–9.1)	NA	NA	275
Other	1,237 (29.0)	27.0 (22.6–31.9)	NA	NA	1,237
Preexisting medical conditions					
Any medical condition	472 (11.1)	11.2 (9.6–13.0)	175 (18.0)	23.9 (19.6–28.9)	647
Diabetes mellitus	38 (0.9)	0.7 (0.4–1.1)	11 (1.1)	0.7 (0.3–1.6)	49
CVD, including hypertension	224 (5.3)	5.5 (4.3–6.9)	68 (7.0)	10.5 (6.3–16.9)	292
Renal disease	2 (0)	0.04 (0.01–0.21)	4 (0.4	1.0 (0.3–3.2)	6
Immunosuppressive condition‡	78 (1.9)	1.8 (1.3–2.5)	39 (4.0%)	5.7 (2.6–11.8)	117
Obesity	12 (0.3)	0.2 (0.1–0.4)	10 (1.0)	0.6 (0.2–1.4)	22
Asthma	104 (2.5)	2.4 (1.8–3.2)	47 (4.8)	6.9 (4.4–10.4)	151
Chronic lung disease, including COPD	8 (0.2)	0.08 (0.04–0.2)	2 (0.2)	0.1 (0.03–0.5)	10
Liver disease	3 (0.1)	0.05 (0.01–0.20)	2 (0.2)	1.0 (0.15–6.0)	5
Other disease	65 (1.6)	2.1 (1.5–2.9)	11 (1.1)	1.4 (0.46–4.2)	76

*COPD, chronic obstructive pulmonary disease; CVD, cardiovascular disease; HFS, health facility staff; NA, not applicable.
†The highest level of education attained. Primary education = 8 y; secondary education = 4 y; tertiary/postsecondary = college/university education.
‡From cancer, chemotherapy, radiation therapy, immunosuppressive medications, self-reported HIV, organ transplant, or inherited immunodeficiency.

rPCR-confirmed SARS-CoV-2 infection was observed in participants 10–14 years of age. Of the 851 specimens collected from HFS, 4 (0.5%, 95% CI 0.1%–1.2%) tested positive. Prevalence was highest among participants 30–49 years of age (0.8%, 95% CI 0.2%–2.0%) and significantly higher among male participants (1.0%, 95% CI 0.3%–2.6%) than among female participants (0.0%, 95% CI 0.0%–0.8%) (p = 0.004).

Seroprevalence of SARS-CoV-2 RBD Total Antibodies

Overall SARS-CoV-2 seroprevalence among community participants was 7.8% (95% CI 6.3%–9.6%) and similar between male participants (8.3%, 95% CI 6.5%–10.4%) and female participants (7.5%, 95% CI 6.0%–9.4%) (Table 2). Participants 30–39 and ≥50 years of age had higher seroprevalence than did other age groups. Seroprevalence was highest in Blantyre (13.1%; 95% CI 9.0%–18.7%) and Mzimba North (12.1%, 95% CI 8.7%–16.6%) and lowest in Mangochi (4.1%, 95% CI 2.6%–6.2%). Overall, the seroprevalence was higher in urban (12.6%, 95% CI 11.2%–14.1%) than rural areas (3.1%, 95% CI 1.8%–5.5%). SARS-CoV-2 seroprevalence among HFS was 9.7% (95% CI 6.4%–14.5%). Seroprevalence was similar by sex; there was a nonsignificant 2-fold difference in seroprevalence between participants in urban (14.5%, 95% CI 9.7%–21.1%) and rural (7.4%, 95% CI 3.6%–14.7%) locations.

We found significant association between community participants self-reporting diabetes and testing seropositive for SARS-CoV-2 in the crude data analysis (crude OR 4.6, 95% CI 1.7–12.5) but not in the adjusted analysis (aOR 2.4, 95% CI 0.9–6.3). Odds of testing seropositive for SARS-CoV-2 were higher among HFS reporting than those not reporting an immunosuppressive condition (aOR 3.1, 95% CI 1.7–8.7), but HFS reporting asthma were less likely to test positive (aOR 0.2, 95% CI 0.03–0.8). In the community participant survey, data on age, district, education, and location remained significant in the multivariable analysis (Table 2).

Signs and Symptoms of SARS-CoV-2 Infection among Seropositive Participants

Among community participants who had a seropositive result, 84.7% reported having no COVID-19–associated signs or symptoms in the 6 months before the survey; 10.6% reported coughing, 9.2% runny nose, and 5.2% muscle pain (Table 3). One (0.7%) seropositive community participant reported being hospitalized, but admission details were unavailable. Among seropositive HFS participants, 76.0% reported no signs or symptoms, 16.6% runny nose, 6.8% fever, 3.6% sore throat, and 2.7% loss of smell; none were hospitalized.

Estimating SARS-CoV-2 Infection among Populations in the 5 Districts

According to seroprevalence rates from this survey, cumulative estimated versus reported SARS-CoV-2 infections per 100,000 population were 13,100 versus 158 for Blantyre, 9,400 versus 24 for Karonga, 6,100 versus 51 for Lilongwe, 4,100 versus 13 for Mangochi, and 12,100 versus 51 for Mzimba North (Table 4). Overall, using an adjusted seroprevalence rate, we estimated 486,771 infections in the 5 districts during April–December 2020, compared with the 4,319 reported rPCR-confirmed cases under the national surveillance program, an underestimation by a factor of 113. Our seroprevalence results show that an estimated 7,800/100,000 persons in the 5 districts sampled were infected with SARS-CoV-2 during April–December 8, 2020; national case-based surveillance data reported 69/100,000 persons for the same period.

Discussion

Our survey results highlight several public health challenges and adds insights about SARS-CoV-2 infection and disease surveillance in Malawi and similar low-income settings. Results show SARS-COV-2 prevalence was very low at the time of the survey but much higher during preceding months. Most infections detected by either rPCR or ELISA were

Table 3. SARS-CoV-2 signs and symptoms in survey participants with a seropositive test result, Malawi, October 2020

Signs/symptoms of SARS-CoV-2 infection in previous 6 mo	Community participants, n = 423		Health facility staff, n = 124	
	No.*	Weighted % (95% CI)	No.*	Weighted % (95% CI
None	368	84.7 (78.4–89.4)	107	76.0 (57.9–87.9)
Fever	12	3.5 (1.7–6.8)	6	6.8 (2.6–17.7)
Shortness of breath	2	0.6 (0.11–3.2)	1	1.1 (0.14–7.9)
Sore throat	3	0.8 (0.2–2.7)	4	3.6 (1.2–10.2)
Runny nose	27	9.2 (5.6–14.7)	8	16.6 (5.9–38.5)
Cough	36	10.6 (6.5–16.9)	10	9 (3.7–19.9)
Muscle pain	12	5.2 (2.6–10.0)	3	1.6 (0.5–5.0)
Loss of smell or taste	4	2.3 (0.7–7.6)	4	2.7 (0.9–7.7)
Other signs/symptoms	5	0.7 (0.2–2.2)	3	2.4 (0.7–8.1)
Hospitalization	1	0.7 (0.001–5.0)	0	NA

*Number of participants who reported the symptom among those who tested positive by serology.

Table 4. Estimated number of cases in the 5 districts from the survey compared with the cases reported to the national surveillance system by facilities in Malawi, December 2020

District	Population*	Total district case estimates/100,000 population	Total district case estimates			Reported cases	Reported cases/100,000 population	Estimation factor
			Lower bound	Middle estimate	Higher bound			
Blantyre	1,304,357	13,100	117,392	170,871	243,915	2,065	158	82.7
Karonga	380,608	9,400	27,784	35,777	46,434	91	24	393.2
Lilongwe	2,770,840	6,100	96,979	169,021	282,626	1,412	51	119.7
Mangochi	1,224,716	4,100	31,843	50,213	75,932	157	13	319.8
Mzimba North	560,129	12,100	48,731	67,776	92,981	594	106	114.1
Total	6,842,977	7,800	393,161	486,771	599,102	4,319	69	112.9

*Population estimates are projections from the Malawi National Statistical Office, 2018 Housing Census report.

asymptomatic and all but 1 of the remaining cases was mild. Only 1 participant reported being hospitalized, a proportion similar to those from other reports. The survey identified several risk factors associated with positive serology, including being an HFS, living in an urban area, and having an immunosuppressive condition or diabetes (Table 2).

The huge discrepancy between SARS-CoV-2 infections estimated based on our survey and the official national count from case-based surveillance was previously documented in Malawi (*7*) and surrounding regions (*9*–*11*). The high proportion of asymptomatic infections and limited access to testing might explain the difference because asymptomatic persons are unlikely to seek testing and diagnostic capacity limited access to testing in Malawi to persons with signs and symptoms and travelers.

Two COVID-19 waves in Malawi have increased the proportion of exposed persons (Appendix). Widespread undetected and unmitigated transmission of SARS-CoV-2 presents an environment conducive for developing variants, undermining efforts to contain the COVID-19 pandemic (*12*). With variants emerging, enhanced support is needed to strengthen outbreak readiness and response among health systems in Africa; surveys and genomic surveillance should be prioritized and integrated into disease response, to inform surveillance and response decisions (*12*).

rPCR-confirmed SARS-CoV-2 infection prevalence during the survey period was similar to the low test positivity from national surveillance data in October (1.6%) and November (0.9%) of 2020. This finding suggests that, although routine health facility–based data might be indicative of the extent of symptomatic infections and disease trends in the community and case-based surveillance useful for monitoring trends in SARS-CoV-2 burden, these data might be insufficient for guiding public health actions to address the full extent of community transmission, driven in part by undiagnosed mild and asymptomatic infections. Alternative approaches, such as sentinel and syndromic surveillance, population-based surveys, and additional testing options, including rapid diagnostic tests or self-testing, are urgently needed to understand and respond to community transmission and prioritize and monitor effects from interventions, including vaccines.

The proportion of persons with asymptomatic SARS-CoV-2 infections in this survey is higher than in most previous studies, which have reported 35%–74% asymptomatic infections (*9*,*13*,*14*). Only 1 seropositive participant reported being hospitalized in the previous 6 months. The high proportion of young participants (median ages were 32 years among community participants and 35 years among HFS), reflective of the national age pyramid (*7*), might explain the predominance of asymptomatic or mild manifestations. In addition, fewer than one quarter of participants reported ≥1 underlying condition associated with an increased risk for severe disease, reflective of health conditions relative to the age distribution. Proportions of the population at risk for severe COVID-19 disease have been estimated at 16% in Africa and 31% in Europe but <4% in Malawi (*15*). The fact that most SARS-CoV-2 infections do not progress to symptomatic disease aligns with the low levels of illness and death from COVID-19 disease in Africa compared with Asia, Europe, and the Americas during the first wave (*16*).

The most critical public health outcomes of SARS-CoV-2 infection are severe disease and death, which in this survey were rare and have remained much lower in Africa than in Western nations after introduction and spread of Beta and Delta variants. Our findings highlight the need to identify context-specific predictors of severe disease and death, which would inform design of national response strategies proportionate to disease burden and public health resources.

The finding of higher prevalence of infection among HFS than the general population is consistent with findings from other studies (*17*,*18*). Because healthcare workforces in low-income countries are acutely limited, interventions and policies should prioritize efforts to maintain health services

by protecting health workers including providing vaccinations and appropriate personal protective equipment. Higher prevalence among urban than rural participants in Malawi, consistent with findings from modeling studies in the region (*19*), was not unexpected because urban areas are more associated with overcrowding, indoor gatherings, and international travel (*20*). Based on testing numbers from each district, national case-based surveillance disease distribution data might have been influenced by testing volume and availability by district rather than reflecting the actual disease burdens by district observed in our results. Correcting unequal access to testing might balance statistical disease distribution patterns; conveying realistic perception of personal risk and the need to reduce associated risk reduction behaviors to the public and efforts to expand public health policy would also likely help address disparities.

Although diabetes has been associated with increased severity of COVID-19 manifestations (*21*) because of its effects on glucose homeostasis, inflammation, immune status, and activation of the renin-angiotensin-aldosterone system, little has been known about its effect on susceptibility to SARS-CoV-2 infection (*22*). This survey provides additional evidence on vulnerability of persons with diabetes to SARS-COV-2 infection. Reliance on self-reported diabetes status could be a limitation, but any misclassification would likely be nondifferential and only have biased the association toward equality.

Among other potential limitations, the Wantai ELISA test might have misclassified antibody status in a proportion of participants based on sensitivity and specificity limits (*23*). Our reliance on participant recall for some data, including presence of signs and symptoms in the 6 months before the survey and underlying health conditions, made data liable to recall bias. A higher proportion of HFS reported underlying conditions than community participants, which might be attributable to differences in health awareness. In addition, the target community participant sample size was not achieved. Refusal to participate in our survey by some communities introduced a small selection bias and also highlights factors such as distrust of health systems and misconceptions or disbelief related to SARS-CoV-2 that influence willingness to accept SARS-CoV-2 testing (*6*). Efforts to engage with communities to improve understanding and address misconceptions and other drivers of behavior should be incorporated into routine community messaging and strategies.

Conclusion

Routine case-based surveillance might reflect trends in symptomatic disease prevalence but highly underestimate the full extent of community transmission. National COVID-19 response in low-income settings needs to use alternative surveillance and testing strategies to accurately track transmission and the effectiveness of interventions. Most infections recorded in this survey were asymptomatic, suggesting the need for research on predictors of symptomatic disease to inform development of contextualized and proportionate surveillance and response strategies.

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Determining Gaps in Publicly Shared SARS-CoV-2 Genomic Surveillance Data by Analysis of Global Submissions

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Viral genomic surveillance has been a critical source of information during the COVID-19 pandemic, but publicly available data can be sparse, concentrated in wealthy countries, and often made public weeks or months after collection. We used publicly available viral genomic surveillance data submitted to GISAID and GenBank to examine sequencing coverage and lag time to submission during 2020–2021. We compared publicly submitted sequences by country with reported infection rates and population and also examined data based on country-level World Bank income status and World Health Organization region. We found that as global capacity for viral genomic surveillance increased, international disparities in sequencing capacity and timeliness persisted along economic lines. Our analysis suggests that increasing viral genomic surveillance coverage worldwide and decreasing turnaround times could improve timely availability of sequencing data to inform public health action.

Viral genomic surveillance is a critical source of information for understanding and responding to the COVID-19 pandemic. Continued high levels of transmission of SARS-CoV-2 worldwide afford myriad opportunities for natural selection; selection pressures favor viral strains with such traits as faster transmission and increased immune escape (*1*). Emerging strains are designated variants of interest and variants of concern (VOCs) by the World Health Organization (WHO) if they have heightened public health or clinical importance because of increased transmissibility, immune escape, increased clinical severity, or other factors (*2*). Efforts are needed to monitor emerging strains of the SARS-CoV-2 virus and identify and classify variants to guide public health response and to aid in the development of diagnostic tests, therapeutics, and vaccines (*3*). As of March 21, 2022, more than 9.4 million SARS-CoV-2 sequences had been uploaded to the GISAID database (https://www.gisaid.org), the leading public online repository for viral genomic data; nearly 4 million SARS-CoV-2 sequences were uploaded to GenBank (https://www.ncbi.nlm.nih.gov/genbank) by that date. The importance of improving viral genomic surveillance capacity around the world is recognized through many initiatives aiming to do so, including through the WHO (*4*) and other international partnerships (*5*). Despite this continued effort, previous analyses have found heterogeneity in publicly available sequencing coverage across regions and countries, with substantial disparities between high-income and low- and middle-income countries (*6*–*8*; A.F. Brito et al., unpub. data, https://doi.org/10.1101/2021.08.21.21262393). Highlighting and understanding these disparities is important because VOCs can emerge from any part of the world, including places where sequencing capacity is low.

A recent case study illustrated the benefits to local and global communities that occurred after publication of South Africa viral genomic surveillance data (*9*). Those benefits included more opportunities for South Africa researchers to collaborate on an international level, better international collaboration around COVID-19 prevention and vaccination in Africa, and improved insights into SARS-CoV-2 transmission in South Africa, which informed public health policy. We present an analysis that aims to update the progress of sequencing capacity up through the emergence of Omicron as a VOC, including the number of sequences and timely sharing of the results, to better understand where further support is needed. Our analysis

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of publicly available viral genomic surveillance data considers the impact of the timeliness of such data to inform major international public health actions during early variant emergence. To expand findings from previous analyses of publicly available viral genomic sequencing data that demonstrated socioeconomic inequalities in viral genomic surveillance coverage (*7*; A.F. Brito et al., unpub. data), we examined the rapid expansion of viral genomic surveillance from the emergence of Omicron and included time-to-submission of collected sequences to assess timeliness. Our analysis further supports the conclusion that addressing these inequalities would improve global pandemic response and preparedness.

Methods

Data

The GISAID database and GenBank are public databases containing genomic sequencing data voluntarily submitted by laboratories worldwide. All available SARS-CoV-2 sequence metadata associated with human infections were downloaded from the GISAID and GenBank Web sites. We obtained reported data on SARS-CoV-2 infections by week from Our World in Data (https://ourworldindata.org) (*10*) and by population from the World Bank (https://databank.worldbank.org/home.aspx) (*11*) for countries and territories.

Inclusion Criteria and Data Management

As of March 21, 2022, there were 9,409,674 sequences (7,280,739 with complete collection and submission dates) from 209 countries and territories in GISAID and 3,967,425 sequences (2,289,627 with complete collection and submission dates) from 111 countries in GenBank; the earliest available sequence collection date was January 1, 2020. For our analysis, we removed duplicate sequences (those with identical sequence and metadata that were uploaded to both databases). We extracted variables from metadata that included specimen collection date, submission date, and country or territory of collection (hereafter country); we excluded sequences lacking that information from our analysis, including any sequence containing incomplete information for month, day, or year of collection. We used a local instance of the computational tool PANGOLIN version 3.1.20 to obtain variant information (Pango lineage) from sequences. We also excluded sequences designated as Omicron with collection dates before the internationally recognized first detection of the Omicron variant (*12*) (10 were collected before November 8, 2021). We included all sequences designated Alpha or Delta if they met other inclusion criteria; <100 Alpha sequences appeared in the dataset before October 2020 and <100 Delta sequences appeared in the dataset before December 2020. We excluded sequences from countries lacking a WHO region designation (listed at http://www.who.int/countries) or lacking a World Bank income designation (available at https://datahelpdesk.worldbank.org).

We assumed the sequence submission date to reflect the first date a sequence was made publicly available, and we then calculated the lag time elapsed between the collection date and submission date. We analyzed the proportion of sequences that featured an elapsed time between collection and submission of ≤14 days because this threshold represents the 99th percentile of the duration of wild-type SARS-CoV-2 incubation time (*13*), an important metric to inform public health case investigations.

We selected different periods of time during the pandemic to highlight important differences between countries. To compare sequencing capacity over a time period when most countries had sustained community transmission and had established testing programs, the 2021 subset includes sequences from specimens collected during the year 2021. To avoid lag time artifact, we included only sequences collected before January 1, 2022, in this subset because, based on median lag times, most samples collected during 2021 would have been submitted by the date of data retrieval in March 2022.

We chose three 8-week time periods that approximately correspond to the first global waves of the Alpha (December 6, 2020–January 30, 2021), Delta (June 6–July 31, 2021), and Omicron (December 6, 2021–January 30, 2022) VOCs. We used the dates of major international public health actions, such as recognition of VOCs or implementation of international travel restrictions, to contextualize the number of sequences submitted and the number of sequences collected by these dates.

Analysis

We used descriptive statistics to analyze the number of sequences submitted to GISAID and GenBank by country, WHO region, and World Bank income designation; sequences submitted within 14 days of collection were analyzed also. We report results by total sequences, by sequences per million population, and by sequences per 100,000 reported SARS-CoV-2 infections. We compared per capita and per infection metrics to identify differences that could be influenced by varying test availability in different countries.

We performed additional similar descriptive analysis on the 2021 subset and the 3 time periods of VOC global emergence. We used χ^2 tests of homogeneity to test the null hypothesis that the distribution of sequences was similar by World Bank income category and WHO region, and we used Kruskal-Wallis tests to evaluate the null hypothesis that the median number of uploaded sequences were similar by World Bank income category across the 3 selected 8-week periods; we considered p values <0.05 significant. We reported the number of VOC sequences collected and the number of VOC sequences submitted around the time of international public health actions introduced to mitigate the spread of that VOC in context of those dates.

Ethics Considerations

This activity was reviewed by Centers for Disease Control and Prevention (CDC). The analysis was conducted according to applicable federal law and CDC policy (45 C.F.R. part 46.102(l)(2), 21 C. F.R. part 56; 42 U.S.C. Sect.241(d); 5 U.S.C.0 Sect.552a; 44 U.S.C. Sect. 3501 et seq).

Results

Descriptive Statistics

After removing duplicate sequences (433,703), sequences with incomplete dates (3,806,733), and sequences without both a World Bank income designation and a WHO region designation (21,593), a total of 9,115,070 sequences were available for analysis. The mean number of sequences per country/territory was 48,744 (median 1,006, interquartile range 218–10,570). Of the total sequences analyzed, 6,533,870 (71.7%) were collected during January 1–December 31, 2021, and are included in the 2021 subset (Table 1).

Comparisons by Income Category

During 2020 and 2021, high-income countries had the greatest number of submissions per capita and increased average daily submissions by >10 times any other income category (Figure 1). Sequences submitted within 14 days of collection increased in all World Bank income categories for this period but remained a minority of sequences submitted during that time in each category (Figure 2).

In the 2021 subset, high-income countries submitted 456 times more SARS-CoV-2 sequences than low-income countries when adjusting for population (5,040 sequences/1 million population versus 11 sequences/1 million population; p<0.001) and 36 times more than upper-middle-income countries (5,040 sequences/1 million population versus 137 sequences/1 million population; p<0.001) (Table 1). Low-income countries had a higher proportion of sequences submitted per reported SARS-CoV-2 infection than lower-middle-income countries (Table 1) but a lower proportion than upper-middle-income or high-income countries. High-income countries had the shortest median lag time in sequence submission, 20 days, whereas low-income countries had the longest median lag time, 98 days.

Comparisons by WHO Region

In the 2021 subset, the WHO Regional Offices for the Americas and Europe had the most sequences per capita and per infection and had the shortest

Table 1. Sequencing volume by population and detected SARS-CoV-2 infections and submission lag, World Bank income category, and WHO regions based on data from GISAID and GenBank, 2021*

Category	No. countries	Total no. (%) sequences	Sequences/ 1 million population	Sequences/100,000 SARS-CoV-2 reported infections	Median lag time, d (IQR)
World Bank income category					
Low	24	6,612 (0.1)	11	524	98 (61–148)
Lower middle	43	172,582 (2.6)	52	352	71 (41–115)
Upper middle	50	350,309 (5.4)	137	556	34 (19–65)
High	68	6,004,367 (91.9)	**5,040**	**5,547**	20 (11–35)
WHO Regional Office					
Africa	41	54,115 (0.8)	47	987	55 (32–101)
The Americas	42	2,617,580 (40.1)	2,611	3,512	27 (18–47)
United States	1	2,161,680 (82.6)	6,493	5,477	24 (17–39)
Non–United States	41	455,900 (17.4)	154	1,302	42 (28–84)
Eastern Mediterranean	20	12,264 (0.2)	17	101	56 (21–135)
Europe	54	3,433,142 (52.5)	3,767	4,066	14 (9–25)
United Kingdom	1	1,542,137 (45.9)	25,200	14,505	10 (8–14)
Non–United Kingdom	53	1,891,005 (55.1)	1,767	2,362	20 (13–34)
South-East Asia	9	139,846 (2.1)	138	818	63 (37–108)
Western Pacific	19	276,923 (4.2)	**72**	**1,259**	49 (29–72)

*A total of 6,533,870 sequences were collected in 2021. Bold indicates significance (p<0.001 by χ^2 test). GISAID, https://www.gisaid.org; IQR, interquartile range; WHO, World Health Organization.

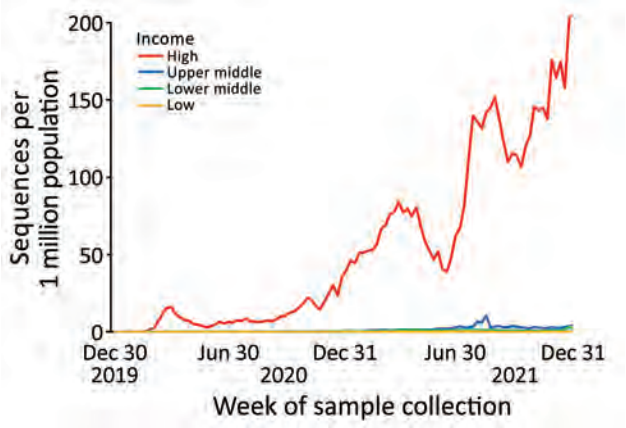

Figure 1. Weekly volume of SARS-CoV-2 sequences collected per 1 million population by income category of country, GISAID (https://www.gisaid.org) and GenBank, 2020–2021. Data include only populations of countries submitting ≥1 sequences. Data are truncated at the end of 2021 to avoid lag time artifact impacting comparison of sequencing volume nearer to the date of data access on March 21, 2022, because only collected samples that were also submitted by March 21, 2022, appear in these data.

lag times; the Eastern Mediterranean region had the lowest sequences per capita and per infection and had the longest lag times (Table 1). A substantial number of submissions from the Americas and European regions were from the United States (82%) and the United Kingdom (50%) (Table 1). By region, the Eastern Mediterranean region had the least sequencing relative to both population and reported infections; differences among regions were significant after accounting for population ($p<0.001$). The Regional Office for Africa had more reported sequences relative to infections detected than the South-East Asia region, but the South-East Asia region had somewhat higher sequencing coverage per capita. Lag times decreased as per capita sequencing volume increased by region (Table 1).

Sequencing volume from some countries and territories was low; for 29 countries and territories, <100 total sequences were submitted. Across these countries and regions with a relatively low submission of sequences, each World Bank income category was represented, including 10% of high-income countries (7/69), 14% of upper-middle-income countries (7/51), 14% of lower-middle-income countries (6/43), and 38% of low-income countries (9/24). By WHO region, 17% of countries or territories from the Africa region (7/41) submitted <100 sequences in total, as did 21% from the region of the Americas (9/43), 20% from the Eastern Mediterranean region (4/20), 7% from the Europe region (4/54), and none from the South-East Asia region (0/9). Of countries or territories from the Western Pacific region, 25% (5/20) submitted <100 sequences in total (data not shown).

Comparisons across Alpha, Delta, and Omicron Emergence

Submitted sequences per 1 million population more than doubled between the selected months that marked the global emergence of the Alpha variant (49 sequences/1 million population) and those months

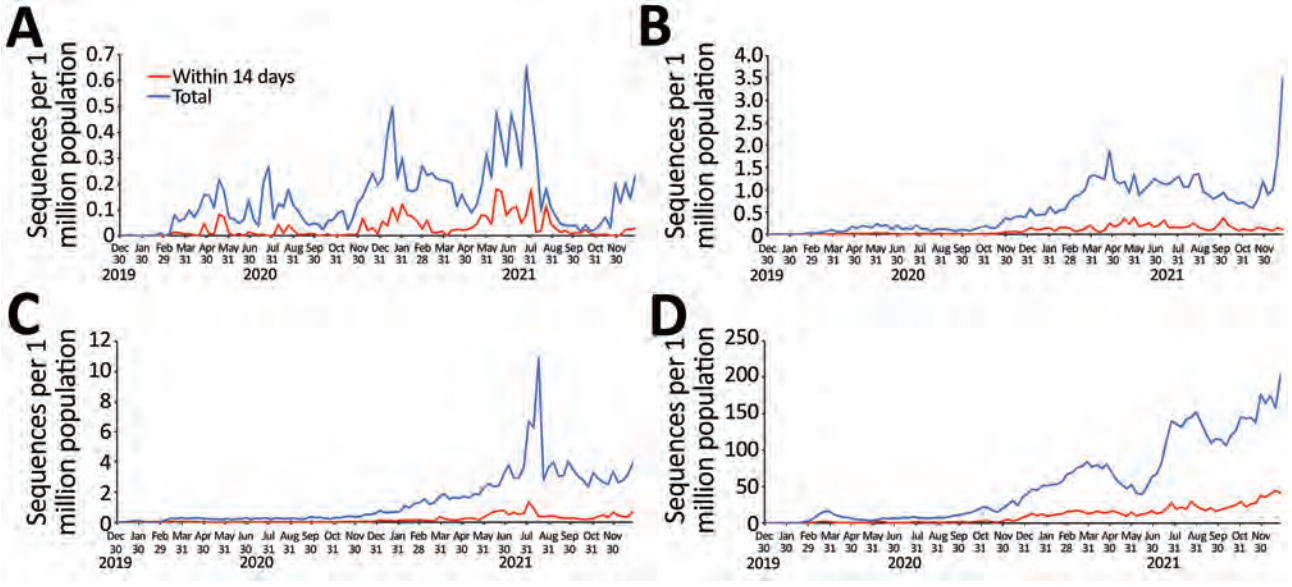

Figure 2. Total SARS-CoV-2 sequences and sequences submitted within 14 days of collection, by population and income category, GISAID (https://www.gisaid.org) and GenBank, 2020–2021. A) Low-income countries; B) lower-middle-income countries; C) upper-middle-income countries; D) high-income countries. Dates indicate sequence collection dates. Data include only populations of countries submitting ≥1 sequence.

that distinguished the emergence of the Delta variant (100 sequences/1 million population). Submitted sequences per 1 million population again more than doubled between the months distinguishing the Delta variant and those that marked the emergence of Omicron (243 sequences/1 million population) (Table 2). When reported infections are accounted for, a similar increase is seen between Alpha (981 sequences submitted/100,000 reported infections), Delta (2,017/100,000 reported infections), and Omicron (4,890/100,000 reported infections) (Table 2). Sequences submitted within 14 days of collection doubled between Alpha and Delta periods, from 10.5 to 21.5/1 million population, and doubled again between Delta and Omicron, to 46.7/1 million population, illustrating a global growth in viral genomic surveillance capacity with later variants (Table 2).

When examined by World Bank income category, high-income countries had both the highest growth and the highest overall sequencing total, by population and by reported infections. Other income categories displayed diminished or even no growth in these measures between the Delta and Omicron periods (Table 2). For sequences submitted within 14 days of collection, high-income countries nearly doubled sequencing submissions between each period: 65/1 million population during Alpha, 124/1 million population during Delta, and 292/1 million population during Omicron. During the same time, low-, lower-middle-, and upper-middle-income countries doubled sequences submitted within 14 days of collection between the Alpha and Delta periods but had fewer during Omicron than Delta. For example, lower-middle-income countries submitted 0.7 sequences/1 million population within 14 days of collection during Alpha and 1.6/1 million population during Delta but just 1.1/1 million population during Omicron (Table 2).

Availability of Surveillance Data to Inform Public Health Action

On December 18, 2020, WHO designated the Alpha variant a VOC (2), and on December 19, 2020, at least 7 countries implemented specific travel restrictions aimed to slow transmission of Alpha (*14*). Based on data pulled from the 2 public databases, 11,586 Alpha sequences were collected before December 19, but only 1,872 (16%) of those had been submitted by December 19 (Table 3). On May 10, 2021, the date WHO designated Delta a VOC (2), 25,433 Delta sequences from 104 countries on 6 continents had been collected but, of those, just 1,910 sequences (8%) had been publicly submitted. Similarly, on November 26, 2021, the date when WHO designated Omicron a VOC (2) and at least 23 countries implemented travel restrictions (*16*), 1043 Omicron samples had been collected from

Table 2. SARS-CoV-2 sequences submitted to GISAID and GenBank with collection dates during 8-week periods of initial global transmission waves of Alpha, Delta, and Omicron variants of concern*

Category	Alpha, 2020 Dec 6–2021 Jan 30	Delta, 2021 June 6–Jul 31	Omicron, 2021 Dec 6–2022 Jan 30	p value†
Sequences collected	376,637	774,534	1,877,225	
Countries submitting sequences	168	164	151	
Median lag time, d	39	23	17*	
Mean sequences submitted/1 million population	48.8	100.4	243.3	<0.001
Low income	2.1	3.2	1.1	
Lower-middle income	3.4	8.7	13.6	
Upper-middle income	4.7	23.7	28.3	
High income	295.6	573.2	1,476.1	
Mean sequences/100,000 SARS-CoV-2 reported infections	981.0	2,017.4	4,889.6	<0.001
Low income	795.8	655.1	170.4	
Lower-middle income	302.1	319.2	378.3	
Upper-middle income	115.8	493.2	351.4	
High income	1,457.2	8,899.4	2,074.2	
Sequences collected within 14 d lag time (% total as of 2022 Mar 20)	81,358 (21.6)	165,758 (21.4)	360,022 (19.2)	
Countries submitting sequences within 14 d of sample collection	118	115	94	
Mean sequences submitted/1 million population within 14 d of collection	10.5	21.5	46.7	<0.001
Low income	0.4	0.8	0.08	
Lower-middle income	0.7	1.6	1.1	
Upper-middle income	0.6	4.9	3.5	
High income	64.7	123.5	291.6	

*Mean time during Omicron cannot be accurately compared to mean lag time during Alpha or Delta because data from GISAID and GenBank were retrieved <2 months after the end of the Omicron period examined in this analysis. GISAID, https://www.gisaid.org.
†By Kruskal-Wallis test.

Table 3. Geographic distribution of Alpha, Delta, and Omicron SARS-CoV-2 sequences before dates of selected international public health actions, based on data from GISAID and GenBank, 2020–2021*

Variant	International action (date implemented)	Sequences collected before that date	Geographic diversity of origin	Sequences submitted before that date (% of total collected)	Geographic diversity of origin
Alpha	International travel restrictions (*14*) (2020 Dec 19)†	11,586	48 countries (5 continents)	1,872 (16)	4 countries (2 continents)
Delta	WHO-designated VOC (*2*) (2021 May 11)	28,257	116 countries (6 continents)	2,257 (8.0)	39 countries (5 continents)
Delta	CDC-designated VOC (*15*) (2021 Jun 15)‡	121,071	137 countries (6 continents)	46,946 (39)	66 countries (6 continents)
Omicron	WHO-designated VOC (*2*); international travel restrictions (*16*) (2021 Nov 26)	1,365	48 countries (6 continents)	76 (5.6)	3 countries (2 continents)

*CDC, United States Centers for Disease Control and Prevention; GISAID, https://www.gisaid.org; VOC, variant of concern. WHO, World Health Organization.
†WHO designated Alpha a variant of concern on December 18, 2020 (*2*).
‡Several countries implemented (Germany, Hong Kong, Lithuania, Slovakia, Belgium) or extended (United States) travel restrictions due to Delta during June or July 2021.

38 countries on 5 continents, but only 76 sequences (5.6%) from 3 countries on 2 continents were submitted to GISAID or GenBank before that date (Table 3).

Discussion

The bank of global, publicly available SARS-CoV-2 genomic sequence data increased substantially during the COVID-19 pandemic. The number of sequences submitted to public databases more than doubled overall (and increased in all income categories) between the Alpha period and the Delta period, doubling again between the Delta and Omicron periods. This increase in sequence submissions might reflect the impact of technological advancements, the continued high utility of genomic sequencing data, and increased prioritization of genomic surveillance between these periods. Continuing to strengthen laboratory and data sharing infrastructure and international partnerships for viral genomic surveillance could improve monitoring and early detection of SARS-CoV-2 variants and might contribute to monitoring and detection of other pathogens.

Despite the general trend of increased sequencing during the pandemic, disparities between World Bank income categories and WHO regions increased during the Omicron wave. Similarly, the number of sequences submitted within 14 days of collection increased between the emergence of 3 major SARS-CoV-2 variants, but disparities persisted in the volume of sequences submitted within 14 days of collection along economic lines. The only exception to this trend was the finding that the lowest income category of countries had higher sequences submitted per 100,000 reported infections detected than did the lower-middle category. This difference is likely related to lower testing and case detection in the lowest income category; when examined by population, per capita sequencing was substantially lower in the lowest income category than the lower-middle category. A greater proportion of low-income countries were associated with ≤100 sequences compared with other income categories, which might be the result of partnerships with other countries for sequencing. Overall median lag times between sample collection and public sequence submission exceeded 14 days, reflecting a need to improve sequencing turnaround time to inform timely global public health decision-making.

Our analysis cannot distinguish between the time from sample collection to sequence result and the time from sequence result to submission to a public database because these variables are not included in GISAID or GenBank metadata. However, using viral genomic surveillance data to inform rapid international public health action depends on both rapid sequencing and the timely sharing of data. For example, global knowledge of Omicron began with timely identification of an unusual SARS-CoV-2 lineage identified by a team of researchers in Botswana, who shared their findings with colleagues in South Africa and on public servers within days (*17*). Sequences made available long after collection can still contribute to knowledge on a pathogen's transmission dynamics and other characteristics, so reducing the time to sequencing and encouraging prompt sharing of data could improve the quality and usefulness of information for public health action.

In terms of limitations regarding our analysis, we examined only sequences uploaded to GISAID and GenBank. Although those are the largest 2 repositories of viral genomic surveillance data, they contain only those reports that laboratories and countries choose to make public. Also, by choosing a time period comparison including a relatively recent 2-month period, the data from the Omicron period reflect only sequences submitted and available to download as of March 21, 2022, and do not include sequences that may have been collected during the Omicron period but submitted after this date. Because of this, the

observed differences in the volume of submitted sequences between the Omicron period and the earlier 2 periods are likely larger than these data reflect. Finally, overall average lag times from the more recent Omicron period cannot be compared with those from the Alpha or Delta periods because the Omicron period was relatively close to the data cutoff and therefore more likely to include sequences with short lag times. The volume of sequences submitted within 14 days of collection can be compared across periods.

For many reasons, including incomplete and variable vaccination coverage (*18*), continued viral transmission is anticipated and the emergence of new SARS-CoV-2 variants is expected (*19*). The availability of samples for sequencing depends on the availability of testing. Because testing is limited in many settings (I. Bergeri et al., unpub. data, https://www.medrxiv.org/content/10.1101/2021.12.14.21267791v2), samples available for sequencing may not represent the true diversity of viral genomes within countries. Testing, viral genomic surveillance, and sharing of data are critical to early detection of new variants and accurate assessment of their spread. The unequal viral genomic surveillance highlighted by this analysis suggests a new variant can circulate widely before detection and public sharing of the new variant's genomic information.

The 3 VOCs we assessed were already present in many countries at the time travel restrictions were imposed. One analysis of Omicron-related travel restrictions found that most countries issuing entry bans did not modify them after widespread community transmission of Omicron was reported elsewhere, and most did not add increased testing or quarantine requirements for travelers (*20*). Faster sequencing and more timely public sequencing availability might contribute to better understanding of how widely variants have spread at the time of their designation as VOCs and might also help encourage policies supporting evidence-based transmission prevention measures, such as increasing masking (*21*), rather than reliance on travel restrictions, which might have only a modest effect on transmission, particularly after introduction has already occurred (*22*).

Supporting the expansion of representative testing across and within countries and regions could increase the quantity of specimens available for sequencing. Addressing the global inequity of viral genomic surveillance information by supporting the expansion of representative viral genomic surveillance—particularly in low-, lower-middle-, and upper-middle-income countries, including through such efforts as the African Pathogen Genomics " Initiative (*23*)—might increase the probability of early detection and characterization of new variants and timely implementation of tailored responses, like nonpharmaceutical interventions, diagnostic approaches, and vaccines. Encouraging timely public sharing of viral genomic surveillance data by supporting countries that report detection of new variants, new outbreaks, or new pathogens could help bolster the ability of all countries to publicly share surveillance information and to set effective, timely public health policy. Together, these efforts could promote global health security during this and future pandemics.

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Comparison of COVID-19 Pandemic Waves in 10 Countries in Southern Africa, 2020–2021

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We used publicly available data to describe epidemiology, genomic surveillance, and public health and social measures from the first 3 COVID-19 pandemic waves in southern Africa during April 6, 2020–September 19, 2021. South Africa detected regional waves on average 7.2 weeks before other countries. Average testing volume 244 tests/million/day) increased across waves and was highest in upper-middle-income countries. Across the 3 waves, average reported regional incidence increased (17.4, 51.9, 123.3 cases/1 million population/day), as did positivity of diagnostic tests (8.8%, 12.2%, 14.5%); mortality (0.3, 1.5, 2.7 deaths/1 million populaiton/day); and case-fatality ratios (1.9%, 2.1%, 2.5%). Beta variant (B.1.351) drove the second wave and Delta (B.1.617.2) the third. Stringent implementation of safety measures declined across waves. As of September 19, 2021, completed vaccination coverage remained low (8.1% of total population). Our findings highlight opportunities for strengthening surveillance, health systems, and access to realistically available therapeutics, and scaling up risk-based vaccination.

As of September 2021, in Africa, 5,650,962 SARS-CoV-2 infections (2.6% of global total) and 135,568 related deaths (3.0% of global total), had been reported (*1*). However,this number was likely a substantial underestimate of the true number of SARS-CoV-2 infections, given limited surveillance capacity and relatively higher positivity reported in seroprevalence studies (*2*–*4*). The first case in southern Africa, home to ≈14% of the population of Africa (*5*), was reported on March 5, 2020 in South Africa (*6*). By September 2021, all countries in southern Africa were experiencing their third COVID-19 pandemic waves.

Although quantitative comparisons of COVID-19 waves have been published, few have

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compared waves in southern Africa (*7*–*9*), despite the region experiencing substantial illness and death across waves (*10*). Furthermore, there has been limited systematic reporting and analysis of public health and social measures (PHSMs) enacted during outbreaks across countries in the region. A comparison of characteristics across waves provides unique insights into reported incidence, mortality, and distribution of variants of concern (VOCs) across geography and time. Population movements between countries in southern Africa, a highly interconnected region, have historically been drivers of HIV and tuberculosis epidemics (*11*) and could influence COVID-19 wave propagation. To inform public health actions to prevent, detect, and reduce the effects of future COVID-19 pandemic waves across the region, we compared trends in reported testing volume, incidence, mortality, genomic surveillance results, PHSMs, and vaccination coverage across pandemic waves in southern Africa during April 2020–September 2021.

Methods

Data Sources and Data Collection

According to the African Union (https://au.int), southern Africa consists of Angola, Botswana, Eswatini, Lesotho, Malawi, Mozambique, Namibia, South Africa, Zambia, and Zimbabwe. We obtained data on testing, incidence, mortality, and vaccination collected during February 7, 2020–September 19, 2021 (final day of data extraction) from the Our World in Data (OWID; https://ourworldindata.org) dataset, compiled by Johns Hopkins University (*1*). We supplemented missing data or errors with data from in-country US Centers for Disease Control and Prevention (CDC) offices, the World Health Organization (WHO), or daily reports from Africa Centers for Disease Control and Prevention (Africa CDC) (*12*). We excluded still-missing data from indicator computations and computed weekly averages for each indicator to reduce potential bias introduced by missed reports. We based the effective reproduction number on estimates published elsewhere (*13*). We obtained publicly available SARS-CoV-2 genomic sequencing results from GISAID (https://www.gisaid.org) (*14*); those data were exported on September 19, 2021, and included specimens collected during March 1, 2020–September 6, 2021.

We extracted publicly available PHSM data from the Oxford COVID-19 Government Response Tracker (OxCGRT; https://covidtracker.bsg.ox.ac.uk), available during January 1, 2020–September 19, 2021 (*15*). OxCGRT contains 23 indicators aggregated into a set of common indices, rated 1–100 to quantify the level of government intervention. All indices, defined on the OxCGRT website, were based on averages of component indicators to provide a measure of how many indicators a government has acted upon and to what degree. We compared the original PHSM stringency, overall government response, containment health, and economic support indices across waves. This activity was reviewed by CDC and conducted consistent with applicable federal laws and CDC policy.

Statistical Analysis

To align with existing analysis of pandemic waves in Africa, we adapted wave definitions published elsewhere (*6*) (Appendix, https://wwwnc.cdc.gov/EID/article/28/13/22-0228-App1.pdf). Different authors independently applied these definitions to determine the wave start, peak, and end weeks (Appendix Table 1); we resolved discrepancies by consensus. We analyzed data in R version 4.01 (The R Foundation for Statistical Computing, https://www.r-project.org). We computed averages and maximums across wave periods and countries for reported COVID-19 incidence (7-day average daily cases and peak cases/1 million persons); mortality (7-day average daily deaths and peak deaths/1 million persons and case-fatality ratio [CFR]); testing (7-day average daily tests/1 million persons, 7-day average test positivity, peak 7-day average test positivity, and 7-day average tests per case); and vaccination (total number of persons vaccinated/100 population, total number persons fully vaccinated/100 persons [defined by OWID as total number of persons who received all doses prescribed by the vaccination protocol/100 persons in the total population], and average weekly vaccinations/1 million persons). We computed peak averages as the maximum 7-day average in a period; OWID defines peak 7-day average test positivity as tests conducted per new confirmed case. We computed regional averages for southern Africa by averaging all available country-specific values for each indicator within the wave period. For example, for each 7-day average indicator, we averaged all available country-level 7-day averages to determine overall regional averages, and all available 7-day averages within country-specific wave periods were averaged for regional averages by wave. We conducted 1-way analysis of variance tests to calculate differences in 7-day average cases, deaths, and tests per 1 million persons across waves. We computed genomic surveillance coverage as the total number of

sequences submitted to GISAID during that period divided by the number of cases per 1 million. However, for ease of interpretation, genomic surveillance coverage was reported as its inverse (number of cases/1 million/sequence submitted). Therefore, a country with a higher number of reported cases per 1 million per sample sequenced has lower genomic surveillance coverage than a country with a lower number. We computed medians and interquartile ranges (IQRs) across wave periods for continuous genomic variables and frequencies for categorical genomic variables. We reported genomic sequences using WHO genome labels (*16*) (Appendix Table 2) and categorized sequences without a WHO label as other lineages (Appendix Table 3). For PHSM data, we computed averages across waves for each index and frequencies for the number of measures mandated at the beginning, peak, end, and throughout the duration of waves.

Results

Burden of COVID-19 in Southern Africa

By September 19, 2021, southern Africa had 3,841,563 SARS-CoV-2 cases, 65.0% of Africa and 1.7% of global totals, and 107,347 COVID-19 deaths, 75.4% of Africa and 2.3% of global totals. South Africa had the highest numbers of cases (75.0%) and deaths (80.3%) among countries in the region. The countries with highest incidence and mortality over the period were Botswana, Namibia, Eswatini, and South Africa (Appendix Figure 1).

Regional Pandemic Wave Propagation Patterns

The earliest start date for the first wave within any country was April 6, 2020 (South Africa); by July 5, 2021, all countries in the region were experiencing a third wave (Figure 1). On average, pandemic waves in the region lasted 16.5 weeks; the first wave, at 19.5 weeks, was the longest, followed by the second, 15.1 weeks, and third, 14.9 weeks (Table 1). Wave durations varied by wave and across countries; the first wave in Angola lasted 30 weeks but the second wave in Zimbabwe lasted 9 weeks. Waves in almost all other countries started an average of 7.2 weeks later than in South Africa, but with some variation: Namibia at 4.0 weeks and Angola at 14.0 weeks later (Table 1).

Regional and Temporal Variations in Testing

The number of 7-day average daily tests per 1 million persons was higher in the 2 upper-middle-income countries, Namibia (549.0) and South Africa (519.3), where testing data were more available, but lower in low-income countries Malawi (37.9) and Mozambique (51.6) (Table 2, https://wwwnc.cdc.gov/EID/article/28/13/28-0228-T2.htm). Testing increased in all 10 countries across successive pandemic waves; the third wave had nearly 3 times (388.0 versus 146.8) the 7-day average daily tests per million persons than did the first wave. There was a statistically significant ($p<0.05$) mean difference across waves in tests within each country and across all countries. However, 7-day average test/case ratio was highest in the first wave (24.8), followed by the second (17.0) and third (13.5) (Table 2).

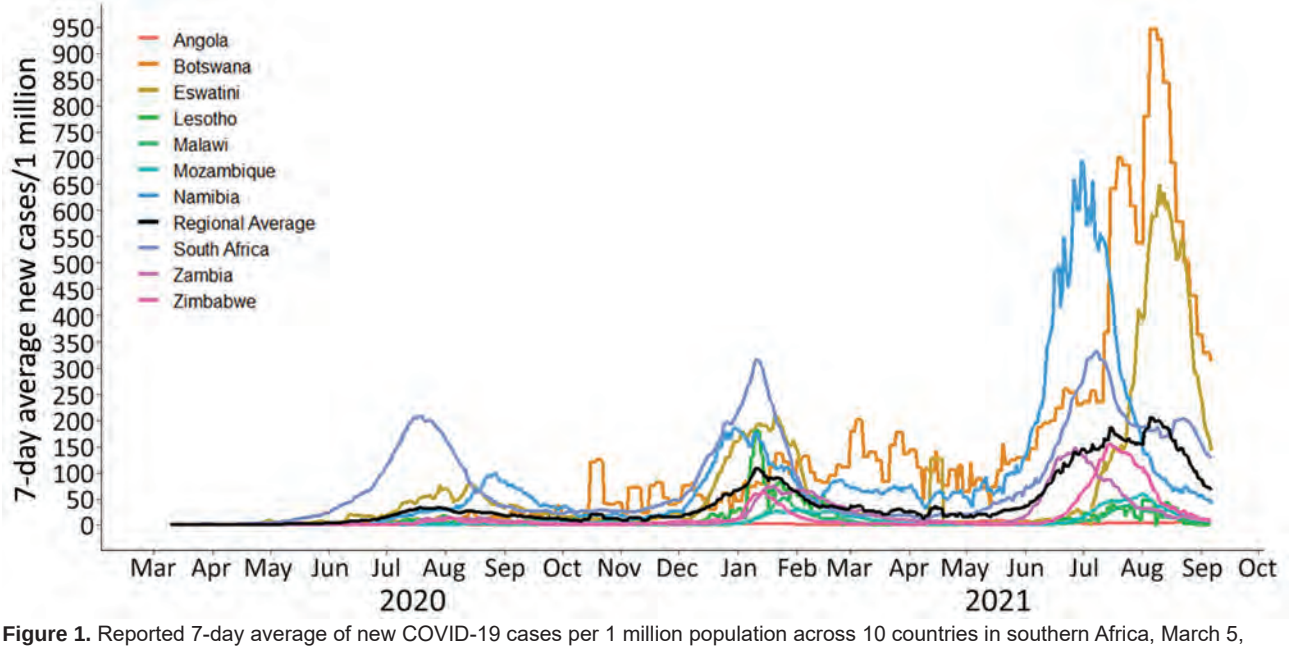

Figure 1. Reported 7-day average of new COVID-19 cases per 1 million population across 10 countries in southern Africa, March 5, 2020–September 17, 2021. Source: Our World in Data (https://www.ourworldindata.org), accessed 2021 Sep 20.

Table 1. Total duration of 3 COVID-19 pandemic waves in 10 countries in southern Africa and time since start of wave in South Africa, April 6, 2020–September 19, 2021*

	Wave 1		Wave 2		Wave 3		Country average	
Country	Total duration, wk	Time from start of SA wave, wk	Total duration, wk	Time from start of SA wave, wk	Total duration, wk	Time from start of SA wave, wk	Total duration, wk	Time from start of SA wave, wk
Angola†	30	13	13	20	10	9	17.7	14.0
Botswana	31	5	16	8	17	2	21.3	5.0
Eswatini	15	11	14	4	10	9	13.0	8.0
Lesotho	16	11	12	3	14	5	14.0	6.3
Malawi	15	10	18	5	15	4	16.0	6.3
Mozambique	20	12	19	6	16	3	18.3	7.0
Namibia	20	10	13	0	17	2	16.7	4.0
SA	22	Referent	16	Referent	19	Referent	19.0	Referent
Zambia	15	13	21	3	17	2	17.7	6.0
Zimbabwe	11	12	9	7	14	5	11.3	8.0
Overall average	19.5	10.8	15.1	6.2	14.9	4.6	16.5	7.2

*Appendix Table 1 (https://wwwnc.cdc.gov/EID/article/28/12/22-0228-App1.pdf) shows dates of starts, peaks, ends, and period definitions of pandemic waves. SA, South Africa.
†Third wave in Angola had not yet reached its peak as of September 19, 2021.

Temporal Changes in COVID-19 Wave Severity

Average incidence (cases/1 million persons/day) increased across waves, from 17.4 in the first to 5.19 in the second 51.9 and 123.3 in the third. Percentage test positivity increased from 8.8% in the first wave to 12.2% in the second and 14.5% in the third. Mortality (deaths/1 million persons/day) increased from 0.3 in the first wave to 1.5 in the second and 2.7 in the third. CFR increased from 1.9% in the first wave to 2.1% in the second and 2.5% in the third (Table 2).

In an unadjusted analysis that did not control for changes in testing capacity over time, we also found a statistically significant ($p<0.05$) mean difference across waves in 7-day average daily cases and deaths per 1 million population within each country and the region. However, for some countries the second wave had the highest reported incidence of cases and deaths (Table 2; Figure 2). The second wave in Lesotho had the highest peak 7-day average number of new cases per 1 million persons and the highest peak in deaths per 1 million persons per day in Lesotho, South Africa, and Eswatini (Table 2). Upper middle-income countries South Africa, Namibia, and Botswana had relatively high overall 7-day average numbers of new deaths per 1 million persons compared with low-income countries.

Genomic Surveillance

During the study period, a collective 23,306 SARS-CoV-2 specimen sequences were submitted to GISAID from all 10 countries in southern Africa, most (89.4%) from laboratories in South Africa (Table 3; Appendix Figure 2). Most (18,464, 79.2%) specimens were collected in South Africa, the fewest (18, 0.1%) in Lesotho (Appendix Figure 3). The largest proportion of specimens (43.3%) were collected during the third wave; the number of sequences submitted increased between the first and second waves in 8/10 countries (Table 4, https://wwwnc.cdc.gov/EID/article/28/13/28-0228-T4.htm; Figure 4).

Genomic surveillance coverage (median number of cases/1 million persons/SARS-CoV-2 genome submitted) varied across countries, from 1.02 (IQR 0.94–2.5)in Angola to 211.40 (IQR 210.7–486.4) in Eswatini (Table 4). For the southern Africa region, genomic surveillance coverage was highest before the start of the second wave, median 1.55 cases/1 million persons/SARS-CoV-2 genome submitted. The prevalence of the Beta variant increased from 13.7% in the period before the second wave to 80.6% during the second wave (Table 3). During the third wave, the prevalence of Beta decreased to 14.8% and the prevalence of Delta increased to 73.8%. Beta variant was predominant in the second wave in 8/10 countries and Delta in the third wave in 9/9 countries (Table 4; Figure 3).

PHSMs

PHSM stringency index decreased from the first through the third waves in 8/10 countries (Table 5, https://wwwnc.cdc.gov/EID/article/28/13/28-0228-T5.htm; Figure 5). Regionally, average stringency, government response, and economic support indices were highest during the first wave (Table 5). International travel restrictions were the most common PHSM and closing public transport the least common (Table 6). During the first wave, more PHSMs were implemented at the beginning of the wave than at the end, whereas during the second wave, more PHSMs were implemented at the end of the wave than the beginning. For all 3 waves, the most PHSMs were implemented at the peak of the wave (Table 7).

Vaccination Coverage

Countries began SARS-CoV-2 vaccination campaigns after the first wave during February 17 (South Africa) through April 14, 2021 (Zambia) (*5*). By the time the second wave began, 7/10 countries (excluding Namibia, Lesotho, and Eswatini) had begun vaccinations; all countries had begun vaccinations by the third wave (Table 2). As of September 19, 2021, 10.8% of the population was vaccinated on average across southern Africa and 8.1% fully vaccinated (Table 2). Coverage varied by country: Eswatini had 16.5% and Zambia 1.5% fully vaccinated. Seven-day vaccinations per 1 million persons steadily increased across waves and were 4.2-fold higher during the third wave (1,087.9) than the second (262.1) (Table 2).

Discussion

Among key findings, we found that patterns of wave propagation throughout the region were similar across almost all country waves. In the absence of a representative regional surveillance system for influenza-like illness, surveillance data from South Africa, where waves were first detected, provided an early warning signal for other countries in the region. Although per person volume of testing increased over time in southern Africa, it remained low compared with resource-rich countries and differed among countries, limiting the ability to compare reported incidence and mortality. Genomic sequencing in the region was limited outside of South Africa. In most countries, reported percentage positivity, incidence rates, mortality rates,

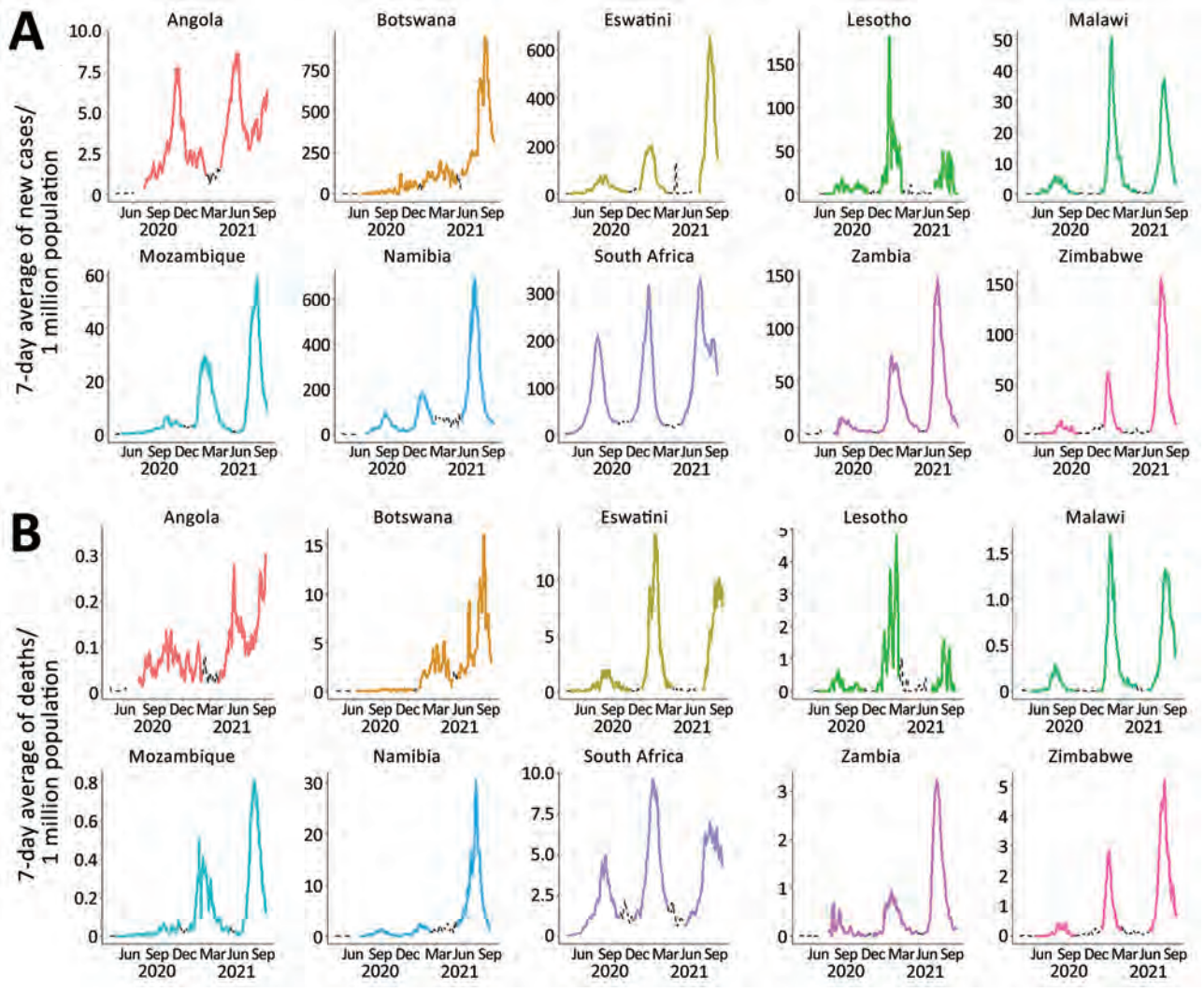

Figure 2. Reported 7-day average new COVID-19 cases (A) and deaths (B) per 1 million persons across pandemic waves in 10 countries in southern Africa, March 5, 2020–September 19, 2021. Colored lines indicate designated wave periods, dashed lines indicate periods between waves. We used differing y-axis scales in this figure to better visualize the wave patterns in each individual country. See Appendix Figure 2 (https://wwwnc.cdc.gov/EID/article/28/13/22-0228-App1.pdf) for the same figure placed on corresponding y-axis scales to compare wave magnitudes across countries. Source: Our World in Data (https://www.ourworldindata.org), accessed 2021 Sep 20.

and CFRs increased across waves, partly caused by the emergence of more transmissible variants. Stringent PHSM implementation declined over successive waves, and vaccine coverage was low.

Because South Africa accounted for >30% of cases in Africa, average wave patterns were similar between southern Africa and Africa as a whole but with notable regional and intercountry variations (*6*). Kenya, in eastern Africa, experienced second and third waves before southern Africa. In southern Africa, all waves followed a similar regional pattern: waves were first detected in South Africa, then throughout the remaining interconnected countries an average of 7.2 weeks later. This pattern was less obvious for Angola, where the second wave started 20 weeks after South Africa (Appendix Table 1). This pattern likely reflects greater testing capacity in South Africa, more sensitive surveillance, and possibly mobility characteristics in the region because South Africa is an international transportation hub. According to phylogenetic analysis, South Africa was determined to be the source of SARS-CoV-2 cases imported to the rest of the region during the first and second pandemic waves (*17*). Awareness of this pattern is critical for future mitigation efforts; pretravel testing and ongoing sentinel surveillance might be critical for detecting cross-border transmission early, and pandemic surveillance and

Table 3. Overall genomic surveillance comparison across 3 COVID-19 pandemic waves for 10 countries in southern Africa, March 1, 2020–September 6, 2021*

Measure	Before wave 2 start	After wave 2 start, before wave 3 start	After wave 3 start	Overall
Total no. (%) specimens,†	5,543 (23.8)	7,660 (32.9)	10,103 (43.3)	23,306 (100)
Originating country, no. (%)				
Angola	615 (11.1)	264 (3.4)	20 (0.2)	899 (3.9)
Botswana	83 (1.5)	216 (2.8)	799 (7.9)	1098 (4.7)
Eswatini	11 (0.2)	77 (1.0)	34 (0.3)	122 (0.5)
Lesotho	2 (<0.1)	16 (0.2)	0	18 (0.1)
Malawi	16 (0.3)	391 (5.1)	104 (1.0)	511 (2.2)
Mozambique	126 (2.3)	388 (5.1)	66 (0.7)	580 (2.5)
Namibia	19 (0.3)	196 (2.6)	48 (0.5)	263 (1.1)
South Africa	4,013 (72.4)	5,601 (73.1)	8,850 (87.6)	18,464 (79.2)
Zambia	426 (7.7)	182 (2.4)	84 (0.8)	692 (3.0)
Zimbabwe	232 (4.2)	329 (4.3)	98 (1.0)	659 (2.8)
Submitting country, no. (%)				
Botswana	83 (1.5)	216 (2.8)	799 (7.9)	1,098 (4.7)
Germany‡	1 (<0.1)	64 (0.8)	47 (0.5)	112 (0.5)
Malawi	14 (0.3)	8 (0.1)	38 (0.4)	60 (0.3)
South Africa	4,794 (86.5)	6,910 (90.2)	9,135 (90.4)	20,839 (89.4)
Spain‡	13 (0.2)	117 (1.5)	0	130 (0.6)
United Kingdom‡	210 (3.8)	189 (2.5)	0	399 (1.7)
United States‡	0	12 (0.2)	0	12 (0.1)
Zambia	426 (7.7)	144 (1.9)	84 (0.8)	654 (2.8)
Patient sex, no. (%)				
F	2,951 (53.2)	4,053 (52.9)	5,695 (56.4)	12,699 (54.5)
M	2,132 (38.5)	3,274 (42.7)	4,044 (40.0)	9,450 (40.5)
Unknown	460 (8.3)	333 (4.3)	364 (3.6)	1,157 (5.0)
Patient age, y, median (IQR)	37 (27–50)	37 (25–52)	39 (27–54)	38 (26–52)
Genomic surveillance coverage,† median (IQR)	1.55 (0.66–2.79)	3.76 (2.68–4.56)	3.98 (3.37–4.58)	3.48 (2.70–4.44)
Detected SARS-CoV-2 variants, no. (%)§				
Alpha, B.1.1.7 + Q.x	33 (0.6)	158 (2.1)	168 (1.7)	359 (1.5)
Beta, B.1.351 + B.1.351.x	749 (13.7)	6,176 (80.6)	1,493 (14.8)	8,418 (36.2)
Delta, B.1.617.2 + AY.x	0	129 (1.7)	7,454 (73.8)	7,583 (32.6)
Gamma, P.1 + P.1.x	1 (<0.1)	0	1 (<0.1)	2 (<0.1)
Variant of interest	0	1 (<0.1)	0	1 (<0.1)
Variant under monitoring	9 (0.2)	37 (0.5)	174 (1.7)	220 (0.9)
Former variant of interest	2 (<0.1)	1 (<0.1)	1 (<0.1)	4 (<0.1)
Lineages with no WHO label	4,673 (85.3)	1,155 (15.1)	812 (8.0)	6,640 (28.6)
January 2020 strain	14 (0.3)	3 (<0.1)	0	17 (0.1)

*Source: GISAID (https://www.gisaid.org), accessed 2021 Sep 20. IQR, interquartile range; World Health Organization.
†Genomic surveillance coverage was defined as the number of reported cases per million per sample sequenced. A country with a higher number of reported cases per million per sample sequenced has lower genomic surveillance coverage than a country with a lower number of reported cases per million per sample sequenced.
‡Germany submitted sequences for specimens collected in Mozambique (n = 1), Namibia (n = 73), Zambia (n = 38). Spain submitted sequences for specimens collected in Mozambique (n = 130). UK submitted sequences for specimens collected in Zimbabwe (n = 401). The United States submitted sequences for specimens collected in South Africa (n = 12).
§Specimens were classified using labels defined by the World Health Organization (Appendix Table 2, https://wwwnc.cdc.gov/EID/article/28/13/22-0228-App1.pdf).

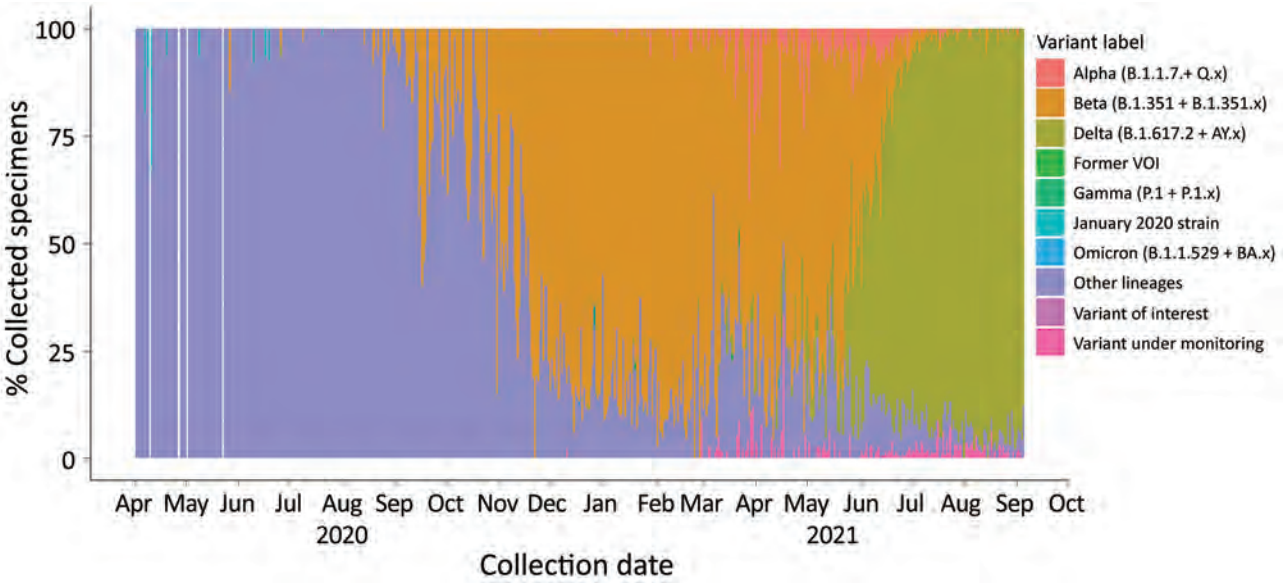

Figure 3. Percentage of SARS-CoV-2 variants among specimens submitted to GISAID in southern Africa, March 1, 2020–September 6, 2021. Definitions of variants are in Appendix Table 2 (https://wwwnc.cdc.gov/EID/article/28/13/22-0228-App1.pdf). Source: GISAID (https://www.gisaid.org), accessed 2021 Sep 20.

reporting in South Africa can serve as an early warning signal for countries with more limited testing capacity. However, a regional, representative, surveillance system for influenza-like illness and severe acute respiratory illness could improve regional detection and response systems.

Although weekly population-level numbers of tests increased, testing per case, an indicator of sufficient coverage in high-transmission periods, decreased across waves, and the region never achieved the WHO-recommended target of 1,000 tests/1 million persons (*18*). The region's average testing volume per person was low compared with resource-rich countries: ≈240 tests/1 million persons/day in southern Africa versus >3,000 tests/1 million/day in the United States (*4*). Even Namibia and South Africa, despite relatively higher testing volumes, were below the WHO target for testing. This target might be unreachable for most countries in this region unless test accessibility for the general population is

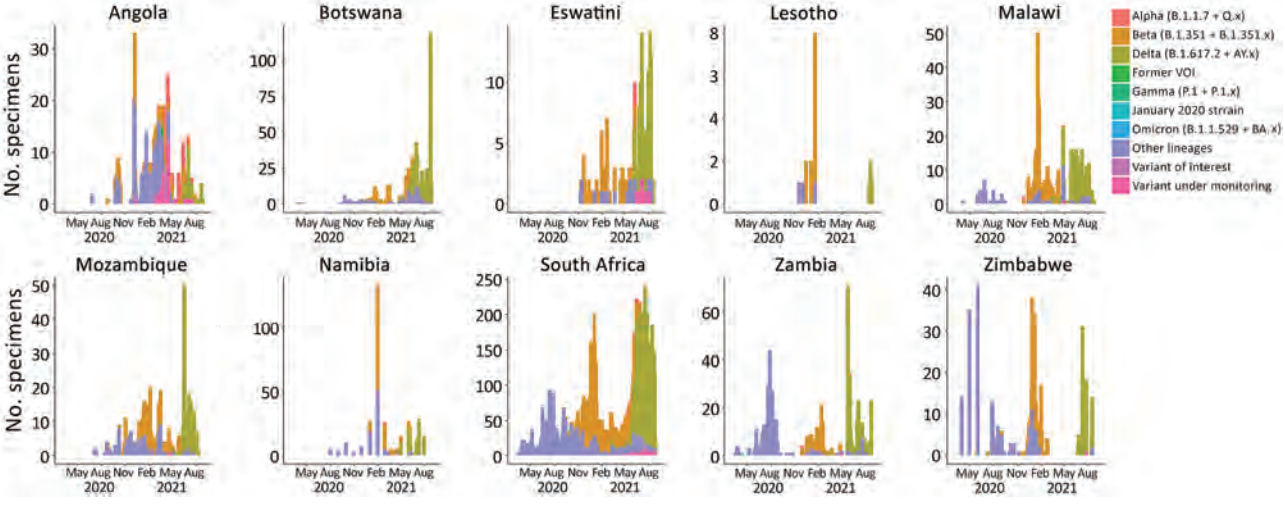

Figure 4. Counts of SARS-CoV-2 variants (World Health Organization classifications) in 10 countries in southern Africa, March 1, 2020–September 6, 2021. Definitions of variants are in Appendix Table 2 (https://wwwnc.cdc.gov/EID/article/28/13/22-0228-App1.pdf). We used differing y-axis scales used in this figure to better visualize genomic sampling patterns in each individual country. See Appendix Figure 3 for the same figure placed on corresponding y-axis scales to compare wave magnitudes across countries. Source: GISAID (https://www.gisaid.org), accessed 2021 Sep 20.

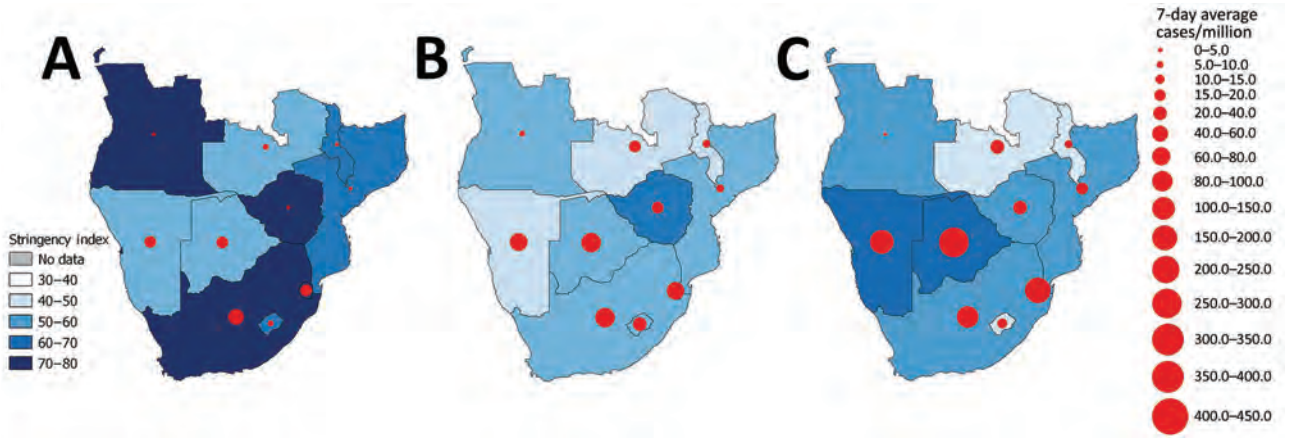

Figure 5. Comparison of public health and social measure stringency and 7-day average new COVID-19 cases per million across 3 COVID-19 pandemic waves in 10 countries in southern Africa, April 6, 2020–July 17, 2021. Source: GISAID (https://www.gisaid.org), accessed 2021 Sep 20.

substantially improved. Increasing availability and feasibility of COVID-19 self-tests, as recommended by Africa CDC (*19*), might increase testing and improve public health mitigation efforts (*20*,*21*).

In this resource-constrained region, testing volumes should be expanded on the basis of need and be designed to collect data to address key objectives for public health response. These data include diagnosing admissions, classifying excess deaths because of COVID-19, defining the timing of pandemic waves, monitoring circulating variants, and informing guidance for work, school, and social engagements. Data gathered from serosurveillance and postmortem activities might also help address these objectives (*3*,*4*,*22*).

Our ability to directly compare SARS-CoV-2 case and death counts in the region using publicly available data was limited by changes over time in test types and availability, low likelihood of diagnosis (*4*), and various and changing testing strategies. Sustaining COVID-19 sentinel surveillance systems in the community and among high-risk populations (*23*), including through targeted use of antigen rapid diagnostic tests (*24*), and improving standard reporting throughout the region to ensure appropriate local epidemiologic evaluations and responses (*25*), could be considered. These data-gathering systems could be coordinated through a regional body such as the recently established Africa CDC Southern Africa Regional Collaborating Centre (*26*).

Table 6. Most frequent public health and social measure types implemented across COVID-19 pandemic waves for 10 countries in southern Africa, January 1, 2020–September 19, 2021*

Wave	Most common measures	Least common measures
Wave 1		
Beginning	Workplace closing, cancel public events, restrictions on gatherings, international travel	Public transport closings
Peak	School closing, workplace closing, cancel public events, restrictions on gatherings, international travel	Public transport closings
End	School closing, workplace closing, cancel public events, restrictions on gatherings, international travel	Public transport closings
Duration	School closing, workplace closing, cancel public events, international travel	Public transport closings
Wave 2		
Beginning	Workplace closing, cancel public events, restrictions on gatherings, international travel	Public transport closings
Peak	School closing, workplace closing, cancel public events, restrictions on gatherings, international travel	Movement restrictions
End	School closing, cancel public events, restrictions on gatherings, international travel	Close public transport, movement restrictions
Duration	School closing, cancel public events, restrictions on gatherings, international travel	Public transport closings
Wave 3		
Beginning	Restrictions on gatherings, international travel	Movement restrictions
Peak	Workplace closing, cancel public events, restrictions on gatherings, international travel	Public transport closings, movement restrictions
End	Workplace closing, international travel	Movement restrictions
Duration	International travel	School closings

*Public health and social measures, as defined and measured by Oxford COVID-19 Government Response Tracker (https://www.bsg.ox.ac.uk/research/research-projects/covid-19-government-response-tracker), accessed 2021 Sep 20.

Table 7. Number of public health and social measures implemented across COVID-19 pandemic waves by type for 10 countries in southern Africa, January 1, 2020–September 19, 2021*

	Wave 1, n = 10				Wave 2, n = 10				Wave 3, n = 10†			
Intervention	Start	Peak	End	Duration	Start	Peak	End	Duration	Start	Peak	End	Duration
School closings	9	10	10	10	9	10	10	10	4	7*	2	1
Workplace closings	10	10	10	10	10	10	9	9	9	9*	10	6
Canceled public events	10	10	10	10	10	10	10	10	9	9*	9	7
Restrictions on gatherings	10	10	10	9	10	10	10	10	10	9*	9	8
Public transport closings	7	6	4	4	2	5	5	0	5	5*	7	2
Stay-at-home requirements	9	9	8	7	7	9	10	6	8	7*	8	7
Movement restrictions	9	9	7	6	6	4	5	2	3	5*	4	2
International travel	10	10	10	10	10	10	10	10	10	9*	10	9

*Public health and social measures, as defined and measured by Oxford COVID-19 Government Response Tracker https://www.bsg.ox.ac.uk/research/research-projects/covid-19-government-response-tracker), accessed 2021 Sep 20.
†For peak of wave 3, n = 9.

Genomic sequencing varied across countries and was limited outside South Africa. Low sequencing limits detection of new VOCs, posing regional and global health security risks. Africa CDC and WHO are strengthening genomic surveillance by establishing a continentwide laboratory network, leveraging existing surveillance systems, to better detect variant evolution (*27*). To improve sequencing of SARS-CoV-2 and other endemic and epidemic pathogens, systematic in-country genomic surveillance could be built and sustained in the region by adopting sequencing targets such as weekly targets based on incidence and estimated prevalence of variants in line with Africa CDC guidelines (*28*–*30*). In southern Africa, Beta variant was predominant in the second wave and Delta in the third.

Across the region, the third COVID-19 wave had the highest 7-day average percentage positivity, daily cases, deaths per 1 million population, and CFR. Increases in reported incidence and mortality at a time of increasing percentage positivity occurred at least partly because of the emergence of more transmissible variants across waves. However, the connection between high testing volume and reported incidence and mortality rates per person in upper-middle-income countries Namibia and South Africa might reflect better testing capacity contributing to improved accuracy of identifying cases and classifying cause of death, leading to higher reported overall incidence and mortality rates (*31*).

Neither emergence of more transmissible variants nor improved testing capacity can fully explain the increase in CFR over time, an observation that has been previously reported for Africa (*32*–*34*). Possible explanations for this increase include increased strain on limited critical care capacity as transmission and hospitalizations increased (*6*,*34*,*35*); health systems with minimal critical care resources are not optimized for managing critically ill COVID-19 cases. A recent prospective cohort analysis found that mortality among critically ill hospitalized patients was 48.2% in Africa, higher than the estimated 31.5% global average (*32*,*34*). Other explanations might include delays in healthcare-seeking behavior by patients, improved differential testing and reporting (i.e., relatively fewer tests among persons who are not ill but more among very ill persons), improvements in classifying COVID-19–related deaths, and declining ability to protect vulnerable populations from SARS-CoV-2 exposure. However, increased CFR in the region suggests the need for improved health systems and access to newer therapeutics for high-risk patients, such as antivirals molnupiravir (*36*) and nirmatrelvir (*37*).

The increased incidence, mortality, and CFR during the third wave were not universal across countries. Lesotho reported highest average incidence rates during its second wave, and Lesotho and South Africa reported highest average mortality rates during the second waves. Eswatini also reported a lower CFR in its third wave than in its second. Possible explanations for those patterns include development of natural immunity to severe disease (*4*), improved outbreak response and service delivery (*38*), or incomplete data analysis because the third wave was not yet complete when we collected data.

Declining stringency in adherence to PHSMs in the region likely occurred as governments acknowledged sociopolitical, cultural, and economic context, rather than just epidemiologic data, to determine appropriate restrictions (*39*). Decreasing acceptance of and adherence to PHSMs has been observed in 4 countries in the region, in part because of negative effects on livelihoods and lack of access to health services (*23*). To improve adherence, PHSMs could be introduced, adapted, and lifted based on situational assessments in each country and considering community feedback (*25*,*40*,*41*). Given likely challenges in implementing and enforcing stringent PHSMs in the future, policymakers could consider targeting new measures towards persons at highest risk for severe disease.

On average, 8.1% of the population in the region was fully vaccinated as of September 19, 2021, compared with 46.7 in Morocco, 53.9 in the United States, and 63.6 in Israel (*5*). Vaccine coverage in southern Africa faced challenges including low domestic manufacturing capacity, donations of vaccines near their expiration dates, vaccine hoarding by high-income countries, and low vaccine uptake (*42*,*43*), highlighting the need to expand equitable access to vaccines and regional vaccine manufacturing capacity (*44*). Considering the WHO-recommended target that 70% of the population be fully vaccinated by mid-2022 might be unrealistic for the region (*45*) and likely high SARS-CoV-2 seropositivity (*4*), vaccination campaigns targeting populations in the region at highest risk for death, such as persons who are elderly or have chronic underlying conditions (*46*), might be effective in reducing severe disease and emergence of VOCs (*47*). To expand access to COVID-19 vaccinations, particularly for immunosuppressed persons, some countries in Africa (e.g., Zambia) have integrated COVID-19 vaccination services into existing health delivery platforms and clinics (e.g., HIV clinics); bringing vaccine access closer to home might aid in uptake (*48*).

We used publicly available datasets, each with data quality challenges. The OWID dataset missed some daily reports, so we requested coauthor data validation from country officials and Africa CDC to ensure reliability of the data. However, missing data from OWID limited our ability to compare pandemic waves between countries, especially those outside South Africa. OWID uses date reported, rather than specimen collection date, meaning that waves might have appeared to begin and end later in countries with time lags between testing and reporting. We assumed standard WHO definitions were used for reporting COVID-19 cases and deaths in the OWID dataset. We did not account for changes in test availability and testing strategies over time, which limited consideration of potential differences in those indicators among countries. The GISAID dataset varied in representativeness because some countries submitted very limited specimens, so we reported genomic surveillance results at a country level to highlight variability among countries. The OxCGRT dataset includes safety and control measures mandated by governments but not the extent of adherence to the measures, which might better correlate with transmission. Regional trends might be more influenced by data reported by an individual country, particularly South Africa, which provided most OWID and GISAID data. Our data were also extracted while the third wave was ongoing in the region, although it was declining except in Angola, where the third wave had not yet peaked by September 19, 2021. Despite those limitations, by soliciting data reviews from representatives for each country, reporting results at a country level, and computing regional indicators averaging country rates adjusted for population size and daily variation, we have compiled a reasonable description of the pandemic situation across southern Africa.

By September 19, 2021, southern Africa had experienced 3 waves of COVID-19, almost all first detected in South Africa, and with successively higher reported percentages of positivity, incidence, mortality, and CFRs. Increased incidence and mortality could be partly explained by the emergence of more transmissible SARS-CoV-2 variants and improved testing capacity and surveillance. Increasing CFRs warrants further research and highlights opportunities for strengthening health systems and increasing access to feasible therapeutics for high-risk persons. Testing volume increased across waves but varied by country and remained low compared with resource-rich countries. Genomic surveillance capacity was limited, although South Africa played a key role in supporting other countries. Stringent PHSM implementation declined over time, indicating a decrease in feasibility. Vaccination coverage remained very low; scale-up, especially among high-risk persons, should be considered. Coordinated regional solutions could be considered to strengthen and sustain sentinel surveillance systems, genomic surveillance capacity, risk-based vaccination, and tailored public health mitigation to better detect, prevent, and reduce the severity of future COVID-19 waves and other outbreaks in southern Africa.

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Using Population Mobility Patterns to Adapt COVID-19 Response Strategies in 3 East Africa Countries

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The COVID-19 pandemic spread between neighboring countries through land, water, and air travel. Since May 2020, ministries of health for the Democratic Republic of the Congo, Tanzania, and Uganda have sought to clarify population movement patterns to improve their disease surveillance and pandemic response efforts. Ministry of Health–led teams completed focus group discussions with participatory mapping using country-adapted Population Connectivity Across Borders toolkits. They analyzed the qualitative and spatial data to prioritize locations for enhanced COVID-19 surveillance, community outreach, and cross-border collaboration. Each country employed varying toolkit strategies, but all countries applied the results to adapt their national and binational communicable disease response strategies during the pandemic, although the Democratic Republic of the Congo used only the raw data rather than generating datasets and digitized products. This 3-country comparison highlights how governments create preparedness and response strategies adapted to their unique sociocultural and cross-border dynamics to strengthen global health security.

Border health systems are structured to prevent, detect, and respond to and mitigate the effects of public health events among mobile populations, notably those traveling across international boundaries (*1*). Throughout the COVID-19 pandemic, cross-border air travel and movement over land and water helped drive the international spread of SARS-CoV-2. National and local government agencies, global public health partners, and private sector stakeholders implemented various border health mitigation measures, which included screening at international point of entry (POE) locations and at domestic point of control (POC) locations in communities and priority locations along travel routes to limit the spread of COVID-19 (*2*).

Although data such as volume and destination are available for formally documented travel by plane or cruise ship, informal traveler movement (i.e., by private conveyance or across porous borders) provides less data for analysis and decision making. Scientists and public health practitioners continue to advance the use of social media and mobile phone data to understand mobility (*3*). The products from these analyses are very informative, but the capacity to create them is often not available in the areas affected by the movement. This deficiency of data or access to advanced analytic methods on international mobility limits the capacity of public health authorities to build strategies adaptable to the unique risks of disease translocation within and between countries.

The US Centers for Disease Control and Prevention (CDC) developed the Population Connectivity

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Across Borders (PopCAB) toolkit as a resource for governments and other stakeholders to gather and analyze data about population mobility to inform public health interventions (*4*). In brief, the toolkit provides template guides for focus group discussions (FGDs) and key informant interviews (KIIs), considerations for developing the base maps for participatory mapping, template materials, and techniques for managing and analyzing the data, and training materials on methods for preparing for, implementing, and applying the data from PopCAB activities. CDC can provide the toolkit to countries and partners along with technical assistance, as interested, throughout the process.

The Democratic Republic of the Congo (DRC), Tanzania, and Uganda ministry of health (MOH) offices sought to develop COVID-19 border health surveillance and mitigation measures better adapted to their unique community connectivity and population mobility patterns (*5*,*6*). To address its goal, each MOH, in collaboration with partners, implemented the PopCAB toolkit after adapting the template materials for FGDs and KIIs with participatory mapping to their country context (*7*). These community engagement activities and their associated analyses provided the implementers with a better understanding of population movement patterns. The countries applied the information to improve COVID-19 surveillance, testing, and border health policies. These COVID-19 response-focused PopCAB activities built on previous PopCAB efforts implemented in all 3 countries during the 2018–2020 Ebola virus disease epidemic in eastern DRC (*8*,*9*). We identified lessons learned and best practices by comparing the PopCAB initiatives the 3 MOHs implemented during the COVID-19 pandemic and how they applied the results.

Methods

During May 2020–March 2022, MOH-led teams in DRC, Tanzania, and Uganda used the PopCAB toolkit to inform COVID-19 response strategies. As part of PopCAB, these teams, in collaboration with CDC and implementing partners in DRC and Uganda, conducted FGDs and KIIs with spatially-accurate participatory mapping to gather information about community-level, domestic, or cross-border population movement and connectivity patterns.

To implement PopCAB, teams completed actions across 4 phases: preparation, characterization, visualization, and application. During the preparation phase, the team identified objectives and priority geographic areas or population groups of focus, adapted the PopCAB materials to address the objectives and context, worked with community leadership structures to identify stakeholders to invite to participate in FGDs and KIIs, and defined the timeline of activities. During the characterization phase, the team implemented as many PopCAB FGDs or KIIs as were needed to gather, process, and consolidate qualitative and spatial data. Depending on project objectives, the team could plan sessions around a specific event, such as a religious festival, or an important temporal rhythm, such as weekly during harvest season. To create the spatial dataset from the annotated maps and locations mentioned in the FGDs and KIIs, the teams geocoded each location of interest (LOI). LOIs represented origins, destinations, or locations along domestic and international travel routes, such as markets, health facilities, border towns, or transit towns. In the visualization phase, the team used the data from the characterization phase to identify, analyze, and visualize population movement and connectivity patterns by creating maps and narrative reports that illustrated population movement with respect to the LOI. Finally, the team used the application phase to adapt and improve programs and strategies with the results. Teams repeated these phases to address evolving public health needs, ensuring that they regularly identified opportunities to share experiences and develop plans to improve adapted materials and implementation approaches.

Analyses

We compared the approaches that teams used to design and implement PopCAB. We compared, by country and PopCAB phase, details about the implementation timelines, team compositions, project goals, priority geographic areas or population groups of interest, data collection strategies, analytic approaches, and the application of results. To consolidate information for the comparative analysis, we gathered qualitative, quantitative, and spatial data from project implementation materials and outputs and qualitative data from discussions with the teams. Here, we intend to present a broad overview of PopCAB results from each country, rather than specific details.

Results

During May 2020–March 2022, teams implemented 94 PopCAB events to inform COVID-19 response measures at binational, national, and local government and POE levels (Table 1; Figure 1): 8 in DRC; 24 in Tanzania; 60 in Uganda; 1 binational between DRC and Tanzania in Kigoma, Tanzania; and 1 binational between DRC and Uganda in Kampala, Uganda. Two of the 8 PopCAB events DRC implemented were also binational and conducted during

cross-border meetings with Angola (in Luanda, Angola) and the Republic of Congo (in Kinshasa, DRC). Overall, the PopCAB participants in the 3 countries identified >2,000 unique LOIs through those discussions or associated annotations on the base maps.

Preparation Phase

The national MOH port health director (in Tanzania and DRC) or border health focal point (in Uganda) led the PopCAB teams; their overall goal was to gather information about cross-border

Table 1. Characteristics of FGDs and KIIs implemented in 3 countries for COVID-19 response, May 2020–March 2022*

Country	No. FGD	No. KII	Participants' job responsibilities or expertise	Geographic scale
DRC	6	0	Each FGD event included representation from the various services operating at the points of entry (POE): General Directorate of Migration, General Directorate of Customs and Excise, Border Police, National Border Hygiene Program (PNHF), National Intelligence Agency, naval force, lake police station, traders, truck drivers	All FGDs were implemented at POE; discussions focused on population movement through and around the POE
Cross-border DRC and Angola	1	0	Minister of Health of DRC, the International Health Regulations National Focal Point of each country, Director of epidemiologic surveillance in Angola, and the agents of the services operating at the borders of the two countries.	National-level FGD; discussion focused on cross-border population movement along the entire shared border
Cross-border DRC and Republic of Congo	1	0	The International Health Regulations National Focal Point of each country and the agents of the services operating at the border of the two countries	National-level FGD; discussion focused on cross-border population movement along the entire shared border with a focus on movement between the capitals of both countries
Tanzania	24	0	Each FGD event included an occupational group: Boda boda (motorcycle or bicycle) drivers (4), business persons (2), business women specifically (1), community leaders (2), dhow (wooden boat) operators (1), fishermen (2), healthcare providers (2), pastoralists (4), pastoralists and cattle traders (1), peasants (1), petty traders (1), salt producers (1), security officers (1), tour guides (1)	All FGDs were implemented at the subdistrict or ward level; Discussions focused on population movement into, through, and out of the administrative level 2 unit where the PopCAB event was being held
Uganda	34		Each event included an occupational group of representatives: Boda boda drivers (1), businesspersons (2), community outreach workers (1), community leaders (3), community persons (5), cultural leaders (2), customs officials (2), district leaders (2), health care workers (2), POE volunteers (2), security officers (2), sex workers (1), traders (2), traditional healers (2), transporters (2), truck drivers (2), village health volunteers (1)	FGDs and KIIs were implemented at district, village, or POE levels; discussions focused on population movement into, through, out of, and around the administrative area or local jurisdiction the person(s) represented
		26	Key informants were (persons with the same title represented different jurisdictions) border internal security officer for different border points (3), district internal security officer (2), deputy district internal security officer (1), district health educator (1), district health officer (1), District Police Commander (3), district surveillance focal person (1), herbalist (1), in-charge of immigration (1), liaison officer (1), local council (2), local council of defense (1), division commander (1), resident district commissioner (4), POE team lead for volunteer health screening (1), traditional healer (1)	
Cross-border DRC and Tanzania	1	0	International Health Regulations national focal points of the 2 countries, MOH representatives for border health and surveillance at national and regional or provincial levels of the 2 countries	National-level FGD; discussion focused on cross-border population movement along the entire shared border
Cross-border DRC and Uganda	1	0	Port Health or border health director of each country, IHR national focal point of DRC, representative of the minister of health for DRC, MOH representatives for border health and surveillance at national and district levels of the 2 countries, director and deputy director of Uganda's National Public Health Institute, public health partners	National-level FGD; discussion focused on cross-border population movement along the entire shared border

*DRC, Democratic Republic of the Congo; FGD, focus group discussion; KII, key informant interview; POE, point of entry; PopCAB, Population Connectivity Across Borders.

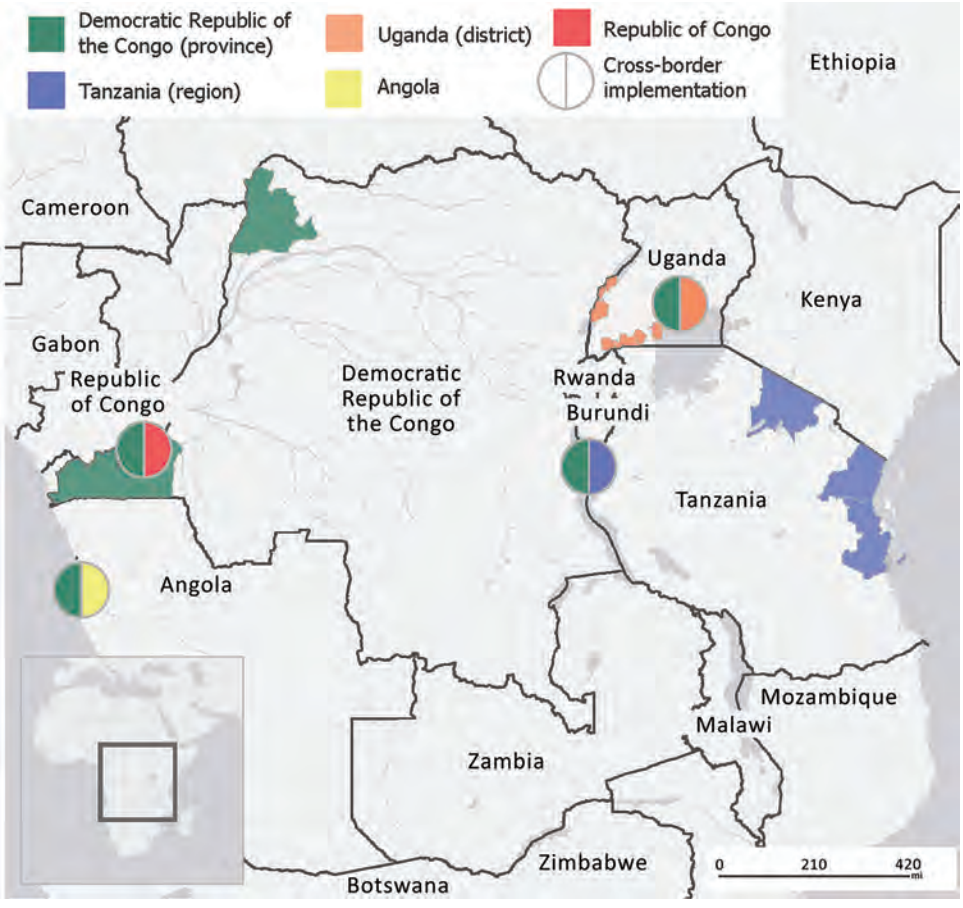

Figure 1. Areas where the Democratic Republic of the Congo, Tanzania, and Uganda ministries of health and their partners implemented Population Connectivity Across Borders events as part of COVID-19 control efforts, May 2020–March 2022.

movement and community connectivity to inform border health strategies (Tables 2–4). Each team also included an International Health Regulations (2005) (*1*) national focal point; MOH national-level port health staff; district-level port health staff where available; government staff with epidemiology, public health surveillance, or emergency operations expertise; and Field Epidemiology Training Program or Field Epidemiology Laboratory Training Program residents. Government leadership for Uganda included the director and deputy director of the National Institute of Public Health. In Tanzania, MOH staff in collaboration with CDC conducted all activities. In DRC and Uganda, the governments led portions of activities independently; the remaining activities were conducted in collaboration with CDC and Africa Field Epidemiology Network; in Uganda, Baylor Uganda, Infectious Diseases Institute, and Rakai Health Sciences Program also supported activities.

The teams implemented their PopCAB activities over 2 years of the COVID-19 response (Figure 2). DRC leveraged previously scheduled staff training, site visits, and cross-border meetings to implement events. In contrast, Uganda and Tanzania implemented PopCAB-focused initiatives to conduct many FGDs and KIIs in a short time. For example, Uganda implemented 30 events in Ntungamo, Isingiro, and Masaka districts near the Tanzania border in May 2020 after a disproportionate increase in COVID-19 cases in the region. Tanzania implemented 24 events in Arusha, Pwani, and Tanga Provinces in July 2020, recognizing the need to adapt COVID-19 response measures for continued cross-border movement and travel. Throughout the pandemic, the DRC border health director incorporated PopCAB events, or orientation to PopCAB, into all cross-border meetings the program joined or hosted. The DRC, Tanzania, and Uganda MOHs shared this accomplishment during bilateral meetings in Uganda with DRC in September 2021 and in Tanzania with DRC in March 2022 (Figures 1, 2).

Across these events, the teams in all 3 countries implemented PopCAB to address a few consistent objectives. One focused on a priority to adapt strategies for surveillance and risk communication at POEs and POCs to limit the spread of COVID-19 across international and domestic administrative boundaries. A

second aimed to enhance public health benefit and judicious use of resources for surveillance and community outreach by identifying and prioritizing specific geographic areas visited by cross-border travelers. A third consistent objective was to prioritize secondary travel routes and areas of interest for mobile populations, including formal and informal POEs, health facilities, and community areas, for enhanced staff training and surveillance. The teams also implemented PopCAB to inform cross-border collaboration. Unique objectives included understanding the influence of COVID-19 lockdown measures on cross-border population movement in Uganda and addressing human activity associated with livestock husbandry in Tanzania.

Characterization Phase

All teams implemented PopCAB events at national and community levels in administrative areas along international borders and in their countries' large urban areas, e.g., Kinshasa, Dar es Salaam, and Kasese. DRC and Uganda also implemented events specifically at POEs; DRC implemented all their community-level events at POEs.

The teams invited various stakeholders to participate in PopCAB events, including security officers, truck drivers, traditional healers, village health volunteers, sex workers, and pastoralists (Table 1). These groups represented not only communities that may move across borders but also those that interact with travelers. Tanzania and Uganda implemented events

Table 2. Components of the Population Connectivity Across Borders preparation phase decisions in 3 countries to inform COVID-19 response measures, May 2020–March 2022*

Component	DRC	Tanzania	Uganda
Implementation lead	MOH, PNHF, International Health Regulations national focal point	MOH Port Health program, International Health Regulations national focal point	MOH Border Health Program, International Health Regulations national focal point, and National Institute of Public Health
Partnerships	CDC, AFENET	CDC	CDC, Baylor Uganda, IDI, Rakai Health Sciences
Team members	National and provincial PNHF staff; FETP residents	MOH national, regional- and district-level officials from Port Health, the Emergency Operations Center, and Surveillance; FETP advisors, and residents	MOH Staff, FELTP mentors, and residents, District-level leadership
Objectives	Identify POE and POC (domestic) for enhanced and adjusted surveillance strategies to limit the spread of COVID-19 across international borders and provincial boundaries Identify specific places and routes of interest with population movement and connectivity patterns that may influence the risk for spread of COVID-19 and other diseases through targeted interventions to enhance public health benefit and judicious use of resources Prioritize locations for enhanced staff training and surveillance Identify secondary travel routes, including in formal border crossing points Identify sociodemographic characteristics of and means of travel among cross-border populations	Identify specific places of interest with population movement and connectivity patterns that may increase the risk for COVID-19 spread and other diseases Tailor interventions to enhance public health benefit and judicious use of resource Prioritize POE, health facilities, and communities for enhanced staff training and surveillance	Tailor border health surveillance strategies for point of entry, informal crossing points, and cross-border communities Modify risk communication strategies for border communities Prioritize POE, health facilities, and other locations for enhanced staff training and surveillance Understand the influence of COVID-19 lockdowns on cross-border movement Identify at-risk areas and populations
Priority geographic areas	Kinshasa, border regions, cross-border environments	Three regions along with Uganda and Kenya border	Western border with DRC, Southern border with Tanzania
Priority population groups	Persons moving across international and domestic administrative borders	Persons moving across borders with an emphasis on pastoralists and movement for animal herding	Mobile populations in general
First implemented for COVID-19 response	December 20	July 2020	May 2020

*AFENET, African Field Epidemiology Network; CDC, US Centers for Disease Control and Prevention; DRC, Democratic Republic of the Congo; FELTP, Field Epidemiology and Laboratory Training Program; FETP, Field Epidemiology Training Program; IDI, Infectious Diseases Institute; PNHF, Programme National d'Hygiène aux frontiers (National Border Health Program); POC, point of control; POE, point of entry; PopCAB, Population Connectivity Across Borders.

Table 3. Components of the Population Connectivity Across Borders preparation phase decisions in 2 cross-border national pairs to inform COVID-19 response measures, May 2020–March 2022*

Component	Binational: DRC and Uganda	Binational: DRC and Tanzania
Implementation lead	DRC PNHF, Uganda MOH	DRC PNHF, Tanzania MOH Port Health
Partnerships	US CDC, AFENET, Baylor Uganda, IDI, Uganda Public Health Fellowship Program	CDC, AFENET
Team members	National and district health and public health leadership	National and district health and public health leadership
Objectives	Identify similarities and differences in prioritized POE and border regions along shared border Characterize cross-border movement to inform cross-border collaboration strategies	Identify similarities and differences in prioritized points of entry and border regions along shared border Characterize cross-border movement to inform cross-border collaboration strategies
Priority geographic areas	Shared DRC and Uganda border	Shared DRC and Tanzania border
Priority population groups	Cross-border mobile populations	Cross-border mobile populations
First implemented for COVID-19 response	September 2021	March 2022

*AFENET, African Field Epidemiology Network; CDC, US Centers for Disease Control and Prevention; DRC, Democratic Republic of the Congo; FELTP, Field Epidemiology and Laboratory Training Program; FETP, Field Epidemiology Training Program; IDI, Infectious Diseases Institute; PNHF, Programme National d'Hygiène aux frontiers (National Border Health Program); POC, point of control; POE, point of entry; PopCAB, Population Connectivity Across Borders.

with persons representing a variety of occupations and responsibilities relevant to a broader geographic scale, such as a district or region. Only Uganda implemented KIIs to gather more information from leadership or to address challenges with gathering multiple representatives for a group of interest, such as traditional healers, security personnel, and medical staff.

Visualization Phase

The countries' teams developed narratives and reports that listed all the LOIs and routes. The reports also described themes from the informal qualitative analyses completed by those who directly conducted the discussions or recorded notes. For example, these reports provided details about cross-border travel patterns to seek care from traditional healers, travel routes community members took when seeking healthcare to conceal residence status, or routes to avoid lockdown policies. The teams included photos of the annotated base maps and photos of participants during the events.

Each team followed a different approach to managing and analyzing the gathered information. The DRC team completed detailed reports rapidly, within 1 week, after each PopCAB event; however, they did not develop qualitative or spatial datasets of LOIs or

Table 4. Comparison of 3 countries' preparation phase decisions for conducting PopCAB to inform COVID-19 response measures, May 2020–March 2022*

Component	Similarities	Differences
Implementation lead	National MOH, Port Health, epidemiology	None
Partnerships	CDC	The Uganda team included many partners, whereas the other countries had teams predominantly or solely composed of MOH staff.
Team members	All countries invited national and district level MOH staff with a variety of expertise, e.g., surveillance, and emergency operations, to support implementation	None
Objectives	All teams implemented PopCAB to strengthen public health and border health systems and resource allocation	While DRC kept the objectives broader, with an interest in informing border health strategies, Uganda and Tanzania included more specific objectives, e.g., inform lockdown measures (Uganda) or explore cross-border animal movement (Tanzania)
Priority geographic areas	Border regions and urban areas visited by cross-border travelers	DRC focused specifically on POE and urban areas, while Tanzania and Uganda focused on administrative jurisdictions, e.g., county, district.
Priority population groups	Cross-border mobile populations	Uganda focused some activities on populations seeking traditional and formal healthcare support across a border. Tanzania focused some activities on populations that live mobile lives, e.g., pastoralists.
First implemented for COVID-19 response	All countries started implementing PopCAB for COVID-19 in 2020	While DRC focused on integrating PopCAB events throughout the pandemic, Uganda and Tanzania implemented intensive PopCAB initiatives at specific times and in specific areas

*CDC, US Centers for Disease Control and Prevention; MOH, ministry of health; PopCAB, Population Connectivity Across Borders.

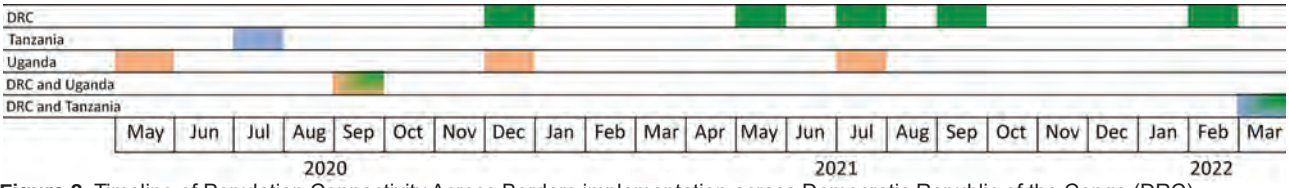

Figure 2. Timeline of Population Connectivity Across Borders implementation across Democratic Republic of the Congo (DRC), Tanzania, and Uganda during the COVID-19 response, May 2020–March 2022.

routes for future visualizations and analyses. They took this approach because they intended to focus on applying results immediately after the discussions and their staff availability to process and manage the data over time was limited.

The Tanzania team developed detailed FGD transcripts after each event to facilitate their ability to integrate and analyze results across multiple PopCAB activities. They also developed, in collaboration with CDC, summary tables listing all annotated LOIs. The Tanzania team worked closely with CDC team members on qualitative data analysis, use of geographic information systems, and cartography to learn new skills in analyzing the qualitative data and geocoding the LOIs. These dedicated data management and analysis efforts led to detailed, formal spatial datasets of the LOIs and routes and initial qualitative thematic analyses. Although a compiled report from each event or group of events took longer to create, the team could use those results to develop improved visualizations for already-defined and future program goals.

The Uganda team focused on developing detailed FGD and KII transcripts after each event, along with detailed summary tables of all mentioned and annotated LOIs and travel routes. This process was supported by dedicated team members who had expertise in qualitative and spatial data management. The team analyzed the qualitative data for themes about reasons and routes for movement. The spatial analysts and cartographers geocoded the results, building robust spatial datasets of >1,000 unique LOIs and routes. The team also combined the results with other data-gathering initiatives completed by partners on the team, including Infectious Diseases Institute and Baylor Uganda, to characterize cross-border healthcare-seeking behaviors.

The data management approaches of Tanzania and Uganda led to the ability to develop more broadly effective reports and presentations. They were able to include visualizations to address various MOH objectives identified during the preparation phase or newly identified during pandemic response initiatives.

Application Phase

All teams used PopCAB results to adapt national, district, and POE-level policies, programs, and resource allocation plans (Table 5). All teams enacted these adjustments using qualitative and spatial information mentioned during the PopCAB events. Despite the different strategies implemented in the visualization phase, all teams continued to use the results from completed events throughout the pandemic. The Tanzania and Uganda teams completed multiple analyses to respond to established and newly identified goals throughout the response, stemming from the approaches they followed to develop robust datasets with the gathered data.

The teams implemented various contextually-specific initiatives using the results to address consistent and unique objectives. The DRC MOH used PopCAB results from FGDs in and around Kinshasa to identify 3 urban locations for new mobile COVID-19

Table 5. Summary of the public health and border health strategies for COVID-19 response adjusted by applying PopCAB results*

Topic	DRC	Tanzania	Uganda
Identify locations or hours of operations for new POE or community-based mobile surveillance sites	X		X
Prioritize locations, e.g., health facilities or villages, for enhanced surveillance and associated staff trainings and resource allocation	X	X	X
Incorporate additional sectors, e.g., market vendors, in COVID-19 outreach and mitigation measures	X	X	X
Modify risk communication strategies by incorporating more contextually-relevant information and locations with cross-border		X	X
Adjust the national response plan to include cross-border population movement considerations	X		X
Tailor border health system lockdown measures			X
Provide provincial and district surveillance and border health officers with data about movement patterns to tailor surveillance	X	X	X
Prioritize cross-border surveillance committees for enhanced action	X	X	X

*PopCAB was performed May 2020–March 2022. POE, point of entry; PopCAB, Population Connectivity Across Borders.

surveillance to increase the ability to detect illness at key traveler congregation points. In addition, the DRC MOH maintained a plan to routinely conduct PopCAB in Kinshasa to guide when and where to adjust the locations of those mobile urban surveillance sites. They also rapidly applied results to extend operating hours for certain POEs to accommodate unique movement patterns identified through the FGDs.

The Tanzania Port Health unit identified areas for increased engagement with village committees and security authorities to strengthen border health surveillance. As part of that effort, they identified community health workers in areas with increased cross-border connectivity in Dar es Salaam and Tanga Provinces and provided them with additional training on event-based surveillance. The MOH also used the data to select high-traffic locations where they enhanced community outreach and installed handwashing stations.

District-level officials in Uganda on the Tanzania border worked with owners of nighttime bars visited by persons from across the border to increase COVID-19 surveillance. The Uganda team also identified mobile phone market vendors that serve cross-border communities to support them in distributing COVID-19 risk communication materials to high-priority population groups. Along that border and the western border with DRC, the Uganda team applied results to identify schools and markets preferred by cross-border communities for enhanced risk communication in preparation for and during the COVID-19 response lockdown. Like Tanzania, Uganda also applied results to identify village health volunteers who worked in areas with increased cross-border connectivity, including those along routes used by persons fleeing conflict from DRC into Uganda, for prioritized refresher training on community-based surveillance.

All of the teams applied the results from the binational PopCAB events during cross-border meetings to prioritize official and unofficial POEs and other LOIs along travel routes across their shared borders for enhanced risk communication and traveler surveillance. They also prioritized groups of contiguous administrative areas in cross-border surveillance zones for more robust and sustained collaboration and information sharing.

Discussion

Throughout the COVID-19 pandemic, the DRC, Tanzania, and Uganda MOHs, in collaboration with CDC and other partners, adapted bilateral, national, and local-level strategies to their complex, cross-border sociocultural contexts by gathering and analyzing community-level information on population movement patterns. Although the countries' MOHs developed implementation goals and plans independently, all 3 followed consistent approaches for developing multisectoral collaboration for participation and applying the results. However, they differed in the intensity of data management and analysis methods, reflecting varying availability of resources including staff time and expertise. Those unique analytic approaches influenced the magnitude of tabulations of locations and routes and qualitative analytical results compiled in formal datasets. Regardless of the depth of analyses, the countries, each with unique COVID-19 epidemiology, border health and public health policies and infrastructure, and cross-border dynamics, provide various examples of ways to incorporate population mobility, a key driver of communicable disease spread, into mitigation measures. Despite differences in data compilation and analysis, their approaches highlight opportunities to achieve impacts across varying staff and financial commitments for creating qualitative and spatial databases.

The teams' experiences revealed challenges with implementing PopCAB overall and during a pandemic. Although the resources needed to implement any one PopCAB event is low, requiring only field travel support and person-time from the implementers and participants to complete the 1.5-hour event in addition to a printed map and supplies such as markers, pens, and paper, leadership had to secure additional funding and person-time to train staff on the toolkit and to process the gathered data. In addition, the teams had to adhere to COVID-19 mitigation measures preventing in-person trainings and field events at different times throughout the pandemic. To address these considerations, the teams designed and employed online training techniques. They also ensured that previously-trained staff participated in subsequent PopCAB implementation over the 2 years with minimal refresher training, introducing a few new staff at a time rather than entirely new field teams. The teams also adjusted field-based protocols to incorporate COVID-19 mitigation measures during FGDs and KIIs, including physical distancing, with only the facilitator annotating the maps, and use of cloth face coverings. Also, highlighted by the DRC MOH's approach, teams adjusted expectations for data processing and analyses to accommodate the available resources.

The teams were not able to attribute trends in COVID-19 epidemiology in their countries to changes they made to mitigation measures and policies using PopCAB data because of the complexity of SARS-CoV-2 translocation among mobile populations and difficulty differentiating travel-associated spread from domestic transmission. However, national MOH leadership overseeing these PopCAB activities expressed confidence that their interventions more appropriately supported their communities because they were adapted to the unique, multisectoral and sociocultural environments and were designed through community-engagement efforts. In addition, district-level leadership participated in the initiatives ensuring continuity of these efforts in local programming and resource allocation decisions.

The 3 governments in East and Central Africa implemented community-engagement efforts using the PopCAB toolkit following various staff-time and data management approaches over 2 years of the pandemic to design COVID-19 mitigation strategies. More specifically, they adjusted public and border health policies and programming to address formal and informal cross-border movement patterns, to enhance surveillance and capacity building at newly identified community-based locations and healthcare facilities, and to strengthen cross-border collaboration between neighboring countries. Those MOH-led, community-based initiatives can complement other analytic methods using existing travel and mobility data to incorporate community dynamics more accurately in border health and other preparedness and response strategies for COVID-19 and other communicable diseases. Furthermore, the MOHs can continue to apply the results to other public health goals, including broader outbreak preparedness strategies and cross-border collaboration priorities. Their experiences reveal options government leadership can follow to integrate population mobility and sociocultural factors into public health preparedness and response strategies.

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Community-Based Surveillance and Geographic Information System–Linked Contact Tracing in COVID-19 Case Identification, Ghana, March–June 2020

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In response to the COVID-19 pandemic, Ghana implemented various mitigation strategies. We describe use of geographic information system (GIS)–linked contact tracing and increased community-based surveillance (CBS) to help control spread of COVID-19 in Ghana. GIS-linked contact tracing was conducted during March 31–June 16, 2020, in 43 urban districts across 6 regions, and 1-time reverse transcription PCR testing of all persons within a 2-km radius of a confirmed case was performed. CBS was intensified in 6 rural districts during the same period. We extracted and analyzed data from Surveillance Outbreak Response Management and Analysis System and CBS registers. A total of 3,202 COVID-19 cases reported through GIS-linked contact tracing were associated with a 4-fold increase in the weekly number of reported SARS-CoV-2 infected cases. CBS identified 5.1% (8/157) of confirmed cases in 6 districts assessed. Adaptation of new methods, such as GIS-linked contact tracing and intensified CBS, improved COVID-19 case detection in Ghana.

The COVID-19 pandemic has elicited various responses to identify and control outbreaks and to save lives. Those responses include improving traditional outbreak investigation methods, enhancing surveillance, and developing vaccines (*1*–*3*). Ghana reported a case of COVID-19 in March 2020 and immediately activated response strategies. As of March 14, 2022, approximately 160,716 cases had been recorded (*4*), and the COVID-19 case-fatality rate was <1% (*5*), probably caused by interventions that were implemented to curb the spread of COVID-19 in this country (*6*).

Mitigation measures were implemented when the first 2 cases were recorded among persons with history of travel to an area experiencing a COVID-19 outbreak. These measures were a nationwide lockdown (*7*,*8*), contact tracing, widespread testing and reporting, and symptomatic treatment. Modern technology, such as use of smart phones to collect data on contacts and use of geographic information system (GIS) techniques in mapping out cases and contacts, were adopted to help improve existing surveillance methods. Subsequent detection of case-patients who did not have a travel history or apparent epidemiologic links to the initial cases, led to increased surveillance activities for early case detection and effective contact tracing at the community level (*7*).

As COVID-19 case-patients were isolated, symptomatically treated, and managed by case management teams, contacts of cases were identified and monitored for symptom development by using a 14-day COVID-19 symptoms diary and the Surveillance Outbreak Response Management and Analysis System (SORMAS) application, an electronic case-based outbreak investigation and response data collection and management tool (*9*). Symptomatic contacts were tested for SARS-CoV-2 and those who were positive were isolated and symptomatically treated.

A media campaign to heighten awareness and knowledge about COVID-19 was implemented across the nation by using radio and television. In periurban and rural areas, community-based surveillance (CBS) activities were also heightened (*8*). Community-based

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surveillance volunteers (CBSVs) were educated on COVID-19, its symptoms, and how to identify and report persons to the appropriate quarters (*10*).

Nevertheless, community transmission increased, and gaps in the SORMAS application and implementation architecture became more evident. Some of these gaps included difficulties in identifying the exact location of contacts and tracing them. As a result, the need for collection of case geolocation data became clear. In addition, unrestricted movement and travel in all other parts of the country also brought out the need for information on COVID-19 to be shared in hard-to-reach areas (*3*).

The routine surveillance focused on case-patients who sought ambulatory care at health facilities and their contacts listed. GIS-linked contact tracing, also known as enhanced contact tracing, is defined as a contact tracing based on spatial mapping of case-patients and contacts, active CBS, and household sampling and testing. GIS-linked contact tracing was implemented on March 31, 2020, in urban areas in Ghana. GIS was used to map documented COVID-19 cases; everyone who lived or worked within a certain distance was considered a possible contact. As an additional way to increase completeness of case identification, CBS was expanded in periurban, rural, and hard-to-reach areas (*6*).

Ghana is a country in West Africa located on the Atlantic Ocean. It shares borders with Burkina Faso to the north, Cote d'Ivoire to the west, and Togo to the east. The country has a population of ≈30 million persons, most (60.4%) of them having the working class ages of 15–64 years (*11*). Because of its rich resources and development, the country has an average influx of 688,944 travelers each year (*12*). The country has a tiered health delivery system. The Ministry of Health serves as the policy directorate, and service delivery is provided through the Ghana Health Service, teaching hospitals, and other public and private agencies under the Ministry. We report the role GIS-linked contact tracing and CBS played in controlling the spread of COVID-19 in Ghana.

Methods

Study Setting and Population

The COVID-19 response in Ghana was implemented through a multisectoral approach with the president of the country leading the response by serving as chair of the Inter-Ministerial Coordinating Committee, a cross-government ministerial body that makes high-level decisions for swift response to the COVID-19 pandemic. The health sector response was led by the Ministry of Health with technical support from the National Technical Coordinating Committee and the National Public Health Emergency Operations Centre.

GIS-Linked Contact Tracing

GIS-linked contact tracing is an advanced form of contact tracing in which mass testing is performed for of all contacts located within a specified distance from confirmed SARS-CoV-2–infected cases. GIS-linked contact tracing was conducted during March 31–June 16, 2020, in 25 of the 29 urban districts starting in the Greater Accra region, which had the highest proportion of cases in the country at the time. GIS-linked contact tracing was extended to 18 of 29 districts in the Ashanti and Eastern Regions during April–June 2020. In those areas, the Global Positioning System (GPS) coordinates of residences and places of employment of case-patients were collected and mapped. Collection and mapping were performed by using an ArcGIS web-based–designed software (https://www.esri.com), which captured the coordinated the home or work location of the case-patient. A 2-km radius around each of the residences of the case-patient was used to define hotspots in which GIS-linked contact tracing would be conducted (*6*). To enable easy identification of persons within the targeted radius, movement within hotspots was also restricted by Security Services of Ghana including the police and military.

Surveillance officers visited households of confirmed case-patients and took GIS coordinates. After GIS was used to map confirmed COVID-19 cases upon identification, all persons who lived or worked within a 2-km radius of the home or work location of a case-patient, regardless of symptoms (*7*) or confirmed close exposure, were identified and considered possible contacts. Because this activity was conducted during the lockdown period, movement was restricted, making persons in the households easily accessible. Surveillance officers visited these households and collected nasopharyngeal specimens from all possible contacts within the demarcated radius and sent to the laboratory for testing by using reverse transcription PCR. Testing of possible contacts was completed within 48 hours after each case was confirmed and details shared with district health directorates.

Clinical specimens collected for SARS-CoV-2 testing were assigned unique barcodes, which were used to link contacts to their test results. GPS coordinates were also collected during specimen collection, and real-time data were generated as specimens were collected and tested. SARS-CoV-2 test results were uploaded into SORMAS by using the assigned barcodes.

For persons who were positive for SARS-CoV-2, these newly identified case-patients were located by using coordinates and telephone details. Persons who were positive for SARS-CoV-2 were picked up by the country's case management team (who came with ambulances and were fully donned in personal protective equipment) and sent to isolation centers for symptomatic treatment. Their close contacts were quarantined in their homes and monitored for 14 days by using the COVID-19 symptoms diary.

Community-Based Surveillance

CBSVs are part of the Ghana Health Service disease surveillance structure and serve as a link between members of the community and the local health facility or district health directorate. They support community surveillance and provide up-to-date information on COVID-19 in the communities.

In rural, periurban, and hard-to-reach areas, COVID-19 cases were identified with the help of the existing CBS health structure. The district health directorate in 6 districts in the Ashanti, Western North, and Upper West Regions intensified activities of CBSVs during May–December 2020 by mobilizing volunteers and educating them about COVID-19, including details on the signs and symptoms of the disease. Those regions had highly active CBSVs who recently reported cases to their respective regions. The CBSVs from 6 districts in the 3 regions then embarked on household visits to conduct COVID-19 education and identify any suspected cases in their communities.

CBSVs identified any suspected COVID-19 case as defined as a person who had ≥1 of the following symptoms within the previous 14 days: fever, cough, shortness of breath, runny or stuffy nose, and headache. CBSVs documented and immediately reported the names of any suspected case-patient to their supervisor and referred the suspected case-patient to the nearest health facility. Name, place of work, place of residence, age, and telephone number of each suspected case-patient were recorded in the CBS register for follow-up, and nasopharyngeal swab specimens were collected from suspected case-patients by the district rapid response teams within 24 hours of identification of the suspected COVID-19 case.

Suspected case-patients were advised to quarantine until their results were made available to the district rapid response team (≈3–4 days). Activities of CBSVs were monitored and analyzed for data completeness and response timeliness on a weekly basis by the district disease control officer to ensure all suspected cases they identified were duly reported to the district. Aggregate CBS register data were reported from the district health directorates to the national level monthly. To assess the contribution of CBS in COVID-19 case detection, we calculated the proportion of cases reported by CBSVs of the total number of cases detected at the district level.

Data Extraction, Management, and Analysis

GIS-linked contact tracing data collected during March–June 2020 describing residential GPS coordinates, date of nasopharyngeal specimen collection, and SARS-CoV-2 test results for cases and contacts in the Greater Accra, Ashanti, and Eastern Region were extracted from SORMAS. The following data were extracted from monthly CBS reports submitted to the national level by the 6 districts during May 2020–December 2020: case-patient place of residence, GPS coordinates, modality of case identification, and test results. All data were cleaned and analyzed in by using Microsoft Excel 2016 (https://www.microsoft.com). Frequencies and proportions of cases detected through routine surveillance and CBS were calculated from both data sources. Heat maps were generated for GIS-linked contact tracing data by using ArcGIS.

Ethics

This activity was part of the national pandemic preparedness response by the Ministry of Health, Ghana Health Service, and in accordance with Act 851 Public Health Act, 2012, Ministry of Health, Ghana. The Ghana Health Service Ethics Review Committee (GHS-ERC 006/05/20) also granted approval for use of data. Data were deidentified before extraction from the national databases to ensure that privacy of cases and contacts was not compromised. Data generated were stored electronically on national servers and password protected and were accessible only by the Ministry of Health, Ghana Health Service.

Results

A total of 3,202 (average 200 cases/week) SARS-CoV-2–infected case-patients were reported through GIS-linked contact tracing during March–June 2020. Approximately 80%–90% of case-patient detected were asymptomatic. Before the GIS-linked contact tracing activity was implemented, the country had identified 193 (average 64 cases/week) positive cases during March 12–31, 2020. The average weekly number of confirmed SARS-CoV-2–infected case-patients increased 4-fold during GIS-linked contact tracing (Table 1).

Through GIS-linked contact tracing, we correctly identified the geolocation of residences of case-patients. With the known location of initial cases, new

Table 1. SARS-CoV-2–infected cases identified through GIS-linked contact tracing, Greater Accra, and Eastern Regions, Ghana, March 31–June 16, 2020*

Modality	Before GIS-linked contact tracing, March 12–30, 2020	During GIS-linked contact tracing, March 31–June 16, 2020
No. contacts of known SARS-CoV-2–infected persons who were reached for SARS-CoV-2 testing	653	86,248
No. SARS-CoV-2 tests conducted among contacts	651	85,463
No. SARS-CoV-2–positive cases identified	193	3,202
Average weekly no. SARS-CoV-2–infected cases identified	74	299

*Source: GHS 2020. COVID-19 sitrep March 2020. GHS, global health system; GIS, geographic information system.

cases were identified near existing cases through mass testing to identify hotspot locations within the region (Figures 1, 2).

Intensified CBS

In the 6 districts in which CBS activities were intensified and assessed, 157 SARS-CoV-2 cases were reported through routine surveillance or CBSVs. These volunteers reported 5.1% (8/157) of all confirmed SARS-CoV-2 cases that were all in hard-to-reach communities (Table 2). In these 6 selected districts, all 157 case-patients detected were followed-up by the district and regional rapid response teams for identification of contacts, contact tracing, and referral to medical care. Most (60%) contacts of case-patients in the district after detection were also followed-up by CBSVs for symptoms monitoring.

Discussion

We report the role that GIS-linked contact tracing and CBS played in detection of COVID-19 cases in Ghana, including asymptomatic cases during the early phase of the pandemic. Those procedures probably assisted in containing the spread of COVID-19 in Ghana. The number of persons who had suspected COVID-19 and were identified for SARS-CoV-2 testing after introduction of GIS-linked contact tracing increased from 63 (average 21/week) to 86,248 (average 5,390/week) persons. The number of positive cases increased from an average of 64 cases/week to

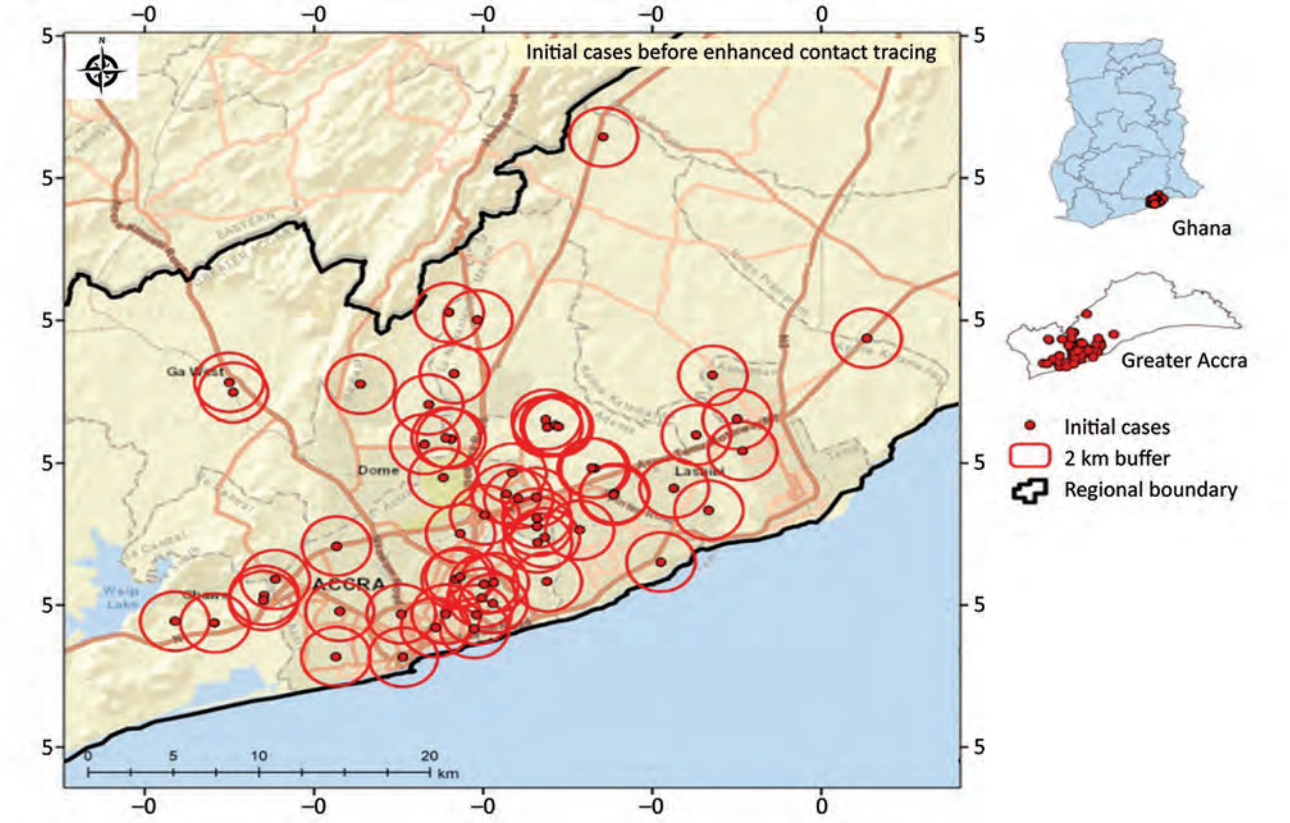

Figure 1. Sample spatial distribution of initial COVID-19 cases defining 2 km buffer around confirmed cases before geographic positioning system–linked contact tracing, Greater Accra Region, Ghana, March 31, 2022. Insets show location of study area in Greater Accra and of Greater Accra in Ghana.

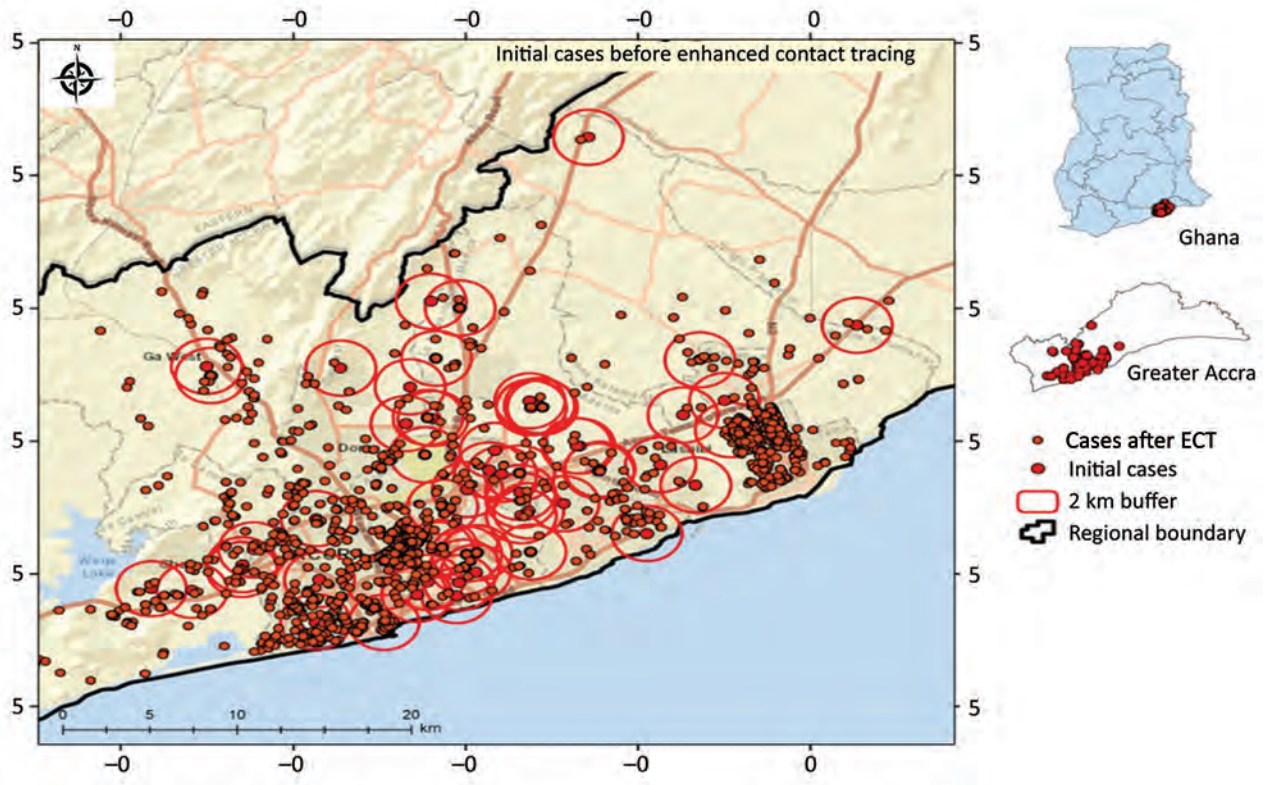

Figure 2. Sample spatial distribution of new COVID-19 cases identified after geographic positioning system–linked contact tracing, Greater Accra Region, Ghana, May 16, 2020. Insets show location of study area in Greater Accra and of Greater Accra in Ghana. Large red circles indicate initial cases, and small red circles indicate cases after ECT. ECT, enhanced contact tracing.

an average of 200 cases/week, and the geographic distribution of the cases was more widespread than before GIS-linked contact tracing was adopted. The GIS-linked contact tracing provided the opportunity to identify other persons who were exposed through community transmission and had SARS-CoV-2 infection develop.

Involvement of CBSVs in tracking contacts of cases during the COVID-19 response might have led to identification of SARS-CoV-2–infected case-patients, which probably would have been missed by traditional facility-based passive surveillance (*13*) because many of these case-patients were asymptomatic (*14*). A large number of case-patients were reached, tested, and recorded outside healthcare facilities as part of CBSVs-assisted and GIS-linked contact tracing and case identification efforts. Timely identification and isolation of cases probably helped reduce further community transmission that would have occurred in the country (*3*).

Despite the positive effect of GIS-linked contact tracing and use of CBSVs, cost implications threaten its sustainability. In Ghana, these implications included shortages of consumables for testing, inadequate human resources to meet the high workload, and other factors such as vehicular challenges. To mitigate some of these setbacks, limited resources were channeled to identify communities with high burden of COVID-19 in which action was needed to contain the spread of SARS-CoV-2 infection.

Table 2. Comparison of SARS-CoV-2–infected persons (cases) identified through routine surveillance and CBS in 6 districts, Ghana, May 1–December 31, 2020*

District	No. cases reported from district	No. cases detected by CBS	Proportion reported by CBS volunteers, %
Amansie Central	60	3	5.0
Bia East	8	1	12.5
Bosome Freho	63	4	6.3
Sefwi Akontonbra	3	0	0.0
Sissala East	7	0	0.0
Sissala West	16	0	0.0
Total of all districts	157	8	5.1

*CBS, community-based surveillance.

The contribution of CBS activities in the hard-to-reach areas and districts far away from hotspot areas demonstrates how their activities helped in preventing community transmission and containment in those districts. CBSVs supported the health system in conducting contact tracing follow-up visits at the community level. Using CBS is a cost-effective strategy for managing community health-related activities because CBS is not given any renumeration. CBS uses persons selected by their communities to offer voluntary services in hard-to-reach areas. Given that 5% of the cases in hard-to-reach areas were identified by CBSVs, including these persons in the health structure is advantageous. To maximize the benefit of CBS, providing targeted training and ensuring that they work closely with health workers in these areas are essential.

Some limitations of this report include the inability to attribute increases in case finding solely to GIS-linked contact tracing or CBSVs because there were also attempts to increase awareness and testing through media. Because spread of COVID-19 also increased over time (despite mitigation and containment efforts), there were generally more persons to find and test. Data loss during the GIS-linked contact tracing implementation period precluded analysis of case-level data. Thus, we are unable to report on indicators such as age, sex, district, and district-specific testing yields. Because GIS-linked contact tracing was implemented in all districts in the selected regions, comparative data during the same period are not available. Despite those limitations, GIS-linked contact tracing and CBS apparently contributed to case finding during the early phases of the COVID-19 epidemic in Ghana. Those 2 response strategies were believed to be crucial to early containment efforts and might have contributed to the slow spread of COVID-19 in participating districts during the first 3 months of the epidemic in Ghana.

Application of enhanced surveillance in Ghana has identified the need to prioritize geospatial data in surveillance activities. Using real-time surveillance to provided specific information during a public health emergency has led to identifying opportunities to build the capacity of surveillance staff in geospatial mapping. Through this approach, a new and improved path for surveillance and response in Ghana has been created. Geospatial data can improve targeted responses in emergency situations leading to better use of limited resources that might be available. GIS-linked contact tracing and community-based surveillance, as part of the overall strategy for combating COVID-19 in Ghana, were beneficial in identification of SARS-CoV-2–infected cases within affected communities, particularly asymptomatic cases that might have been missed by passive health facility–based surveillance approaches.

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The Future of Infodemic Surveillance as Public Health Surveillance

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Public health systems need to be able to detect and respond to infodemics (outbreaks of misinformation, disinformation, information overload, or information voids). Drawing from our experience at the US Centers for Disease Control and Prevention, the COVID-19 State of Vaccine Confidence Insight Reporting System has been created as one of the first public health infodemic surveillance systems. Key functions of infodemic surveillance systems include monitoring the information environment by person, place, and time; identifying infodemic events with digital analytics; conducting offline community-based assessments; and generating timely routine reports. Although specific considerations of several system attributes of infodemic surveillance system must be considered, infodemic surveillance systems share several similarities with traditional public health surveillance systems. Because both information and pathogens are spread more readily in an increasingly hyperconnected world, sustainable and routine systems must be created to ensure that timely interventions can be deployed for both epidemic and infodemic response.

As safe and effective COVID-19 vaccines have become more widely available, vaccine misinformation and disinformation have continued to permeate societies, often at astonishing rates. In fall 2021, nearly 2 years into the pandemic in the United States, 78% of persons believed or were unsure about ≥1 falsehood about COVID-19 or the vaccine (e.g., COVID-19 deaths are exaggerated or vaccines contain microchips), and 32% believed or were unsure about ≥4 falsehoods (*1*). Globally, rumors, stigma, and conspiracy theories about COVID-19 have been pervasive (*2*), and persons can find information about COVID-19 to be conflicting, confusing, and overwhelming (*3*).

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The overabundance of information (accurate or not) that occurs during an epidemic has been referred to as an infodemic and was highlighted as a major threat by the World Health Organization (WHO) (*4*) and the US Surgeon General (*5*). We consider infodemics to include not only the rumors, falsehoods, and conspiracy theories that characterize misinformation (accidental falsehoods) and disinformation (deliberate or engineered falsehoods) but also an information overload of inaccurate or accurate information that can increase susceptibility to misinformation by increasing confusion and mistrust (*6*). Conversely, a lack of high-quality information can also lead to information voids that are rapidly filled by misinformation and disinformation (*7*). Infodemics can spread online through social media and messaging applications, or offline in conversations and through traditional media (e.g., newspapers, television, and radio). Because infodemics can be highly complex, responding to an infodemic requires collaboration across multiple disciplines, including the social sciences, communications, public health, epidemiology, data science, marketing, and clinical services.

Although the effect of infodemics on population health are challenging to measure, the COVID-19 infodemic probably had negative effects on health. Exposure to negative information or conspiracy theories about COVID-19 has been associated with lower acceptability of COVID-19 vaccination in many countries (*8*) and reduced likelihood of adherence to public health guidance (*9*). Effects of the COVID-19 infodemic also extend beyond vaccine hesitancy or delay, including promoting false treatments, creating drug shortages, and eroding trust in public health institutions and government (*2*), all of which can lead to negative effects on healthcare systems, societies, and economies (*10*).

Consequently, public health systems need to be able to detect and respond to outbreaks of misinformation, disinformation, information overload, and

information voids, or any combination of these events. Responding to such outbreaks with public health action is only possible after these events are detected. Building surveillance systems is especially important for ensuring the sustainability of infodemic management activities, because responding to individual events on an ad hoc basis is resource-intensive and does not build preventive capacities for the future. Reactionary ad hoc approaches are not designed to identify harmful information before it becomes prevalent, representing a missed opportunity for organizations to preemptively debunk or "prebunk" harmful information (i.e., build resiliency and fill information voids) before it spreads. Permanent systems ensure that staffing and resource capacities are maintained over time and that preventive actions can be routinely implemented before a new emergency strikes.

The science of infodemic management is nascent, however, and the challenge of building systems can be daunting. In this article, we provide a vision for infodemic surveillance as a core public health function by highlighting our experiences using the COVID-19 State of Vaccine Confidence Insight Reporting System at the Centers for Disease Control and Prevention (CDC).

CDC's State of Vaccine Confidence Insight Reporting System

In response to the COVID-19 infodemic, CDC developed the COVID-19 State of Vaccine Confidence Insight Reporting System to routinely collect and analyze data on the public's questions, concerns, frustrations, and circulating misinformation; these data have been used to produce and disseminate biweekly COVID-19 State of Vaccine Confidence Insights Reports since February 2021 (*11*). The overarching goal is to produce actionable insights that are grounded in data, theoretical frameworks, and an organizational strategy to guide communications content and intervention development. Reports are disseminated to ≈1,000 partners and publicly available on the CDC website. Intended audiences include public health professionals at local, state, federal, and international partner agencies.

The report is generated using a mixed-methods approach to synthesize multiple primary and secondary data sources, including social media, news media, search engine queries, polling data, scientific literature, and direct inquiries from the public submitted to CDC (Table). An iterative consensus-building process is used to analyze the data and identify themes, using a mixed inductive and deductive approach. Themes are grounded in the Behavioral and Social Drivers of Vaccination framework (*12*) and CDC's COVID-19 Vaccinate with Confidence Strategy (*13*), focusing on the identification of the public's concern in alignment with specific topical areas and behavioral and social variables believed to effect vaccine uptake. The themes also draw on the strategy's 3 pillars to craft ways readers can take action, such as building trust, empowering healthcare personnel, engaging communities and individuals, and providing research opportunities.

We prioritized identified themes by using a threat matrix and then classified and color-coded them by risk on the basis of reach, dissemination, and potential effect on vaccine confidence and vaccine uptake. We also characterized each theme by time and labeled it as increasing, decreasing, or stable over multiple reports. The intention of these visual markers is to support the use of these reports as an early warning system for public health action and to provide early detection of acute threats to public safety. For example, we highlighted conspiracy theories regarding ivermectin highlighted as a high-risk, increasing theme (*14*) and reported it more than a month before the CDC health alert warning of an increase in adverse effects from ivermectin misuse and overdose (*15*).

We identified a selection of themes on the basis of volume and potential effect on vaccine confidence. We then complied these themes into a regular biweekly report, which provides summary descriptions and community questions and concerns, frustrations, information needs, and circulating misinformation. We presented descriptors and exemplars of each theme alongside information voids identified and potential ways to act. The report highlights each theme with concrete examples and descriptions for the purposes of informing public health action.

The report is primarily qualitative in nature. Particularly for the purposes of intervention design, the qualitative nature of the report is critical because nuance and context must be considered. Although quantitative measures of pace of transmission (virality) or reach of a message on social media provide value in understanding how far the theme has spread, qualitative description of the identified themes and their context provides valuable information about the nuances of the theme itself and potential reasons why a particular message gained traction and became amplified. For example, understanding the community's specific safety concerns about COVID-19 vaccines (e.g., infertility or thrombosis risks) must be combined with data that report on the prevalence of COVID-19 safety concerns more generally to enable the generation of actionable recommendations.

The first limitation of the CDC State of Vaccine Confidence Insight Reporting System is that report generation is highly labor-intensive and requires a specialized, interdisciplinary team to analyze a large amount of data on a regular basis. The report is generated at a national level, which can limit its usability for practitioners who work at a subnational or local levels. Third, comparing the pervasiveness of themes between different data sources requires a subjective lens; for example, many data sources do not have easily accessible information about reach, impressions, or number of views of individual content. Fourth, because public discourse can change rapidly, publications such as CDC's State of Vaccine Confidence Insight Report must be published as soon as possible, but the dissemination of the findings may be delayed by organizational clearance and approval processes. Finally, as infodemic surveillance remains a nascent

Table. CDC COVID-19 State of Vaccine Confidence Reporting System inputs and sources*

Type and input	Frequency	Sources	Tactics for use
Social media listening and media monitoring			
Communication surveillance report	Daily on weekdays	• Google news • Meltwater • CrowdTangle • Native platform searches	• SOV analysis to identify themes • Emerging topics
Meltwater	Daily	• Facebook, Twitter, Instagram • Blogs • News media • Online forums	• SOV analysis • Emerging theme topics • Identify high reach and velocity topics
CDC's OADC channel COVID-19 postmetrics	Weekly	• Sprout Social • Native OADC account analytics	• Analyze number of posts, topics • Success of messages, number of impressions, reach, number of engagements
OADC channel comment analysis	Daily on weekdays	• Native platform searches	• Sentiment analysis • Identify message gaps and voids
Direct reports			
CDC-INFO metrics	Weekly	• CDC-INFO inquiry line list • PR usage report	• Cross-compare PR usage with inquiry theme analysis • Sentiment analysis • Identify information gaps and voids
VTF media requests	Weekly	• Media request line list	• Leading indicator for news coverage • Identify information gaps and voids
Web metrics	Weekly	• Top pages • Google search queries • Top FAQs • Referring domains	• Identify information gaps and voids, • Identify keywords and search terms, changes in web traffic
Research			
Poll review	Weekly	• Harris, Pew Research, Gallup, and KFF polls • New data related to vaccine hesitancy	• Identify socio-behavior indicators related to motivation and intention to vaccinate
Literature review	Weekly	• PubMed, LitCovid, ProQuest Central, Altmetric • New data related to vaccine hesitancy	• Identify current vaccination intention • Identify barriers to vaccination
Third-party reports			
Tanaq social listening and media monitoring report	Weekly	• Meltwater • Sprout Social • First Draft • Native platform searches	• Trending topics • Demographic and geographic conversation monitoring
CrowdTangle content insights report	Biweekly	• Facebook	• Top pages (voices), groups • General trends and sentiment analysis • News analysis through posts
First Draft News vaccine misinformation insights report	Monthly	• Proprietary methods	• Media trends analysis • Emerging threats and data deficits • Online vaccine narratives
Project VCTR	Weekly	• Proprietary methods	• National and regional trends in negative attitudes toward vaccination • Conversations around Legislation
Virality Project	Weekly	• Proprietary methods	• Misinformation and disinformation trends related to COVID-19 vaccine

*CDC, Centers for Disease Prevention and Control; FAQ, frequently asked questions; KFF, Kaiser Family Foundation; OADC, Office of the Associate Director of Communication; PR, prepared response; SOV, share of voice; VCTR, Vaccine Communication Tracking and Response; VTF, Vaccine Task Force.

science, case definitions, data collection procedures, and reporting processes must be continually refined to better meet the needs of public health agencies and their partners.

Vision and Considerations for Infodemic Surveillance Systems

The CDC State of Vaccine Confidence Insight Reporting System is an infodemic surveillance system in its infancy, particularly when compared with more established public health surveillance systems. Although few other examples of infodemic surveillance systems exist (*16*–*19*), the idea for these systems is not new. Multiple public health experts have pointed out the need for routinized infodemic data systems for the purposes of detecting and responding to infodemics (*20*–*24*). Furthermore, the system can be considered a progression of traditional social media and news monitoring because additional data are included to focus on the concerns and perceptions of the general public, and programmatic recommendations and research opportunities are generated beyond focusing on communication strategies alone (*25*,*26*). We propose 4 key functions of an infodemic surveillance system.

Key Functions of an Infodemic Surveillance System

Monitoring the Information Environment by Person, Place, and Time

Identifying trends and patterns of misinformation, disinformation, information voids, perceptions, and questions of public health concern over time is critically important because the goal is to detect infodemics and respond quickly and effectively with public health action. An early warning system, for example, might detect an acute rise in misinformation that could be addressed through community engagement and targeted and tailored communications.

Using Digital Media Analytics to Identify Infodemic Events

Worldwide, most persons now regularly use social media or messaging apps (e.g., WhatsApp, Instagram, Facebook, Wechat, Douyin, and TikTok) (*27*), and the prevalence of health misinformation is high in online spaces (*28*). Data collection systems that focus on social media, websites, and other online content may provide an opportunity to assess the incidence and prevalence of misinformation, disinformation, or information gaps, although the data are not always accessible by governments or researchers, and analysis requires specialized expertise.

Conducting Offline Community-Based Assessments

Ideally, infodemic surveillance systems should not rely only on analyses of digital media. Many persons lack access to the internet, even in high-income countries (e.g., 15% of persons in the United States do not own a smartphone) (*29*). Digital analytics do not capture experiences lived offline, and persons increasingly communicate using direct messaging apps that do not have data readily available for researchers (e.g., dark social media, including text messages, email, WhatsApp, or Wechat) (*30*,*31*). Offline assessments could include regular surveys, polls, focus groups, observations, or rapid qualitative assessments.

Generating Timely Routine Reports to be Used by the Public Health Community.

Infodemic listening data can be complex, so infodemic surveillance requires both an integrated analysis of online and offline data sources and a synthesis of quantitative and qualitative data with public health judgment. Infodemic surveillance systems must create timely reports that are usable by public health authorities to design and implement interventions rapidly in both routine and emergency settings. These reports must also be timely because the advent of the internet and social media specifically have enabled rapid communication that can quickly shift as new topics and concerns dominate the public discourse.

These 4 functions highlight important commonalities with traditional public health surveillance systems. Defined as "the ongoing systematic identification, collection, collation, analysis and interpretation of disease occurrence and public health event data, for the purposes of taking timely and robust action" (*32*), many public health surveillance systems have functions that extends beyond laboratory detection of disease. Event-based surveillance systems, for example, includes media monitoring to identify stories, rumors, or other information reported from the community for the detection of outbreaks or other events of public health importance (*33*), as found in systems like the WHO's Epidemic Intelligence from Open Sources initiative (*34*). The Behavioral Risk Factor Surveillance System in the United States uses surveys to collect data about risk behaviors (*35*). Infodemic management systems should be considered as public health surveillance systems that similarly rely on media monitoring and surveys and share the goal of monitoring trends and patterns over time to inform timely action by public health authorities.

More important, both infodemic and traditional public health surveillance systems are reliant on

epidemiologic thinking. Critics might highlight that traditional public health surveillance seeks to detect disease, whereas infodemic surveillance systems fundamentally seek to detect ideas. However, the core concepts of person, place, and time are as valuable for understanding the transmission of ideas throughout a population as they are for disease. Epidemiologic models of idea transmission have long been used in fields including the evolutionary behavioral sciences and gene-culture coevolutionary theory (*36*) and have been applied specifically for the COVID-19 pandemic (*37*,*38*).

Consequently, many of the key characteristics of a traditional public health surveillance system will apply for an infodemic surveillance system. Infodemic surveillance could be active or passive, event-based or indicator-based, and would need to be designed based on both capacity and needs of the public health authority. Traditional evaluation frameworks (e.g., simplicity, flexibility, data quality, and acceptability) for surveillance systems are also largely transferrable (*39*). In contrast to traditional public health surveillance, however, we offer a few key considerations of public health surveillance system attributes with specific applications for infodemic surveillance systems.

Considerations of Public Health Surveillance System Attributes with Specific Applications for Infodemic Surveillance Systems

Case Definitions

Traditional public health surveillance relies on quantitative metrics and well-established epidemiologic concepts, such as incidence and prevalence. Although similar metrics for infodemics have been proposed (*23*), their usage is nascent and global experience limited, and many of the existing tools are borrowed from marketing for the purposes of brand management rather than for public health investigation. Further complicating this situation is the fact that, unlike traditional public health surveillance, recognizing an infodemic requires an understanding of discourse and meaning; quantitative consumption metrics of a single online post, for example, are only useful if the meaning of the post and the populations involved are also understood. Contextual information is also important in determining the degree of urgency in response. A subjective, qualitative, and interpretive lens is essential for infodemic surveillance, but integrating this subjectivity into more objective measures of the rate of spread of misinformation and disinformation needs further development to ensure their utility for health programs.

Timeliness

Although timeliness is an important feature for all public health surveillance systems, it is critically important for infodemic surveillance. Information can be transmitted faster than infectious diseases because information lacks an incubation period and is consumed with the click of a mouse or tap of a finger. Infodemics are highly dynamic and change rapidly, and surveillance systems must be able to detect and respond at a similar pace.

Resolution of Place

In descriptive epidemiology, place refers to the geographic variation of disease and may refer to either specific locations (e.g., countries or counties or hospitals) or place categories (e.g., urban or rural). Although many in public health are more comfortable with country-level data (e.g., national surveys of knowledge, attitude, and practice), surveillance systems must consider their ability to focus on specific places to ensure that the geographic level of analysis for the data outputs match the geographic level of feasible interventions. For example, if intervention resources become available for a specific region or subpopulation of interest, the ability of surveillance systems to focus on those specific regions or subpopulations would greatly help inform intervention design. However, technical limitations exist, especially because many online data sources aggregated by regions or subpopulations are not readily available. In addition, communities identified may not be geographically clustered but exist in virtual spaces where interventions may need to be implemented virtually.

Personnel

The interdisciplinary nature of infodemics requires expertise from multiple fields of research, including the social sciences, communications, social media marketing, and public health. Surveillance systems need to be supported by both human technical capacity (e.g., infodemic managers) and institutional capacity (e.g., budgets and organizations).

Information Systems

Surveillance systems often appear simple on the surface but require substantial infrastructure. Data sources need to be established, incoming data must be analyzed, and users have to receive the data to take action. Each individual step requires considerable coordination, formalized partnerships, political will, organizational infrastructure, and resources.

Integration and Coordination.

International standards for surveillance systems emphasize the importance of harmonizing resources and working together to use methods efficiently (*32*). Because infodemic surveillance is a relatively new activity for public health, however, new units probably need to be created on organizational charts and relationships formed between departments that previously did not exist to ensure that any data generated is acted on. Responding to an infodemic event may require new partnerships, including subnational or local public health authorities, as well as collaborations with technology sectors, media companies, and fact-checking organizations.

Legality, Privacy, and Ethics

Although traditional public health surveillance uses more objective diagnostic criteria, infodemic surveillance requires some subjectivity and raises ethical questions. Regarding misinformation, for example, who determines whether something is factually accurate and what policies would be applied? What is the role of public health authorities as arbiters of truth? Societal concerns regarding individual freedoms of expression must be considered, as well as the fact that information often changes rapidly and what is considered factually accurate may change over time. Additional considerations exist concerning the collection of private data or data that persons perceive as private. For example, social media has made it easy to join private groups and follow individual persons who might not make their social media posts publicly available, but there are ethical considerations when doing this while not presenting oneself as a member of a public health organization.

Although those key considerations require careful deliberation when new systems are established, none are insurmountable. In fact, the same considerations are also present in traditional public health surveillance systems, although the nuances and importance of each consideration might be different in the context of infodemic surveillance. Those considerations are critically important to ensure that infodemic surveillance systems can serve as early warning systems for public health response. Within the pandemic setting, potential responses may include not only countering misinformation and crisis communication but also fighting stigma, addressing mental health, and providing psychological preparedness (*40*). Early detection and response is especially important to address inequities in the public health response and help minimize disparities as much as possible; for example, addressing misperceptions on whether undocumented persons are eligible for vaccinations or testing (*41*). These actions can only be taken, however, after an infodemic has been detected.

Although infodemic surveillance activities may be intensified during a pandemic or outbreak response, infodemic surveillance systems would be equally important in routine nonemergency settings. Infodemics affect health behaviors outside of vaccines and infectious diseases, including nutrition, cancer, and diabetes (*42*). Misinformation about e-cigarettes and vaping products circulating misinformation on social media channels popular with teens, for example, has strongly affected teenagers (*43*). Tracking and understanding these infodemics through routine infodemic surveillance systems is a critical first step toward designing interventions to promote population health. By building trust and information literacy, routine infodemic surveillance systems can potentially prevent severe infodemics that might accompany future outbreaks and emergencies.

Conclusions and Opportunities

Based on the experience of developing and deploying the CDC State of Vaccine Confidence Reporting System, this article presents a vision for the future of infodemic surveillance systems. Although there are many similarities to traditional public health surveillance systems, we have highlighted several key considerations that require careful deliberation when establishing and evaluating infodemic surveillance systems. Evaluation is particularly important to establish scientific rigor for infodemic surveillance systems and further develop evidence-based practices within infodemic management.

It is also important to recognize that the fundamental idea of infodemic surveillance systems is not new within public health. The WHO Technical Guidelines for Integrated Disease Surveillance and Response in the WHO African Region, for example, includes language highlighting the importance of understanding public perceptions and deploying surveys, interviews, and social media monitoring (*32*). The WHO Joint External Evaluation tool, used regularly by countries to assess public health capacity, includes a risk communication technical area where countries receive maximum scores for the presence of a "strong system for listening and rumour management on a permanent basis which is integrated into the decision-making and response actions" (*44*). Communication and media monitoring have also been previously conducted in outbreak settings (*25*,*26*).

Despite those efforts, however, such activities are typically not perceived as part of routine public health

surveillance. Although we have highlighted the differences between traditional and infodemic surveillance, their similarities greatly outweigh the differences. As sharing both information and pathogens spreads more readily in an increasingly hyperconnected world, sustainable and routine systems must be created to ensure that timely interventions can be deployed for both epidemic and infodemic response.

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Continuing Contributions of Field Epidemiology Training Programs to Global COVID-19 Response

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We documented the contributions of Field Epidemiology Training Program (FETP) trainees and graduates to global COVID-19 preparedness and response efforts. During February–July 2021, we conducted surveys designed in accordance with the World Health Organization's COVID-19 Strategic Preparedness and Response Plan. We quantified trainee and graduate engagement in responses and identified themes through qualitative analysis of activity descriptions. Thirty-two programs with 2,300 trainees and 7,372 graduates reported near-universal engagement across response activities, particularly those aligned with the FETP curriculum. Graduates were more frequently engaged than were trainees in pandemic response activities. Common themes in the activity descriptions were epidemiology and surveillance, leading risk communication, monitoring and assessment, managing logistics and operations, training and capacity building, and developing guidelines and protocols. We describe continued FETP contributions to the response. Findings indicate the wide-ranging utility of FETPs to strengthen countries' emergency response capacity, furthering global health security.

Field Epidemiology Training Programs (FETPs), modeled on the Epidemic Intelligence Service (EIS) of the US Centers for Disease Control and Prevention (CDC), are competency-based training programs designed to strengthen national and regional health security infrastructure and enhance the epidemiologic capacity of the public health workforce (*1*–*3*). FETP expands on the EIS model with 3 tiers of training of increasing duration and complexity: 3–4 months of frontline, 5–9 months intermediate, and 2 years of advanced training (*1*,*4*,*5*). The Global Health Security Agenda (GHSA) was launched in 2014 to strengthen countries' capacities for detection, response, and prevention of public health threats and to accelerate progress toward meeting the World Health Organization (WHO) International Health Regulations 2005 (IHR 2005) targets (*6*,*7*).

The COVID-19 pandemic highlighted global vulnerability to infectious-disease threats. The widespread and sustained response it required further emphasized the need for strengthened field epidemiology workforce capacity across all regions and levels of public health systems. Although recent reports feature FETPs' response to COVID-19 (*8*–*10*), a need for global-level documentation remains. We sought to document and characterize the contributions of FETP trainees and graduates to COVID-19 preparedness and response around the globe at 13 months into the global pandemic.

Study Design and Methods

We conducted and presented findings from our first survey of program directors of FETPs around the world in March–April 2020 (*11*); we conducted a second survey of program directors during February–April 2021. Those surveys included questions about which tiers of FETPs were implemented and about the engagement of program trainees and graduates in COVID-19 response activities categorized according to the COVID-19 Preparedness and Response Plan's 10 strategic pillars (*12*) (Table 1). The pillars are the following: pillar 1, country-level coordination, planning, and monitoring; pillar 2, risk communication and community engagement; pillar 3, surveillance, rapid response teams, and case investigation; pillar 4, point of entry; pillar 5, national laboratories; pillar 6, infection prevention and control; pillar 7, case management; pillar 8, operational support; pillar 9,

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Table 1. Ten pillars of the World Health Organization Strategic Preparedness and Response Plan for COVID-19*

Pillar no.	Public Health Preparedness and Response area
1	Coordination, planning, financing, and monitoring
2	Risk communication, community engagement and infodemic management
3	Surveillance, epidemiologic investigations, contact tracing, and adjustment of public health and social measures
4	Points of entry, international travel and transport, and mass gatherings
5	Laboratories and diagnostics
6	Infection prevention and control, and protection of the health workforce
7	Case management, clinical operations, and therapeutics
8	Operational support and logistics, and supply chains
9	Maintaining essential health services and systems
10	Vaccination

*As of February 2021. Source: World Health Organization (*11*).

maintaining essential health services and systems; and pillar 10, vaccination (against COVID-19). Pillars 9 and 10 were added to the original 8 (*13*). We asked each program director for the total number of graduates and current trainees in their program. We asked if persons in any stage of their FETP training (trainees) or those who successfully completed their graduation requirements (graduates) or both were engaged in response activities and asked for brief descriptions of those activities.

We distributed invitations to respond to the online SurveyMonkey (Momentive Inc., https://www.surveymonkey.com) survey to 92 FETP program directors via email in February 2021 in coordination with the Training Programs in Field Epidemiology and Public Health Interventions Network (TEPHINET), a global network of FETPs. If a program director had responded to our first survey in 2020, they were asked to report on the activities conducted since that submission. If a program director had not responded to the first survey, we asked them to report on all the activities in which FETP trainees or graduates had engaged for COVID-19 preparedness or response. We followed up on incomplete or duplicate responses by email or telephone calls with respondents during April–July 2021 to complete or reconcile responses.

Quantitative Analysis

We mapped the responding programs to describe the geographic distribution. We analyzed selected characteristics of responding programs: years between the establishment of the program and July 2021, and days between the report of the first case of COVID-19 in the country and the date of survey response. We calculated medians and reported minimum and maximum values aggregated by WHO region. We tabulated responses and calculated by WHO region and WHO pillar percentages of programs reporting FETP trainee or graduate engagement in COVID-19 preparedness or response activities by using Microsoft Excel (Microsoft, https://www.microsoft.com).

Qualitative Analysis

Four team members conducted content analysis on qualitative responses using MaxQDA (VERBI Software, https://www.maxqda.com). Each analyst reviewed the original codebook used for the qualitative analysis of the responses to our first survey (*11*). After reviewing all responses, we updated the codebook to reflect novel responses, new codes, new themes, and the activities corresponding to the 2 new response pillars. The 4 staff met weekly to reach consensus on new codes, consolidate codes, and identify themes across the 10 WHO pillars with appropriately illustrative quotes. Some survey respondents answered in their primary language; bilingual CDC staff translated responses in French, Portuguese, and Spanish, and we used Google Translate (https://translate.google.com) for responses in Ukrainian and Chinese.

Results

Quantitative Findings

Of 92 program directors invited to the survey, 32 (35%) responded, reporting on COVID-19 preparedness and response activities in 69 countries across all WHO regions (Figure 1, panel A). Thirty of the respondents represented national programs and 2 represented regional programs, 1 serving 24 countries in the Caribbean (Americas region, Pan American Health Organization [PAHO]), and the other 19 countries covered by the WHO Regional Office for the Eastern Mediterranean (EMRO). Four programs in Belize, Haiti, Egypt, and Ukraine implemented training nationally but were also served by a regional program. Of the 32 responding programs, 17 (53%) were implementing frontline training as well as advanced, intermediate, or both tiers; 6 programs were implementing all 3 tiers of field epidemiology training. Among responding programs, 4 (13%) were implementing frontline only.

Half of the programs that responded to this survey were ≥10 years old, and nearly all were in countries

in which the earliest known COVID-19 case was ≥1 year prior (Table 2). Only the 4 reporting programs in the PAHO region had yet to surpass the 1-year mark between the earliest reported case of COVID-19 and responding to this survey. Programs <5 years old from 3 WHO regional offices responded; those countries were Burkina Faso (Regional Office for Africa [AFRO]), Ukraine (Regional Office for Europe [EURO]), and Afghanistan and Somalia (EMRO). Of note, the Somalia FETP established frontline training in 2021, during the COVID-19 pandemic. The 32 programs reported a combined total of 2,300 trainees and 7,372 graduates.

All 32 responding programs reported engagement of FETP trainees and graduates in all pillars of WHO response activities. The most frequently reported pillars of engagement for trainees or graduates, in order of decreasing frequency, were WHO pillar 3, surveillance, rapid response teams, and case investigation; pillar 1, coordination, planning, financing, and monitoring; pillar 2, risk communication and community engagement; and pillar 4, points of entry (Figure 2). Engagement of FETP trainees or graduates variable in activities corresponding to pillar 5, national laboratories; pillar 7, case management; pillar 6, infection prevention and control; and pillar 8, operational support (Figure 3). More programs reported engagement of graduates than reported engagement of trainees in response activities. Most evident of this trend were reports of engagement in activities of pillar 8, operational support and logistics; pillar 7, case management; and pillar 9, maintaining essential health services and systems. Notable exceptions to the more frequent engagement of graduates than trainees were in the EMRO region, where programs reported more trainees than graduates engaged in pillar 3, surveillance, response teams and case

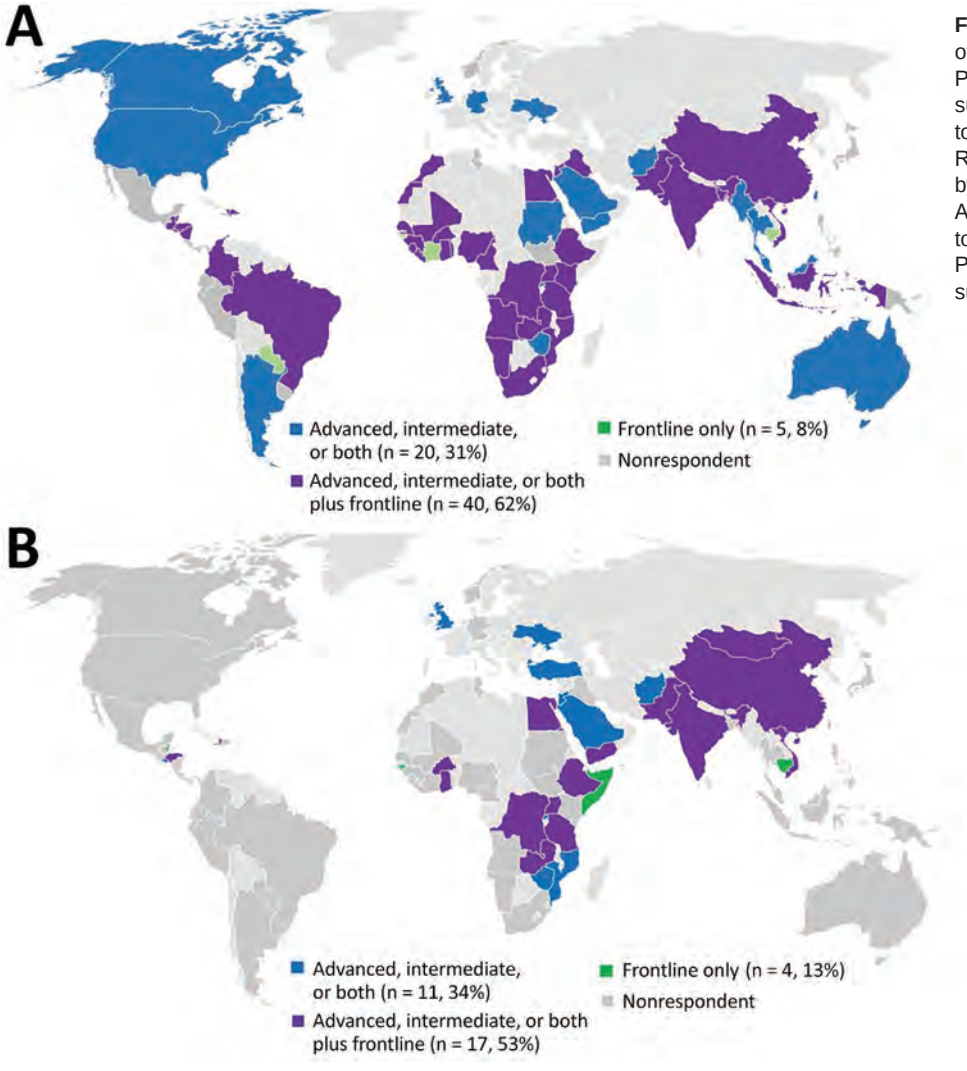

Figure 1. Geographic distribution of Field Epidemiology Training Programs invited to respond to a survey about their contributions to global COVID-19 response. Responding programs are identified by the tiers of training implemented. A) Programs invited to respond to the 2021 survey (n = 92). B) Programs invited to the 2020 survey (n = 88; Hu et al. [*10*]).

Table 2. Selected characteristics of the Field Epidemiology Training Programs that responded to surveys about COVID-19 response, 2020–2021*

	This study			Survey 1†		
WHO regional office	No. reporting country programs (no. invited)	Median age of program, y (range)	Median days since first reported COVID-19 case in country (range)‡	No. reporting country programs (no. invited)	Median age of program, y (range)	Median days since first reported COVID-19 case in country (range)‡
Africa	11 (30)	11 (3–28)	405 (322–491)	24 (27)	8 (2–27)	19 (3–35)
Eastern Mediterranean	7 (12)	15 (0–32)	414 (376–508)	9 (11)	10 (1–31)	33 (14–51)
Europe	4 (9)	9 (3–10)	446 (411–498)	6 (9)	11 (2–25)	47 (23–52)
Americas	5 (21)	20 (10–20)	340 (330–399)	15 (22)	19 (3–69)	27 (11–74)
Southeast Asia	1 (6)	20 (20–20)	448 (448–448)	5 (7)	19 (2–40)	34 (16–74)
Western Pacific	4 (14)	11 (10–20)	425 (407–565)	6 (12)	18 (9–36)	73 (56–105)
All programs	32 (92)	11 (0–32)	412 (322–565)	65 (88)	11 (1- 69)	25 (3–105)

*One regional program in Europe and 1 in the Americas were excluded from calculation of days to survey response since first COVID-19 case was reported. Refer to Table 1 for numbers in each region by survey.
†Survey 1, Hu et al. (*10*).
‡Regional programs serving multiple countries and four programs (Guinea-Bissau, Mozambique, Sierra Leone, and Yemen) that responded to the survey before the first COVID-19 case was reported in their country were not included in the calculation of days to survey response since first COVID-19 case was reported.

investigations; in the AFRO region in pillar 6, infection prevention and control activities; and in the EURO region in pillar 7, case management. Although pillar 9, maintaining essential health services and systems, and pillar 10, vaccination, were introduced in the updated WHO response plan of February 2021, ≥25% of programs reported that trainees and graduates were involved in activities of these new pillars (Figure 4).

Qualitative Findings

Six themes emerged during content analysis that illustrate the contributions of FETPs to COVID-19 preparedness and response a year into the pandemic (Table 3). We identified these themes from the activity descriptions across multiple WHO pillars.

Theme I: Epidemiology and Surveillance

Respondents commonly described epidemiologic and surveillance activities. This quote from Ethiopia captures the myriad ways FETPs are used: "Residents [i.e., trainees] are involved in case investigation […] and outbreak investigation, school reopening preparedness assessment. The graduates report surveillance data to the next level and analyze and report trends of diseases. They provide orientations to surveillance focal persons on the reporting mechanism, case definitions, reporting formats, and investigation procedures. Residents and graduates have supported serosurveillance and [severe acute respiratory infections] sentinel site surveillance at hospitals." Several programs across the regions also reported that their trainees or graduates assisted in the development of the standard case definition for COVID-19 and led healthcare-associated infection investigations.

Theme II: Leading Risk Communication

When reporting on trainee and graduate risk communication activities, commonly reported work was medium-specific (staffing call centers, providing press interviews, posting on social media, etc.) or target population-specific messaging (healthcare workers, travelers, administrative officials, etc.). In Rwanda, "Advanced graduates provided radio and television interviews to disseminate public health messages." In Egypt, trainees "[developed] timely and transparent communication messaging and materials for public regarding COVID-19 enquiries" and graduates "[developed] and updated the risk communication strategy, […detected] and quickly respond to misinformation and rumors." Graduates were more commonly involved in the development of strategic planning or liaising with government officials—especially those who are employed at the ministry of health—whereas trainees were more frequently reported to be involved in direct interfacing with the public through public hotlines and social media. Graduates in Burkina Faso conducted "COVID media training [and] sensitization of leaders (community, religious and political) on COVID."

Theme III: Monitoring and Assessment Activities

FETPs supported infection prevention and control activities for public and private institutions such as schools and companies (in Tanzania and Rwanda), risk assessments for healthcare facilities and schools (in India, Ethiopia, and Zimbabwe), and "monitoring and audit of infection prevention and control practices and feedback at hospital level" (in Egypt).

Graduates in El Salvador worked on event-based monitoring. Both graduates and trainees in Turkey

and Ukraine monitored case numbers, surveillance data, and laboratory testing data to evaluate surveillance methods. In India, the COVID-19 vaccine rollout also provided opportunities for graduates to conduct "[monitoring] and supervision [of] vaccine rollout in states" and do "field monitoring of surge staff."

Theme IV: Managing Logistics and Operations

FETPs trainees and graduates managed logistics and operations at all levels, from testing and sampling to vaccine supply chain management, liaising between different institutions, and organizing staff deployments. In Zimbabwe, graduates worked on "adopting and disseminating SOPs [Standard Operating Procedures]… for specimen collection, management, and transportation for COVID-19 diagnostic testing."

Theme V: Training and Capacity Building

FETP trainees and graduates were heavily involved in efforts to train and build COVID-19–related response capacity across sectors and levels of society. The data showed that from the community level (such as in Uganda, where graduates conducted "training of village health teams of community-based health surveillance") all the way to the national and state levels (as in India, where trainees and graduates conducted "cascade training of national and state level officials on IPC [Infection Prevention and Control]"), their expertise was widely required. Programs reported their participation in training for the following response-related activities: point-of-entry screening, infection prevention and control at healthcare facilities and in the community, case management, specimen collection, and the incident management system.

FETP trainees and graduates served as trainers for vaccine-related rollout activities. They contributed to training on cold-chain standards (Rwanda), training healthcare workers on how to administer the vaccine (Jordan); and "training on abnormal response monitoring," also known as adverse events monitoring (China).

Theme VI: Developing Guidelines and Protocols

FETP trainees and graduates were engaged in developing guidelines and protocols. They developed standard operating procedures and participated in national-level strategic planning, particularly for the preservation of essential health services and vaccine rollout. Their wide participation in vaccine-related planning was illustrative, as in this example from China: "FETP participants were integrated into the National Immunization Centre Vaccine Task Force to participate in the Vaccination Information Group." Drafting case-management guidelines were also reported by many programs, such as in Jordan where both graduates and trainees "[established] guidelines to deal with suspected

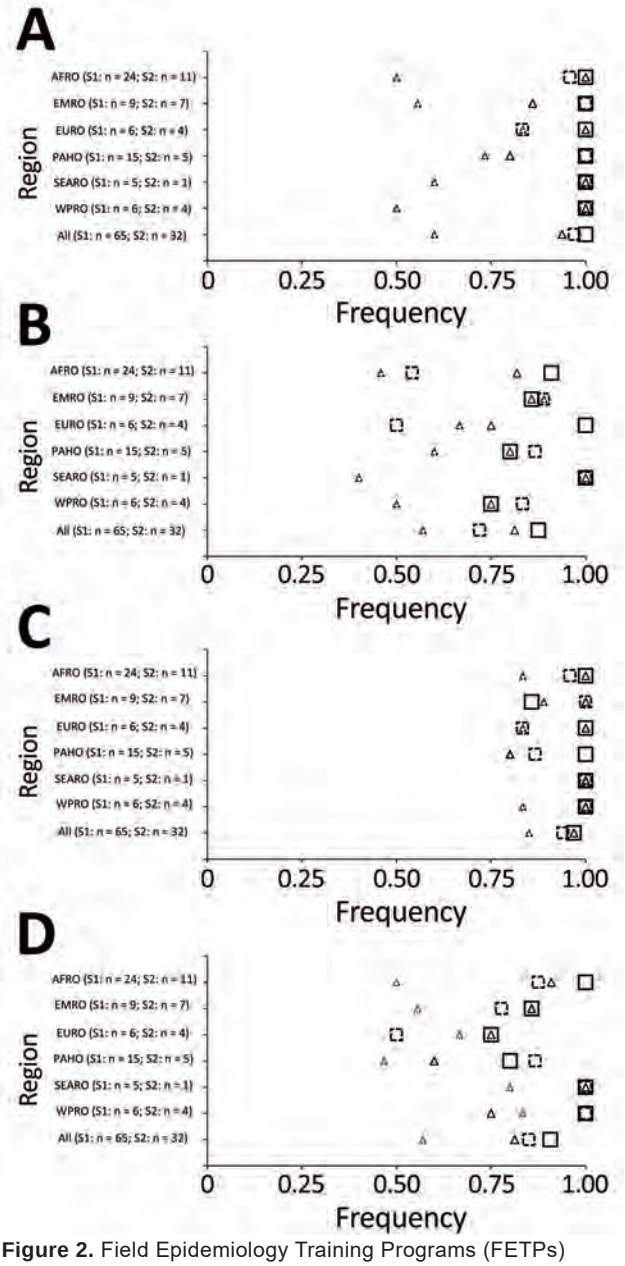

Figure 2. Field Epidemiology Training Programs (FETPs) reporting trainee or graduate support to COVID-19 preparedness and response by WHO response pillar and WHO regional office (AFRO, Africa; EMRO, Eastern Mediterranean; EURO, Europe; PAHO, Americas; SEARO, Southeast Asia; WPRO, Western Pacific). Programs indicating engagement of FETP trainees, graduates, or any FETP involvement (trainees or graduates) are shown. A) Pillar 1, country-level coordination. B) Pillar 2, risk communication and community engagement. C) Pillar 3, surveillance, response teams, case investigations. D) Pillar 4, points of entry. S1, survey 1; S2, survey 2; WHO, World Health Organization.

cases coming to Jordan and confirmed as well" and "were responsible for updating the management guidelines as soon as it needed and follow up [on] admitted cases."

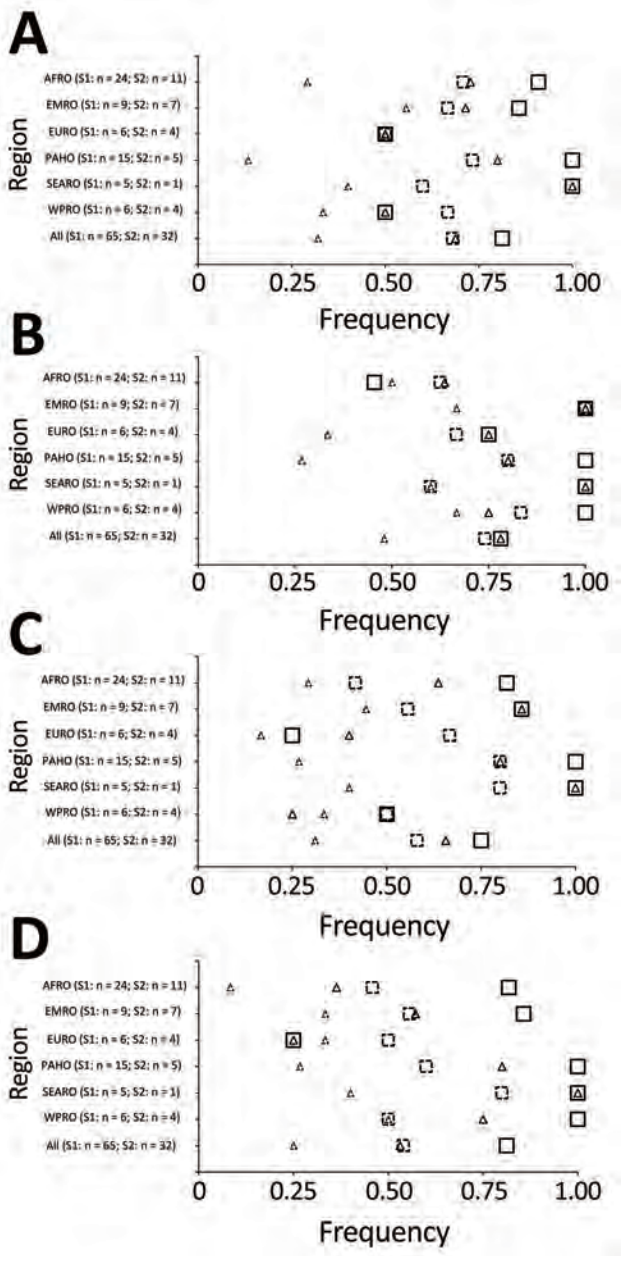

Figure 3. Field Epidemiology Training Programs (FETPs) reporting trainee or graduate support to COVID-19 preparedness and response by WHO response pillars 5, 6, 7 and 8, and by WHO regional office (AFRO, Africa; EMRO, Eastern Mediterranean; EURO, Europe; PAHO, Americas; SEARO, Southeast Asia; WPRO, Western Pacific). Programs indicating engagement of FETP trainees, graduates, or any FETP involvement (trainees or graduates) are shown. A) Pillar 5, national laboratories. B) Pillar 6: infection prevention and control. C) Pillar 7, case management. D) Pillar 8, operational support and logistics. S1, survey 1; S2, survey 2; WHO, World Health Organization.

Discussion

We documented the diverse contributions of FETP trainees and graduates to COVID-19 preparedness and response activities 1 year into the pandemic, across all WHO regions and response pillars, including the new pillar 9: maintaining essential health services and systems, and pillar 10: vaccination. Programs more commonly reported graduate than trainee engagement. Through content analysis, common themes emerged describing active engagement and vital roles in all types of activities of COVID-19 preparedness and response. The more frequent reporting of trainees and graduates working in specific pillars and the emerging themes reflect the core competencies of the advanced and intermediate tiers of FETPs (Table 4). The FETPs' core competencies of epidemiologic methods, communication, and management and leadership were closely aligned with the pillars of most frequently reported trainee and graduate engagement: pillar 3, surveillance, rapid response teams, and case investigation; pillar 1, coordination, planning, financing, and monitoring; pillar 2, risk communication and community engagement; and pillar 4, points of entry. FETP trainees and graduates were also reported as involved in activities of the 2 new pillars in the revised WHO response plan (strengthening essential health services, and vaccination activities). FETPs' contributions to these 2 pillars demonstrated that trainees and graduates can leverage their skills and knowledge to take on related response activities, likely with additional orientation as needed.

We found differences between this survey and our March–April 2020 survey (*11*) documenting FETPs' contributions to COVID-19 preparedness and response. The response rate for this survey was lower than for the first (35% vs. 74%) (Table 2). Three (9%) programs responded to the second survey that had not responded to the initial survey: Mongolia FETP, Turkey FETP, and Somalia FETP. Among the 29 (91%) programs that responded to both surveys, more programs reported engagement of trainees and graduates than in the first survey. All programs responding to this second survey were well into COVID-19 response activities, having passed or approaching 1 year since COVID-19 introduction into their respective countries. This increase was noted across all WHO regions and pillars, underscoring the contributions of FETPs, its integration into national responses, and its adaptability through the engagement of FETPs in the new pillars. The themes that emerged in this survey were comparable to those identified in the first survey. The ongoing

engagement of FETP trainees and graduates in COVID-19 response across all WHO regions and programs demonstrates FETPs' value to ministries of health as a surge workforce to be leveraged in public health emergencies. Trainees and graduates were employed in their country's response to the pandemic across the emergency response and preparedness pillars, and often in leadership roles.

The diverse, sustained, and increasing engagement of FETP trainees and graduates in COVID-19 responses around the world highlights FETPs' far reach. WHO's Joint External Evaluation (JEE) tool, developed to assess countries' implementation of the IHR (2005), recognizes the importance of FETPs with a specific indicator (D.4.2 in JEE Tool version 1 and D.4.4 in version 2): FETP or other applied epidemiology training programs in place (*7*). Recent publications describe the discrepancy between JEE scores and outbreak response performance (*14*,*15*). One of Yemen's highest JEE technical area score of 4 was in the workforce development indicator, stating that the country has "two levels of FETP or comparable applied epidemiology training programs in place in the country or in another country through an existing agreement." However, the JEE assessment of IHR (2005) framework functions showed capacity to detect outbreaks but limited or no capacity to prevent or respond to them, reflecting that an FETP alone cannot yield an effective outbreak response. Our survey findings support that implementing FETPs could positively influence JEE results beyond the workforce development technical area, including the areas of emergency preparedness, emergency response operations, medical countermeasures, personnel deployment, risk communication, and points of entry. Engagement of FETP trainees and graduates in response operations and logistics, which are not FETP core competencies (Table 4), highlights the importance of regular assessments of the skills needed by the modern field epidemiologists or potential public health staffing gaps which FETPs may be filling (*1*).

We identified 4 limitations in the contribution of FETPs to COVID-19 preparedness and responses worldwide. First, the response rate to the second survey was about half that of the first (35% vs. 74%); responses from programs >20 years old were absent in most regions (EURO, PAHO, Southeast Asia Regional Office, and Western Pacific Regional Office). In the midst of the global pandemic, in the first quarters of 2021 when we conducted this follow-up survey, there were several factors that may account for the reduced response rate: program staff may have had limited time to respond to detailed surveys or to track graduates, and the expanded information requested made the second survey more time-intensive to complete. Second, FETP trainees and graduates bring diverse skillsets to the training, which limits our ability to attribute their contributions solely to their participation, particularly with regard to response pillar activities that do not align with FETP core competencies. Trainee and graduate engagement in pillars that did not require field epidemiologic competencies may be a function of either skills trainees had before enrolling in an FETP, skills they acquired elsewhere, seniority associated with career progression since

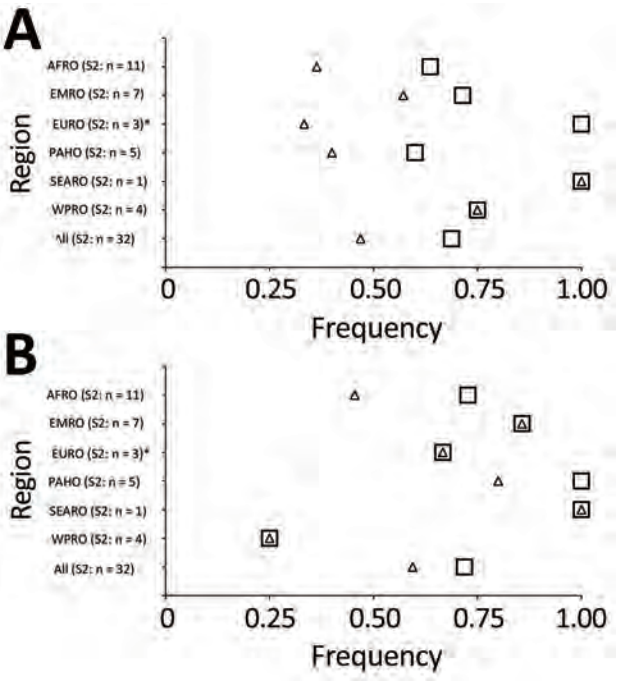

Figure 4. FETPs reporting trainee or graduate support to COVID-19 preparedness and response by WHO response pillars 9 and 10, and by WHO regional office (AFRO, Africa; EMRO, Eastern Mediterranean; EURO, Europe; PAHO, Americas; SEARO, Southeast Asia; WPRO, Western Pacific). Programs indicating engagement of FETP trainees, graduates, or any FETP involvement (trainees or graduates) are shown. A) Pillar 9, maintaining essential health services and systems. B) Pillar 10, vaccine country readiness and delivery. S1, survey 1; S2, survey 2; WHO, World Health Organization.

Table 3. Main themes identified from the descriptions of 10 pillars of World Health Organization response activities provided by Field Epidemiology Training Programs

Theme	Pillar
Epidemiology and surveillance activities	1, 2, 3, 4, 6, 7
Leading risk communication efforts	1, 2, 4, 7, 10
Monitoring and assessment activities	4, 5, 6, 8, 9, 10
Managing logistics and operations	1, 5, 6, 7, 8, 9, 10
Training and capacity building	1, 2, 3, 4, 5, 6, 7, 8, 10
Developing guidelines and protocols	1, 4, 5, 6, 7, 9, 10

Table 4. Competencies in Field Epidemiology Training Programs by public health topic area*

Competency	Activity
Epidemiologic methods	Use epidemiologic practices to conduct studies that improve public health program delivery; respond to outbreaks
Biostatistics	Analyze epidemiologic data using appropriate statistical methods
Public health surveillance	Set up, manage, and evaluate a public health surveillance system
Laboratory and biosafety	Use laboratory resources to support epidemiologic activities
Communication	Develop written public health communications; develop and deliver oral public health communications
Computer technology	Use computers for specific applications relevant to public health practices
Management and leadership	Manage a field project; manage staff and resources; be an effective team leader and member; manage personal responsibilities
Prevention effectiveness	Apply simple tools for economic analysis
Teaching and mentoring	Train public health professionals; mentor public health professionals
Epidemiology of priority diseases and injuries	Evaluate and prioritize the importance of diseases or conditions of national public health concern

*Source: Traicoff et al. (*1*)

FETP graduation, or a combination of those factors. Third, reporting bias is inherent to this documentation approach because of respondents' motivation to inflate engagement of programs and their graduates. Quantifying the level of support needed by the trainees and graduates to participate effectively in response activities was beyond the scope of this effort. Finally, English was not the dominant language of some respondents. Misinterpretation of questions, inaccurate translations, and loss of nuance were possible. Nonetheless, the consistency of findings about engagement across the 2 surveys, in all WHO regions and response pillars, supports the importance of FETPs in countries preparing for and responding to public health threats.

This second documentation of FETPs' contributions to responses to the COVID-19 pandemic highlights 3 needs in field epidemiology training. Systematic chronicling of how trainees, graduates, and program staff work to detect, respond, and prevent public health threats would help to build the body of evidence that field epidemiology training is valuable, and merits continued investment. Periodic tier-by-tier assessments could ensure that the skills developed through this training are the skills required by most field epidemiologists. Finally, regular updating of each tier of the FETP curriculum would assure that new skills required for field epidemiologists can be developed through FETPs.

Future assessments of FETPs could include eliciting feedback from public health institutions on the quality of the contributions to the COVID-19 response of trainees, graduates, and staff. FETP evaluators can also engage with human-resource offices to ensure alignment of competencies with job requirements, pay scale, and a career path for epidemiologists. In addition, assessments can elicit self-reported information from FETP graduates about progression in their career attributable to training in field epidemiology.

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India Field Epidemiology Training Program Response to COVID-19 Pandemic, 2020–2021

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The India Field Epidemiology Training Program (FETP) has played a critical role in India's response to the ongoing COVID-19 pandemic. During March 2020–June 2021, a total of 123 FETP officers from across 3 training hubs were deployed in support of India's efforts to combat COVID-19. FETP officers have successfully mitigated the effect of COVID-19 on persons in India by conducting cluster outbreak investigations, performing surveillance system evaluations, and developing infection prevention and control tools and guidelines. This report discusses the successes of select COVID-19 pandemic response activities undertaken by current India FETP officers and proposes a pathway to augmenting India's pandemic preparedness and response efforts through expansion of this network and a strengthened frontline public health workforce.

The COVID-19 pandemic has raised concerns globally about continued vulnerability to infectious disease threats. With a population of >1.3 billion spread across 37 states and union territories, 31 international airports, 11 seaports, 7 ground crossings, and 8 bordering countries, India remains susceptible to global health security threats (*1*,*2*). This vulnerability underscores the need for strengthened core public health capabilities across disease surveillance and laboratory systems, public health workforce, and emergency response. In response to the COVID-19 pandemic, the government of India has reinvigorated its pledge to advance public health capacity through enhanced investments in public health institutions across India and plans to substantially expand the public health workforce.

The Field Epidemiology Training Program (FETP) is a globally recognized workforce development program (*3*–*5*). FETP is a 3-tiered program consisting of a 3-month frontline training program, a 9–18-month intermediate program (Applied Epidemiology Program [AEP]), and a more comprehensive 2-year advanced program (Epidemic Intelligence Service [EIS]) (*5*). India has adopted all 3 tiers of the FETP; program governance is held by central and state departments in close collaboration with the US Centers for Disease Control and Prevention (CDC). These trainings are imparted through 3 hubs: National Centre for Disease Control, Government of India (NCDC); Indian Council for Medical Research–National Institute for Epidemiology; and World Health Organization (WHO) Country Office for India (*6*). The Ministry of Health and Family Welfare steers these trainings through NCDC. FETP alumni (FETP officers trained before COVID-19) are distributed across various multinational, national, state, academic, and nongovernmental institutions in India, enabling the broad dissemination of skills and knowledge gained through FETP. In total, 7 alumni are working with the government of India at the national level, 22 at state government level, 22 with WHO, 7 in various academic institutions, 8 in nongovernmental organizations, and 2 with CDC.

Author affiliations: National Centre for Disease Control, Ministry of Health and Family Welfare, Delhi, India (S.K. Singh, T. Dikid, M. Dhuria, A. Bahl, R. Chandra, T.P. Vaisakh, S.M. Prajapati, N. Nirwan, L. Paul); National Institute of Epidemiology, Indian Council for Medical Research, Tamil Nadu, India (M. Murhekar, P. Kaur, G. Parasuraman, P. Bhat); World Health Organization Country Office, Delhi (S. Longjumer, K.A. Dzeyie, P. Bhatnagar, N.T. Minh); US Centers for Disease Control and Prevention India Country Office, New Delhi, India (S. Tanwar, R. Yadav, M. Desai)

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During the pandemic, current and alumni FETP officers were consistently deployed to assist local and state authorities in COVID-19 response activities. FETP officers and FETP alumni at the district and state level were involved in cluster investigations, contact tracing, capacity building and training, response management, surveillance strengthening, infection prevention and control training, and supporting guidelines development. This report describes the successes of the FETP program in India from early 2020 through June 2021 and includes select examples of FETP activities and investigations, both completed and in progress, that have informed response efforts across the country and helped to define the future direction of the India FETP.

Methods

COVID-19 Epidemiologic Investigations

During March 2020–June 2021, a total of 50 FETP officers (26 officers from AEP and 24 officers from EIS) participated in >44 COVID-19 response projects across India. The 24 EIS officers, 26 AEP officers, and 73 FETP alumni were distributed throughout the country as of June 2021 (Figure 1). EIS officers and FETP alumni were working in 22 (61%) of the 37 states and union territories; the largest concentration of EIS officers and FETP alumni was in New Delhi. As part of the COVID-19 response, broad areas of support from FETP officers to local and state public health authorities were surveillance data analysis and surveillance system strengthening, cluster outbreak investigations in the community and institutional settings such as residential and healthcare centers, epidemiologic studies, and developing and implementing assessment tools for infection mitigation (Table 1). Select FETP officer epidemiologic investigations and their successes are discussed next.

Involvement of the India FETP in India's COVID-19 response began in March 2020 with reporting of initial COVID-19 cases. When India reported its first cluster of COVID-19 in March 2020 in a city

Figure 1. Distribution of India Field Epidemiology Training Program officers (advanced and intermediate current officers and alumni) during COVID-19 response, India, March 2020–June 2021. Circle sizes indicate number of officers.

Table 1. India Field Epidemiology Training Program (Advanced and Intermediate) projects during COVID-19 response, March 2020–June 2021

COVID-19 response	No. projects
Surveillance system strengthening	11
Surveillance data analysis	5
Capacity building and training	4
Cluster investigation in education institute	4
Community outbreak cluster investigation	3
Epidemiologic study	3
Infection mitigation practices assessment survey	3
Assisted living facility outbreak investigation	2
Case investigation	2
Healthcare facility outbreak investigation	2
Market place outbreak cluster investigation	2
Residential housing complex cluster investigation	2
Assessment of best practices	1
Total	44

in northern India, NCDC deployed EIS officers to develop a containment plan and establish influenza-like illness (ILI) surveillance in the community. Reverse transcription PCR (RT-PCR) testing of potential cases was conducted alongside contact tracing. Using case mapping, 3 containment zones were identified, and >1,700 field teams conducted a door-to-door survey of ILI cases. Over the course of 17 days, 3,561 ILI cases were identified. Of these, 8 cases were laboratory confirmed as COVID-19; of those cases, 3 (38%) case-patients had a history of recent travel outside India, 4 (50%) were in direct contact with a person confirmed to have COVID-19, and 1 (13%) was an indirect contact of a confirmed COVID-19 case-patient (second-generation case). Officers implemented a COVID-19 cluster containment plan that included enhanced surveillance around identified clusters and contact tracing using rapid response teams. The plan was successful in preventing case transmission beyond the second generation.

In March 2020, a COVID-19 cluster was reported among healthcare workers in a cancer hospital in northern India. In the early days of the pandemic, healthcare facilities did not have COVID-19–specific protocols for source reduction. EIS officers led an investigation to identify potential factors associated with these infections and recommended steps to prevent further transmission. Testing and contact tracing identified 25 case-patients, of which 18 (72%) persons were involved in aerosol-generating procedures without following precautions against airborne transmission. Support from FETP officers led to the development of infection prevention and control checklists for healthcare settings and, during the course of the pandemic, served as a successful strategy for ongoing cluster containment activities nationwide. (7).

In June 2020, a coastal community in the southern part of India reported 620 COVID-19 cases. An investigation led by an EIS officer was initiated to identify potential risk factors associated with this cluster. A 1:2 case–control study was conducted at the community health center level. A case-patient was defined as a resident of the identified locality who tested positive for COVID-19 during June 17–July 25, 2020. Cases started rising in the first week and peaked in the second week of July (Figure 2). This case–control study demonstrated that 31% (15/49) of case-patients had exposure to the local fish market compared with 10% (9/93) of controls (odds ratio [OR] 3.9, 95% CI 1.4–11), and 37% (18/49) of case-patients had a family member in the fish business compared with 16% (15/93) of controls (OR 2.8, 95% CI 1.2–6.7). These findings underpin the need for adherence to physical distancing to minimize contact with infected persons and the benefit of wearing a face covering or mask.

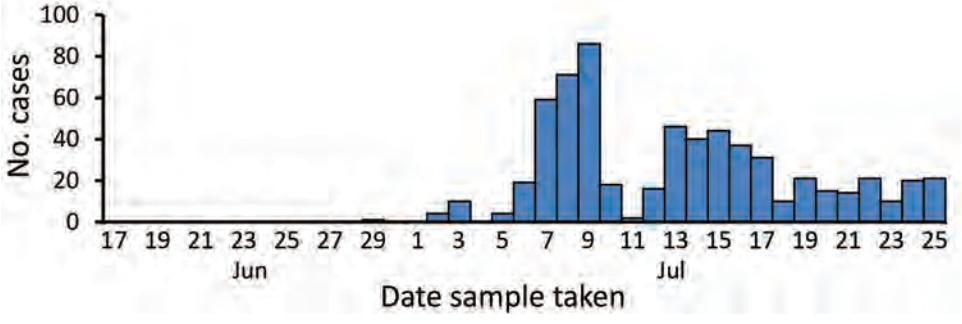

Figure 2. COVID-19 cases in a coastal fishing community in southern India, June–July 2020.

On March 30, 2021, a COVID-19 outbreak was reported in a residential training institute in the northeastern part of India. Students at the institute came from across India. The infections began after the reopening of training sessions after the lockdown was lifted in February 2021. An AEP officer investigated the outbreak and recommended containment measures. A total of 114 COVID-19–positive case-patients (111 confirmed through RT-PCR) were identified (attack rate 99%). The median patient age was 24 years (range 1–78 years), and 27 (24%) were symptomatic. Of the 114 case-patients, 98 (86%) were students; the remainder were faculty and staff. The investigation led to the closing of the school and implementation of school infection control assessment tool (*8*).

Operational Support Activities

India FETP officers supported district administrations in strengthening local level surveillance systems, which helped authorities closely monitor COVID-19 activity and the delivery of supplies. An EIS officer was appointed as the nodal officer for COVID-19 containment by the district administration of Udupi, a district in southern India. This officer received the mandate to establish a new surveillance system across the district to guide containment efforts. Early in the pandemic, the officer helped the district transition from paper-based forms to digital surveillance using the EpiCollect5 application (https://five.epicollect.net), a free and easy-to-use mobile data-gathering platform. The application proved especially useful in helping to trace returnees from abroad. The new surveillance system used a virtual platform for trainings, meetings, and discussions. With the help of information gathered through the early transition to digital surveillance, revised guidelines were disseminated and implemented in the district within 2 days (rather than months) of their update. This pace has been maintained throughout the pandemic. The local EIS officer in Udupi in the state of Karnataka played a crucial role in implementing changes in surveillance activities in the district (Figure 3).

During the second wave of COVID-19 in India in April 2021, the district of Udupi observed a 100% increase in cases, which stretched healthcare infrastructure and led to a shortage of consumables such as oxygen and diagnostic supplies. An EIS officer appointed as the nodal officer for COVID-19 containment in the district was assigned to assess oxygen consumption. The officer's analysis revealed that ≈17% (120/750) of hospitalized patients needed ventilatory or high-flow oxygen support during the peak of the outbreak. Because of patient compliance and ease of use, physicians initially preferred high-flow nasal oxygen cannulas for treatment. These continuously use oxygen at the same flow rate during inspiration and expiration, which results in waste. Unlike high-flow nasal oxygen, ventilators or nonrebreathing masks use oxygen only during inspiration, which has been shown to reduce oxygen consumption by 25%–30%. Along with this intervention, an EIS-led team audited oxygen demand in the district hospitals, which calibrated oxygen administration to maintain blood oxygen saturation of 90%–95%. This exercise reduced oxygen requirement by 8%–10%. Under the officer's supervision,

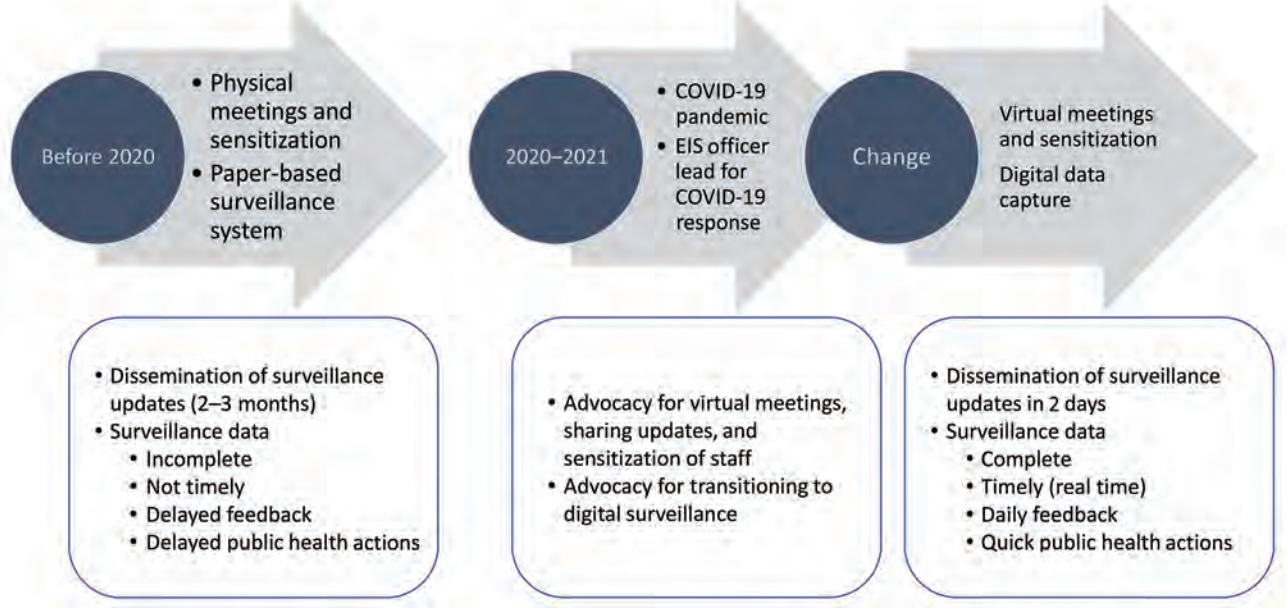

Figure 3. Implementation changes in surveillance activities in Udupi, Karnataka, India, 2020–2021. EIS, Epidemic Intelligence Service.

Table 2. Policy implications of select COVID-19 response efforts by the India Field Epidemiology Training Program, March 2020–June 2021*

Response type	FETP officers	Location and date	Policy implications
COVID-19 cluster containment in the initial phase of the pandemic	2	Northern India, March 2020	Implementation of a coordinated containment plan served as a template for management of COVID-19 clusters in India.
COVID-19 outbreak investigation in a healthcare facility	2	Northern India, March 2020	Infection prevention control checklist developed for routine healthcare delivery during the pandemic (*7*).
COVID-19 outbreak linked to a fish market—a case-control study	2	Southern India, June 2020	Findings underpinned the need for adherence to physical distancing, masking, and implementation of testing and contact-tracing programs in marketplaces during periods of ongoing community transmission.
COVID-19 cluster investigation in a residential training institute	1	Northeastern India, March 2021	Implementation of school infection control assessment tool (*8*).
Support in establishing digital COVID-19 surveillance system	1	Southern India, May 2020	Surveillance system provided flexibility to accommodate changes in the testing and contact-tracing guidelines, resulting in optimal testing and contact tracing.
Monitoring consumption of oxygen during the second COVID-19 wave	1	Southern India, April 2021	Timely interventions reduced the district oxygen requirement by >43% (1,765–1,004 L per patient per day). Similar models were recommended to be replicated in other districts to optimize the oxygen requirement.
Response to Kumbh Mela	16	Haridwar, Uttarakhand, India, March 2021	Daily feedback from FETP officers led to an overall increase of 21% (62%–83%) in mask use and a 14% (31%–45%) improvement in the correct use of masks among those who were already using a mask.

*FETP, Field Epidemiology Training Program.

a detailed oxygen delivery pipeline inspection was conducted in major hospitals to find and correct leakage points, saving another 5% of oxygen.

Kumbh Mela, a mass religious gathering that occurs once every 12 years, brings pilgrims from all parts of India and other countries to Haridwar, Uttarakhand. The Kumbh Mela in 2021 was scheduled to take place within a 12.3 km^2 area during the months of March and April 2021. More than 10 million pilgrims were expected to participate in this religious gathering, essentially doubling the state population over a period of 1 month. The state government provided guidance to attendees on recommended COVID-19–appropriate behaviors, including mask-wearing. WHO and NCDC EIS and AEP officers participated in public health response activities in addition to regular disease surveillance and preparedness duties. FETP officers assessed mask-wearing compliance among Kumbh Mela attendees in Haridwar (6,200 persons observed in 3 weeks) and provided daily updates on COVID-19–appropriate behavior to the administration. Those updates were then used to plan corrective measures. They also assessed acceptance of the COVID-19 vaccine among Kumbh Mela pilgrims ≥18 years of age and determined factors associated with vaccine hesitancy. Among the interviewed pilgrims, 44% (140/318) had received ≥1 dose of COVID-19 vaccine, and among the 56% (178/318) unvaccinated persons, 63.0% (112/178) were not eligible for vaccination (persons <45 years of age were not eligible for vaccination in March–April 2021).

Results

Policy and Global Health Implications

Many of the COVID-19 cluster investigations and operational support activities undertaken by India FETP officers had policy implications at the state and national level (Table 2). These implications included standardizing infection prevention and control practices in healthcare settings and schools and establishing robust surveillance systems in select districts (*7*,*8*).

The COVID-19 pandemic has highlighted the contribution of trained field epidemiologists in a public health emergency and recognized them as an integral part of the public health workforce on the frontline. Most currently enrolled and alumni FETP officers supported COVID-19 pandemic response work at their respective duty stations. The remainder mentored current FETP officers in investigative and containment activities. The importance of a strong network of trained field epidemiologists is now well accepted at the highest level in the government. A Parliamentary Standing Committee review report on COVID-19 response has recognized the crucial gap of epidemiologists in India's public health system (*9*). The committee also observed that, per the Workforce Development Action Package under the Global Health Security Agenda, the country needs to work toward achieving the target of 1 trained field epidemiologist per 200,000 population (*10*,*11*).

Although the pandemic has provided insights into strengthening the public health workforce on the

frontline (epidemiologists and surveillance officers), it has also pushed the FETP program to become more innovative in curriculum delivery. Officers from all 3 hubs are spread across the country, but the FETP struggled to provide in-person training opportunities for officers because of travel restrictions, which delayed the completion of some core learning activities. However, because the FETP officers were part of the public health system, they received multiple opportunities both through the FETP and their placement sites to participate in COVID-19 response efforts. At each hub, the FETP adopted innovative hybrid instructional and mentoring methods using online platforms such as Zoom Video Communication (https://zoom.us) (*12*) for induction trainings and remote mentoring sessions to provide learning opportunities for officers.

In addition to highlighting opportunities to modernize curriculum delivery, the pandemic also raised awareness regarding the inequitable distribution of trained public health workers within India. Such inequities in remote rural areas are difficult to address because current public health services are already constrained. This challenge could be managed through training models with an information technology–based learning management system, hybrid models of training, flexible options for placement, and on-site one-to-one mentoring opportunities. The FETP in India is exploring options to develop system tools to optimize learning and training management.

Discussion

India needs to strengthen its frontline public health workforce with the same level of commitment it has demonstrated in advancing healthcare and clinical medicine over the years. Public health training programs in India provide strong academic knowledge but offer limited hands-on exposure and applied epidemiology skills (*6*). Focused on-the-job epidemiology training, especially for in-service public health personnel, must be provided. The FETP offers the flexibility to provide training that is directed toward the necessary scope of work.

FETP needs support from the Ministry of Health and Family Welfare in establishing professional recognition (in partnership with universities), career pathways, and incentives for trained FETP officers. Recruiting and using FETP officers in public health leadership positions within the government system can help generate support for FETP training at the district and state levels. As a program, gaps in the FETP implementation must be identified and solutions put in place to ensure quality and rapid scale-up. In addition, a strong FETP alumni network in India and other countries can provide the required mentorship to support FETP expansion and response surge capacity in India and the surrounding region.

During the past decade, the FETP in India has trained >70 officers in advanced epidemiology, and >300 epidemiologists and surveillance officers have been trained under the frontline FETP. However, with a population of 1.4 billion, India requires a much larger public health workforce (≈7,000). Both advanced and intermediate FETP has contributed immensely to national and state-level responses to COVID-19, but rapid expansion of the frontline FETP is needed at the district level. Strengthening its public health workforce capacity through the expansion of all 3 levels of FETP is arguably the most critical element of India's pandemic preparedness and response efforts.

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Dr. Singh has worked for public health in various capacities with the Government of India for more than 30 years. He is currently the Director of India's National Centre for Disease Control and has successfully led the COVID-19 surveillance and response for the country.

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COVID-19 Response Roles among CDC International Public Health Emergency Management Fellowship Graduates

Sharanya Krishnan, Catherine Espinosa, Michelle N. Podgornik, Seghen Haile, José J. Aponte, Christopher K. Brown, Sara J. Vagi

Since 2013, the US Centers for Disease Control and Prevention has offered the Public Health Emergency Management Fellowship to health professionals from around the world. The goal of this program is to build an international workforce to establish public health emergency management programs and operations centers in participating countries. In March 2021, all 141 graduates of the fellowship program were invited to complete a web survey designed to examine their job roles and functions, assess their contributions to their country's COVID-19 response, and identify needs for technical assistance to strengthen national preparedness and response systems. Of 141 fellows, 89 successfully completed the survey. Findings showed that fellowship graduates served key roles in COVID-19 response in many countries, used skills they gained from the fellowship, and desired continuing engagement between the Centers for Disease Control and Prevention and fellowship alumni to strengthen the community of practice for international public health emergency management.

Public health emergencies originating from outbreaks of emerging infectious diseases have fueled the need for countries to develop their capacities to prevent, detect, and respond to public health threats (*1*–*6*). To manage responses to these threats, countries around the world, beginning in about 2012, began to establish public health emergency operations centers (PHEOCs) (*7*). PHEOCs serve as command centers for coordinating various functions of health emergency responses, such as information management, risk communications, logistics, and operations (*7*,*8*). Establishing PHEOCs introduced the need for trained personnel to manage and operate these facilities. In 2013, the US Centers for Disease Control and Prevention (CDC) responded to this need by establishing the Public Health Emergency Management (PHEM) Fellowship program (https://www.cdc.gov/cpr/eoc/EmergencyManagementFellowship.htm) to help build a workforce to strengthen emergency management capacity among international public health communities (*9*–*11*). The PHEM Fellowship program trains international midcareer public health professionals in emergency management principles using a competency-based curriculum that incorporates lectures, case studies, and participation in real-world experiences. As of 2020, CDC had trained 141 fellows, representing 36 countries worldwide, in 12 semiannual cohorts conducted during August 2013–May 2020.

The magnitude of the COVID-19 pandemic highlighted the need in many countries for experts with public health emergency management skills to organize, lead, and streamline response efforts. Although anecdotes from the field demonstrated notable roles by PHEM Fellowship program graduates in providing emergency management leadership in COVID-19 response efforts, details of their roles and skills had not been systematically captured. Also, although some fellowship alumni have requested remote technical guidance during the COVID-19 pandemic, the type and extent of technical assistance needed had not been systematically surveyed. Identifying COVID-19 response roles and remaining training needs of PHEM Fellowship graduates can inform curriculum development for future training activities.

To quantify program graduates' contributions during COVID-19 and training and assistance needs, CDC staff, in 2021, designed and administered a survey. The

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objectives of the survey were to assess the number and proportion of total graduates engaged in COVID-19 response in the public health emergency management system in the respondent's country; identify the organizations served and positions filled by graduates within the country's public health emergency management system before and during the COVID-19 response; identify public health emergency response skills acquired through the PHEM Fellowship program that the respondent considered useful after graduation; identify additional technical skills related to public health emergency management needed to sustain the COVID-19 response; and identify modes of technical assistance support (remote or onsite) preferred by graduates.

Methods

We developed a 21-question web-based survey that could be answered in 10–15 minutes designed to address the 5 survey objectives (Appendix, https://wwwnc.cdc.gov/EID/article/28/13/22-0713-App1.pdf). We analyzed responses grouped by semiannual cohort (n = 12) and region. On March 20, 2021, we sent an email with a secure link to the survey to all persons who had graduated from the PHEM Fellowship program by that date (n = 141). The survey remained open for 5 weeks; reminder emails were sent 2 and 4 weeks after the initial mailing. CDC reviewed the activity and determined that it did not involve human subject research and therefore did not require Institutional Review Board approval.

The survey collected deidentified information on respondents' countries, roles, graduation month and year (cohort), and organization type of current and any previous employment. Survey questions required multiple-choice, multiple-answer, free text, or 5-point Likert scale responses (*12*). We created the survey in the Epi-Info Secure Web Survey tool (https://www.cdc.gov/epiinfo/index.html) and included relevant skip patterns to simplify entry for respondents. We used the number of graduates of the PHEM Fellowship program from each country and cohort to determine the expected number of responses, then compared those to survey responses to identify and remove duplicates.

Once the survey closed, we combined French and English responses based on common data elements, then cleaned and analyzed the data using Epi Info and Microsoft Power BI (https://powerbi.microsoft.com). We calculated response rates using standard definitions (*13*). We calculated 95% CIs around percentages with the finite population correction factor for known population size (n = 141 graduates). To examine differences by region, we organized respondents by their corresponding World Health Organization (WHO) regional offices (Table 1).

Results

We successfully reached 136/141 (96.5%) PHEM Fellowship program graduates. Overall, respondents submitted 111 completed surveys; 21 were duplicates, and 1 did not include country name and cohort (Figure). Duplicates were most likely to occur right after the respondent's first submission or shortly after reminder emails were distributed. After excluding duplicates and the 1 incomplete response, we analyzed data from the remaining 89 surveys, a response rate of 74.2% (*13*). Respondents from WPRO (Western Pacific Regional Office) countries had a 42.9% response rate, lower than those for other WHO regions: AFRO (Africa), 77.5%; SEARO (South-East Asia), 91.7%; EMRO (Eastern Mediterranean), 100%; and EURO (Europe), 100%. There were no PHEM Fellowship program graduates from the Americas at the time the survey was conducted. Overall, the first 2 cohorts had lower response rates (0% for cohort 1 and 14.3% for cohort 2) and cohort 10 had a higher response rate (93.8%) than those for the other groups combined. The distribution of survey participants by WHO region was similar to the overall distribution of total fellowship participants by region (Table 1). We analyzed the survey data to assess the 5 predetermined survey objectives.

Table 1. Number of graduates from the US CDC Public Health Emergency Management Fellowship program during 2013–2020 and participants in April 2021 survey of COVID-19 and other activities, by WHO Regional Office

WHO Regional Office	Countries	No. (%) fellowship graduates	No. (%) survey respondents
Africa	African Union, Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Democratic Republic of the Congo, Ethiopia, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Mali, Mauritania, Nigeria, Rwanda, Senegal, Sierra Leone, Tanzania, Togo, Uganda	91 (64.5)	62 (69.7)
Eastern Mediterranean	Jordan, Pakistan, Saudi Arabia	6 (4.3)	5 (5.6)
Europe	Kazakhstan, Republic of Georgia	3 (2.1)	2 (2.2)
South-East Asia	Bangladesh, India, Indonesia, Myanmar, Thailand	16 (11.3)	11 (12.4)
Western Pacific	Australia, China, Japan, Malaysia, South Korea, Vietnam	25 (17.7)	9 (10.1)
Total		141 (100)	89 (100)

*CDC, Centers for Disease Control and Prevention; WHO, World Health Organization.

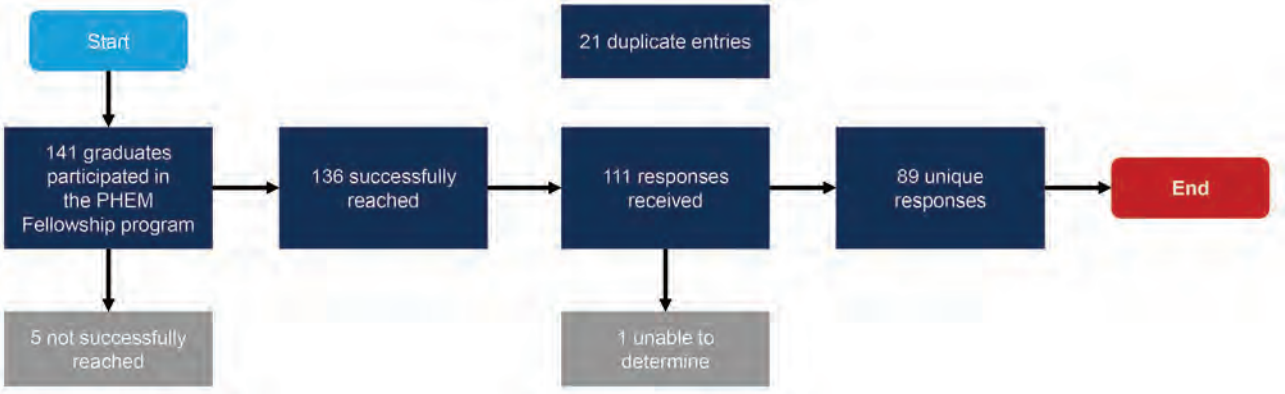

Figure. Flowchart illustrating overall summary of survey responses from graduates of the Centers for Disease Control and Prevention PHEM Fellowship program contacted during April 2021. A total of 141 fellows representing 36 countries worldwide have completed the program in 12 semiannual cohorts conducted during August 2013–May 2020. PHEM, Public Health Emergency Management.

Objective 1: Assess Number and Proportion of Graduates Engaged in the Country's PHEM System during the COVID-19 Response

Overall, 80/89 (89.9%) survey respondents have supported their country's COVID-19 response in various PHEM roles. At the time of the survey, 49/89 (55.1%) respondents had spent 76%–100% of their work time on emergency preparedness or response activities for COVID-19 or any other public health emergency; 17 (19.1%) had spent 51%–75%, 10 (11.2%) had spent 26%–50%, 6 (6.7%) had spent 1%–25%, and 1 (1.1%) had spent no time on these activities. Of the 62 respondents from AFRO, 35 (56.5%) had spent 76%–100% of their time working on emergency management preparedness or response activities, compared with 2/5 (40.0%) EMRO respondents, 4/11 (36.4%) SEARO respondents, and 7/9 (77.8%) WPRO respondents.

Objective 2: Identify Organizations and Positions of Graduates in the Country's Emergency Management System before the PHEM Fellowship and during the COVID-19 Response

The 89 respondents reported diverse professional backgrounds, and many had served in several different positions before participating in the PHEM Fellowship program. More respondents (n = 60, 67.4%) worked for the country's ministry of health than any other organization type. During the COVID-19 pandemic, more respondents reported engaging in emergency response functions after graduating from the fellowship program than before. More than half (n = 47, 52.8%) served in managerial or nonmanagerial roles in emergency operations centers to support COVID-19 and other public health responses (Table 2). Among respondents, 80/89 (89.9%) supported the COVID-19 response in a variety of traditional incident management system (IMS) functional roles as incident managers or in operations, planning, or logistics support (Table 3). Most respondents reported being involved in COVID-19–related scientific technical assistance (n = 38, 47.5%) or planning (n = 34, 42.5%).

Objective 3: Identify Public Health Emergency Response Skills Acquired through the PHEM Fellowship that Have Been Useful after Graduation

Among respondents, 81/89 (91.0%) indicated they had used ≥1 specific emergency management skill in the context of COVID-19 and other public health emergencies since graduating from the fellowship program. Among respondents, 97.4% agreed that the fellowship program had provided useful training skills in IMS, coordination, and communication; 96.5% in developing policies, plans, and procedures; 97.5% in preparedness, exercises, and evaluation; and 93.3% in other emergency management skills. Of 19 public health emergency management skills detailed in the survey, respondents reported performing a median of 13 (interquartile range 9–18); 16 respondents reported performing 18/19 skills. When asked about their confidence in performing those skills, 79.9% felt confident performing tasks associated with IMS, coordination, and communication; 69.3% felt confident developing emergency response policies, plans, and procedures; and 73.9% felt confident in their skills for preparedness, exercises, and evaluation (Table 3).

Objective 4: Identify Current Technical Needs Related to Emergency Management that Are Critical to the COVID-19 Response

To address COVID-19 response needs, 65/89 respondents (73.0%) requested ≥1 type of technical support from CDC emergency management specialists. Among the 65 respondents that requested emergency

Table 2. Organization, position types, and roles held by Public Health Emergency Management fellowship program graduate survey respondents at time of survey (April 2021) and during the COVID-19 response (January 2020–April 2021)*

Characteristics	No. responses (95% CI)
COVID-19 response organization types, n = 89	
Ministry of health	58 (52.2–64.7)
National public health institute	31 (25.6–37.3)
Other organization	18 (13.1–22.8)
Nongovernmental organization	8 (4.5–11.3)
US Centers for Disease Control and Prevention country office	6 (2.7–8.5)
Local department of health	10 (6.3–13.9)
Animal health sector	6 (2.7–8.5)
Other ministry	8 (4.5–11.3)
World Health Organization	10 (6.3–13.9)
Ministry of defense	1 (–0.2 to 2.5)
Position areas within COVID-19 response organizations, n = 89	
Scientific or technical response	55 (48.8–61.4)
Emergency operations center staff, managerial	53 (46.5–59.1)
Rapid response team manager	35 (28.8–40.9)
Other position	27 (21.3–32.6)
Scientific or technical, nonresponse	26 (20.3–31.4)
Emergency operations center staff, nonmanagerial	18 (13.1–22.8)
COVID-19 roles, global, n = 80†	
Scientific or technical assistance	48 (40.3–54.7)
Planning section	43 (35.3–49.7)
Operations section	35 (28.1–41.9)
Situational awareness	28 (21.0–34.0)
Emergency operations center manager	18 (12.0–23.0)
Rapid response team	18 (12.0–23.0)
Other role	14 (8.8–18.7)
Incident manager	13 (7.7–17.3)
Liaison officer	9 (4.7–12.8)
Logistics section	6 (2.7–9.8)
Public information officer	4 (1.0–6.5)
Finance and administration section	3 (0.2–4.8)
Safety officer	3 (0.2–4.8)

*Respondents could select multiple options so no. of responses can exceed n values.
†Three respondents did not support COVID-19 response; 6 respondents did not provide a response to this survey question.

management technical support, 57 (87.7%) requested general support for workforce development in their country, 35 (53.8%) technical support to develop plans and standard operating procedures, 30 (46.2%) support on the PHEOC physical infrastructure, 31 (47.6%) technical support on rapid-response training, and 31 (47.7%) technical support on exercises related to developing, executing, and evaluating responses.

Objective 5: Identify Methods of Technical Assistance Desired by Graduates

Among respondents from all cohorts and regions, 73/89 (82.0%) said they would participate in additional PHEM training opportunities, among whom 49/73 (67.1%) preferred a combination of in-person and virtual training modalities, 17 (23.3%) preferred in-person training, 6 (8.2%) virtual training; 1 person (1.4%) did not answer that question. Capacity development support between graduates was common. Among respondents from all cohorts and regions, 55 (61.8%) indicated they had either provided support to or received support from other PHEM fellowship program graduates, 18 (20.2%) had not given or received support, and 16 (18.0%) did not answer that question; 63 respondents (70.8%) said they would be willing to present in future PHEM trainings.

Discussion

This survey provided information on how participation in the PHEM Fellowship program contributed to improving international workforce capacity to manage public health emergencies. The PHEM Fellowship program provides standard training and mentorship and networking components that enable countries to build systems unique to their needs and context. Nearly 90% of respondents indicated that they held a role in their country's COVID-19 response, demonstrating the relevance of a trained public health emergency management workforce during emergencies. Program graduates credited the fellowship with developing skills essential for public health emergency management, including conducting risk assessments, developing response plans, aiding with training and exercises, and managing resources, and most expressed interest in sharing their experiences.

PHEM fellowship program graduates are likely more culturally aware of local politics, resources, languages, and challenges than are US-based experts. Anecdotal examples from the survey of initiatives by graduates in the field included conducting reciprocal site visits between Uganda and Sierra Leone to observe how other nations operate their PHEOCs and providing technical assistance (e.g., Cameroon supporting the Democratic Republic of the Congo by sharing risk assessment and response plans). Other opportunities for in-depth, longitudinal relationship management with PHEM graduates are likely and could be modeled after the alumni engagement networks of other CDC training programs.

All data were self-reported and therefore possibly subject to biases that tend toward overestimates. Respondents might have been more likely to rate their skills and confidence more positively (social desirability bias) and attribute skills gained from a CDC program more highly on a survey conducted by CDC (acquiescence bias) (*14*). Several factors might have suppressed the overall response rate, including differences in language understanding and perception, length of time since participation in the fellowship, lack of time because of engagement in the COVID-19 response, or incorrect contact information. Regions such as WPRO were underrepresented in survey responses compared with AFRO, which could affect generalizability of the results and subsequent programmatic recommendations.

Overall, our findings indicated that fellowship graduates served key roles in country COVID-19 responses, used skills gained from participating in the fellowship, and desired ongoing engagement between CDC and fellowship alumni to continue strengthening the community of practice for international public health emergency management. Investments in this program could address the growing demand for public health emergency responders with the expertise to combat future epidemics and pandemics (*15,16*). Response needs prompted by the COVID-19 pandemic have increased interest from more countries and regions to provide applicants to future fellowship cohorts (CDC PHEM Fellowship Program, unpub. data).

Strong investments in building international workforce capacity should combine time-limited intensive in-person learning with ongoing mentorship and cultivated alumni networks. CDC is working to expand the fellowship's curriculum, develop advanced training opportunities, and translate materials into additional languages. The goal of these

Table 3. Confidence to perform emergency management skills acquired in the CDC PHEM Fellowship program as reported by respondents to a survey of program graduates, April 2021*

	Emergency management skills used†			Confidence to perform activity without CDC support‡		
Skill	Agree or strongly agree	Total no.§	% (95% CI)	Confident or very confident	Total no.§	% (95% CI)
IMS, coordination, communication						
Develop a situation report	64	64	100 (100.0–100.0)	55	64	86 (79.6–92.3)
Develop an incident action plan	66	68	97 (94.2–100.0)	55	68	81 (74.1–87.6)
Develop response objectives	72	72	100 (100.0–100.0)	61	72	85 (78.9–90.6)
Develop risk communications	43	45	96 (90.6–100.5)	31	45	69 (57.7–80.1)
Manage meetings	73	75	97 (94.8–99.8)	61	75	81 (75.3–87.4)
Serve in an IMS functional role	66	67	99 (96.4–100.6)	51	67	76 (68.7- 83.5)
Track tasks	61	66	92 (87.8– 97.1)	51	66	77 (69.9–84.7)
Policies, plans, SOPs						
Create a PHEOC handbook	43	46	94 (87.6–99.4)	31	46	67 (56.2–78.6)
Create standard operating procedures	70	70	100 (100.0–100.0)	54	70	77 (70.1–84.1)
Develop a concept of operations	47	50	94 (88.7–99.3)	34	50	68 (57.6–78.4)
Develop an all-hazards plan	44	45	98 (94.2–101.3)	32	45	71 (60.1–82.1)
Develop hazard-specific contingency plans	53	57	93 (87.8–98.1)	38	57	67 (57.2–76.1)
Develop legal authorities for PHEOC	46	48	96 (91.2–100.4)	30	48	63 (51.3–73.7)
Preparedness, exercises, evaluation						
Conduct a risk assessment	50	52	96 (92.0–100.3)	35	52	67 (57.1–77.5)
Conduct an after-action review	54	56	96 (92.6–100.2)	41	56	73 (64.2–82.3)
Contribute to exercise development	60	61	98 (96.0–100.8)	45	61	74 (65.4–82.1)
Facilitate PHEM trainings in-country	65	67	97 (94.1–100.0)	50	67	75 (67.1–82.2)
Perform watch desk duties	48	48	100 (100.0–100.0)	39	48	81 (72.3–90.2)
Other	14	15	93 (81.4–105.3)	10	15	67 (44.0–89.3)

*CDC, Centers for Disease Control and Prevention; PHEM, Public Health Emergency Management; PHEOC, public health emergency operations center; SOP, standard operating procedure.
†Complete survey question: The PHEM fellowship program introduces many emergency management skills. Which of those skills have you performed individually or as part of a group, before, during, or after a public health response?
‡Complete survey question: How confident were you in your abilities to implement the activity in your country without any technical support from CDC?
§No. respondents answering questions. Questions were dependent on a skip pattern, so no. respondents differed for each question.

training improvements and advancement of peer-to-peer mentoring is to continue strengthening international public health emergency management workforce capacity. Using a combination of virtual and in-person trainings, peer-to-peer learning, and sharing best practices can strengthen the nascent global network of fellowship graduates and other public health emergency management experts. As the field of public health emergency management continues to advance, systematic evaluations are needed to understand how best to support PHEM fellowship program graduates and identify strengths and gaps of the program at large. CDC is developing an evaluation framework and evaluation plan to address this need.

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Exploratory Literature Review of the Role of National Public Health Institutes in COVID-19 Response

Alexandra Zuber,[1] Yesser Sebeh,[1] Dennis Jarvis,[2] Shelly Bratton[2]

To help explain the diversity of COVID-19 outcomes by country, research teams worldwide are studying national government response efforts. However, these attempts have not focused on a critical national authority that exists in half of the countries in the world: national public health institutes (NPHIs). NPHIs serve as an institutional home for public health systems and expertise and play a leading role in epidemic responses. To characterize the role of NPHIs in the COVID-19 response, we conducted a descriptive literature review that explored the research documented during March 2020–May 2021. We conducted a name-based search of 61 NPHIs in the literature, representing over half of the world's NPHIs. We identified 33 peer-reviewed and 300 gray articles for inclusion. We describe the most common NPHI-led COVID-19 activities that are documented and identify gaps in the literature. Our findings underscore the value of NPHIs for epidemic control and establish a foundation for primary research.

National public health institutes (NPHIs) are "science-based organizations… that provide leadership and coordination for public health at the national level" (*1*). NPHIs provide an institutional home for many public health functions, which can improve coordination of public health activities; streamline human and financial resources; and improve the generation, sharing, and use of public health data and evidence (*2*–*9*). During public health emergencies, NPHIs can increase countries' capacity to mount quick, decisive, and coordinated responses (*2*,*3*,*5*,*10*,*11*). An NPHI is often a government agency within a ministry of health but may in some cases represent a parastatal or nongovernmental entity. Approximately half of the countries in the world have an NPHI (n = 94), and they vary in maturity, form, and function (*12*).

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Despite their critical role, however, NPHIs have not been a focus of the growing body of research related to characterizing the response to COVID-19 by national governments (*13*–*16*; C.T. Lee et al., unpub. data, https://www.medrxiv.org/content/10.1101/2021.02.02.21251013v1). In 2021, researchers from the World Health Organization and the International Association of National Public Health Institutes (IANPHI) reported that COVID-19 revealed global inequities in public health capacities and established that an "urgent need to examine sources of global knowledge and understand how NPHIs… can be better used, particularly in under-resourced settings" (*17*). To this end, we conducted an exploratory, descriptive literature review to examine 1 question: What clues can the literature give us on the role of NPHIs in the COVID-19 response globally?

Methods

We conducted an electronic database search of articles published in scientific journals (peer-reviewed literature) and a targeted search of documents or reports published outside of academic publishing (gray literature) (Appendix 1, https://wwwnc.cdc.gov/EID/article/28/13/22-0760-App1.pdf). For our electronic search, we selected the World Health Organization COVID-19 Global Research Database on the basis of its comprehensive inclusion of articles from multiple electronic databases and its topical focus on COVID-19 (Figure 1) (*19*). Our search terms (Appendix 2 Table 1, https://wwwnc.cdc.gov/EID/article/28/13/22-0760-App2.pdf) included "national public health institute" as well as the proper names of 61 NPHIs, as listed on the IANPHI website (*12*). We designed a sample frame of these

[1]These co–principal investigators contributed equally to this article.

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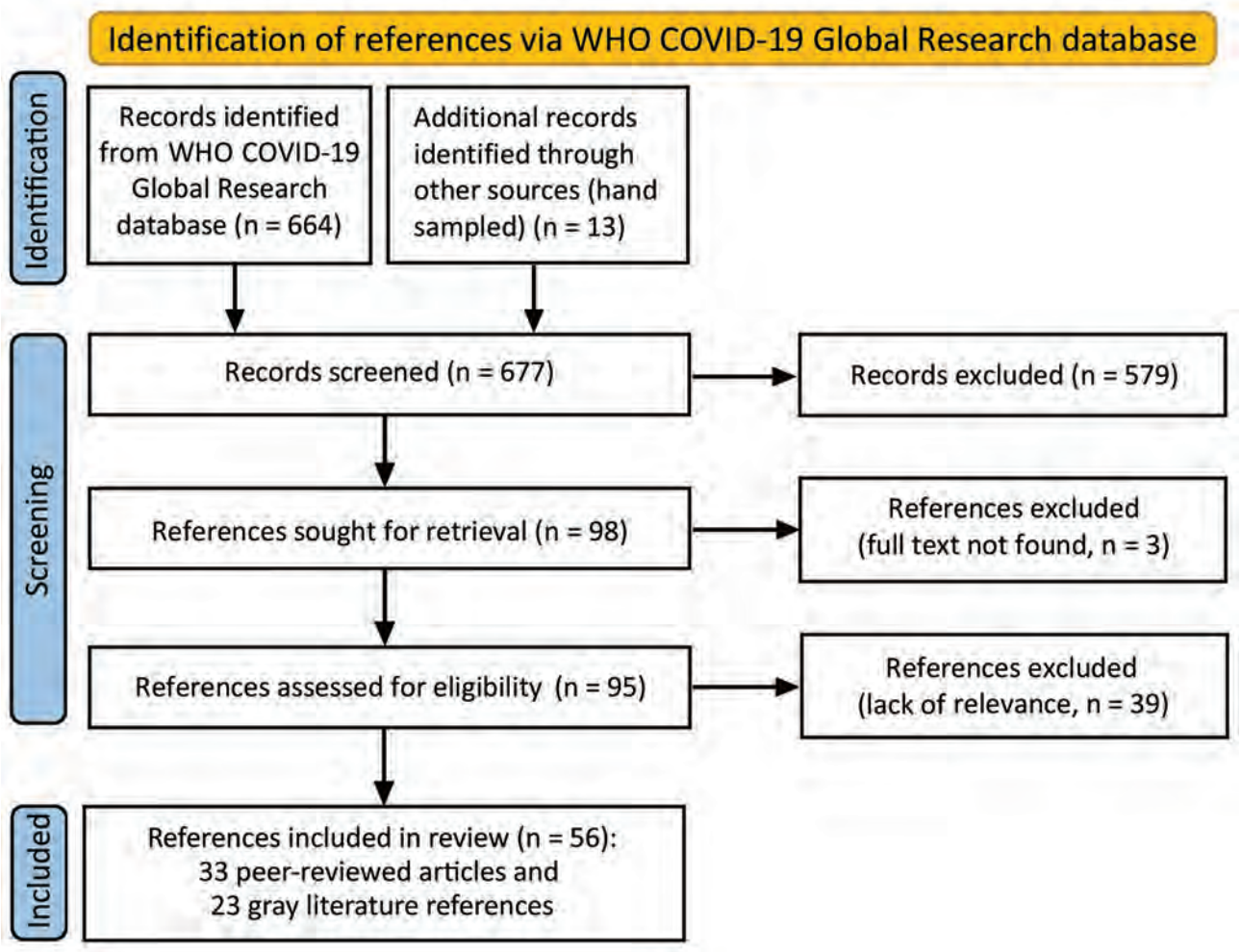

Figure 1. Electronic database search conducted for literature review of the role of national public health institutes in COVID-19 response. Source: (*18*). WHO, World Health Organization.

61 NPHIs by categorizing all 111 IANPHI members by their country's position on 4 World Bank income levels (i.e., high, upper-middle, lower-middle, and low) and 6 World Bank regions. We then selected 2–3 NPHIs per tier from each of the 6 regions. The NPHIs represented 52 countries because some countries have >1 IANPHI. One researcher conducted the electronic search.

We also searched gray literature for a subsample of 8 NPHIs (selected from the 61 NPHI sample frame). We selected 2 NPHIs from each World Bank income tier, at least 1 per World Bank region. Two researchers searched Google, websites, and social media accounts of the 8 NPHIs. Our Google search terms included the proper name of each of the 8 NPHIs in English, the name in the language of origin, and "COVID-19." For both searches, we included all studies, reports, new articles, and websites in any language that described activities conducted by NPHIs as part of the COVID-19 response. We used Google Translate for articles not in English (Appendix 2 Table 2).

We imported electronic search articles to NVIVO software (*20*) and gray search articles to an Excel database (Microsoft, https://www.microsoft.com) for qualitative thematic analysis (Appendix 2). We conducted our analysis by following a 3-step, evidence-based strategy (*21*). We used a codebook of deductive and inductive codes and established a coding agreement between reviewer pairs through independent coding and comparison of 2 sample returns. Our conceptual framework was the IANPHI Essential Public Health Functions framework (*22*). This framework describes 11 core public health functions supported by NPHIs, which we used as our exclusive list of deductive codes to categorize NPHI activities in the COVID-19 response (Appendix 2 Table 3).

Results

Characteristics of the Literature

From our electronic database search, we screened 667 references by title and abstract and reviewed the full text of 95 articles. A total of 33 peer-reviewed and 23 gray articles met our inclusion criteria. Through our search of gray literature, we identified 277 relevant returns: 75 websites, 62 news articles, 60 social media postings, and 80 guidelines and reports (Appendix 2 Table 4). All articles were published during March 2020–May 2021; 84% were published during June 2020–January 2021.

Articles included in the review described NPHI activities in 20 countries, which represent 39% of the 52 countries searched and 21% of countries globally that have NPHIs (Figure 2; Appendix 2 Table 5). Most articles summarized NPHI activities in a single country (only 3 articles featured NPHI activity in >1 country). The literature from the electronic search was skewed toward 3 countries: Brazil, South Korea, and the United States (representing 33 [59%] of 56 electronic search returns). Returns from the gray literature search of 8 countries represented 236 (71%) of total returns from all searches. As a result, 269 (81%) of the total articles included in the review were focused on 10 countries. The electronic search returned no articles or reports for 34 (65%) of the countries searched.

NPHI Functions and Activities during the COVID-19 Response

COVID-19 activities among the 20 NPHIs included in this review were reported across all 11 public health functions but most commonly for 5 functions (Appendix Table 3). Because included articles did not document NPHI activities in a consistent fashion across all functions in each country, this summary is an underrepresentation of the full role of each NPHI.

Public Health Surveillance, Problem Investigation, and Control of Risks and Threats to Public Health

Collecting and Sharing Surveillance Data

NPHIs were lead authorities for collecting and analyzing epidemiologic data to project COVID-19 cases,

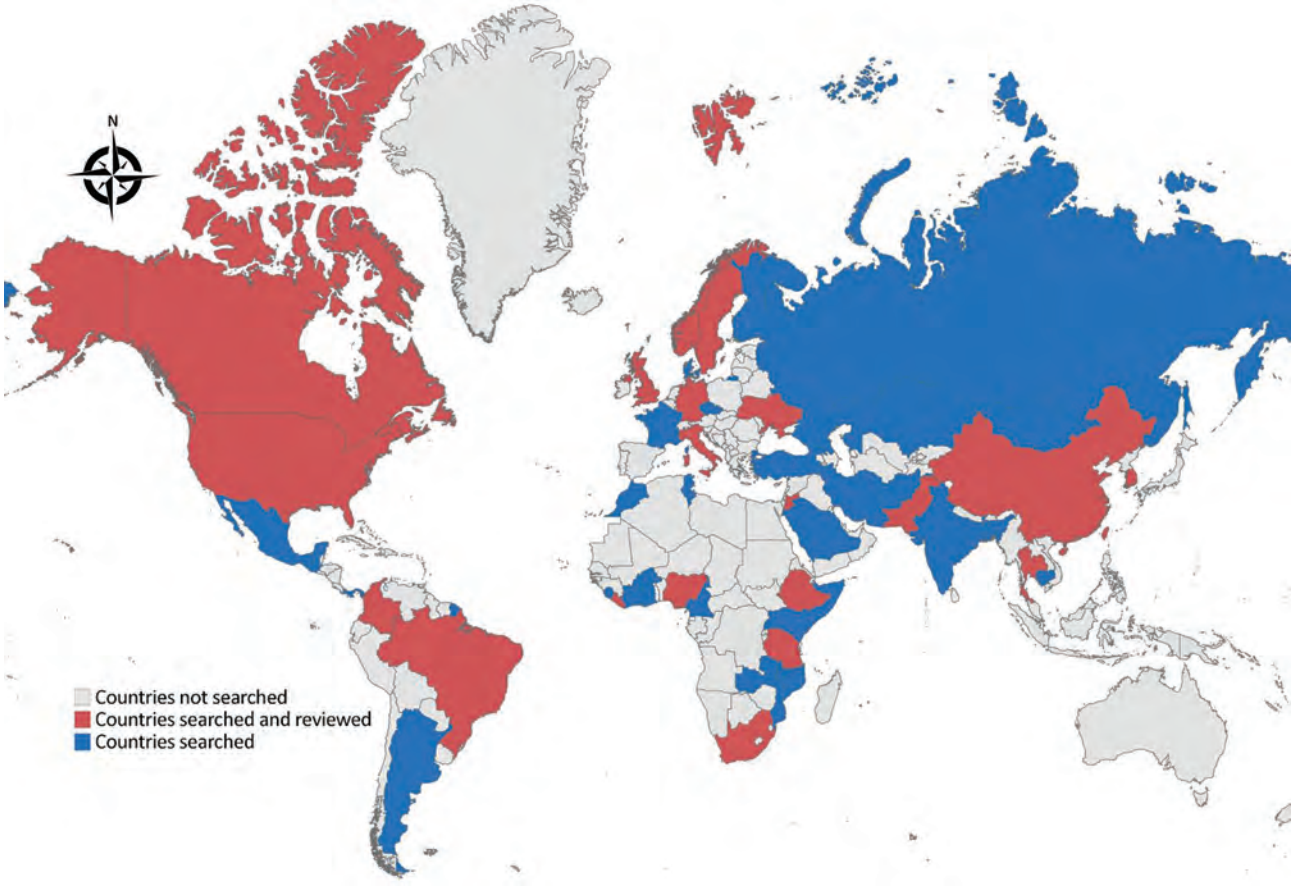

Figure 2. Countries with International Association of National Public Health Institutes members searched and reviewed for literature review of the role of national public health institutes in COVID-19 response.

deaths, transmission patterns, and hospitalization rates. To manage COVID-19 data, NPHIs from England and Italy built upon existing integrated disease surveillance systems for infectious disease, including use of sentinel surveillance, vaccine uptake, and household and seroprevalence studies. NPHIs from Canada, Colombia, and Brazil designed and deployed mathematical models to determine scenarios for COVID-19 transmission and to evaluate public health approaches such as quarantine and social distancing. For example, to provide real-time projections of COVID-19 transmission, hospitalizations, and deaths, Brazil used smartphone Global Positioning System data and measured population mobility in combination with COVID-19 deaths, hospital use, and adherence to isolation measures.

Setting COVID-19 Case Definitions

For the purposes of disease surveillance, NPHIs set case definitions or standard criteria to classify whether a person has COVID-19. NPHIs in Pakistan, Ethiopia, South Korea, and Jordan established case definitions for screening of passengers at international airports, laboratory and hospital managers of COVID-19 case-patients, and healthcare workers.

Managing Laboratory Services

Many NPHIs led laboratory services in the COVID-19 response. For example, the South Korea NPHI partnered with the Korean Society for Laboratory Medicine to develop comprehensive guidelines for laboratory diagnostics for COVID-19, which included selection of persons to test, transport of specimens, diagnostic methods, interpretation of test results, and biosafety. The Pakistan NPHI disseminated standard operating procedures for specimen collection, management, and transport of samples for COVID-19 testing.

Many NPHIs produced the first diagnostic technology for COVID-19 in their countries, including collecting the first samples of COVID-19 and genotyping the virus. The Ethiopia NPHI repurposed existing personnel and infrastructure for malaria, HIV, and other disease research to provide diagnostic capability for COVID-19. The South Korea NPHI leveraged previous efforts to improve coronavirus testing in the wake of the Middle East respiratory syndrome (MERS) epidemic to rapidly establish COVID-19 testing capability as early as December 2019, which enabled extensive early detection of cases. NPHIs from South Korea and Thailand were also involved in genomic sequencing of SARS-CoV-2 virus, which became especially valuable for public health decision-making as new strains emerged.

As COVID-19 cases increased, several NPHIs were at the forefront of COVID-19 case confirmation. The Pakistan NPHI built upon its national public health laboratory and laboratory-based systematic influenza surveillance network to make COVID-19 confirmation testing available by using real-time PCR. Italy NPHI laboratories were opened around the clock to perform confirmation testing; they also provided technical support to other central laboratories for confirmation testing. The Brazil NPHI created COVID-19 Diagnostic Support Units with a testing capacity of 20,000 tests/day.

NPHIs also typically designed and managed the public health laboratory network within each country. The South Korea NPHI ensured that real-time diagnostic capability was established in 18 provincial public health laboratories, and test results became available within 6 hours. The Colombia NPHI first collected all patient samples from 32 departments nationwide for testing in its national reference laboratory; thereafter, it decentralized the process so that ≈172 reference laboratories nationally could support COVID-19 testing. The South Korea NPHI performed quality control of all public and private sector laboratories for in-country COVID-19 diagnostic testing.

Screening

NPHIs were engaged in COVID-19 screening of travelers from high-risk countries and of patients, guests, and employees of the hospital system. For example, the US NPHI partnered with the airline industry and other federal authorities to set standards for medical evaluation of passengers before allowing them entry into the country and for mandatory quarantine. Those data were shared with state-level health authorities for follow-up.

Testing

NPHIs were lead authorities for COVID-19 testing, which included developing national multisectoral testing plans, overseeing testing facilities, and providing training and technical support to testing facilities across sectors. To improve data matching for results, the England NPHI established procedures for individual self-testing, which included arranging for samples to be sent to the Public Health England national laboratory and linking to the person's National Health Service identification number. The Liberia NPHI provided COVID-19 testing directly to all incoming air passengers. The Pakistan NPHI monitored subnational testing activities and developed

quality indicators for point-of-care testing. To expand COVID-19 testing, it also provided training, technical advice, and support to testing facilities nationwide.

The South Korea NPHI developed a national plan for COVID-19 testing, which included 137 testing facilities across public facilities, public hospitals, and referral laboratories. It also managed an advanced testing network, which included 638 public health centers, a COVID-19 hotline for healthcare providers, and drive-through and walk-through testing centers to enable throughput of patients in ≈10 minutes. Testing strategies in South Korea were also tailored to the level of risk identified by the NPHI, and highly affected regions were targeted for testing by deploying rapid response teams.

Quarantine

NPHI support for quarantine activities included helping formulate quarantine policy, providing healthcare service to quarantined populations, and working with government agencies to enforce quarantine. The Liberia NPHI collaborated with county governments and international partners to set up a quarantine facility. The Jordan NPHI provided special medical and healthcare services to quarantined populations. The China and South Korea NPHIs provided data on confirmed cases for local-level police and other authorities to support home-based and facility-based quarantine implementation.

Contact Tracing

NPHIs commonly led contact tracing programs. Through the use of technology and wide-ranging multisectoral partnerships, the South Korea NPHI managed a single coordinated contact tracing system that combined smartphone data, credit card transactions, closed-captioned television footage, and more, which enabled public health practitioners to determine a patient's movement and potential exposures for the past 48 hours. The database also assisted early research on clusters by providing accurate contact mapping. Through international collaboration, the Germany NPHI conducted cross-border contact tracing with other member states in the European Early Warning System and through communication with International Health Regulation national focal points. The China NPHI conducted contact tracing for all confirmed cases in the country identified from its national disease surveillance system.

Emergency Operations Centers

Nigeria, the United States, and Ethiopia also led Emergency Operations Centers. In Nigeria, the first confirmed COVID-19 case led to activation of the country's National Emergency Operations Centre to level 3, and the Nigeria NPHI led this group with the support of Lagos State Health authorities to conduct strict epidemic control measures.

Public Health Research

NPHIs actively led public health research for COVID-19. NPHIs from Brazil, Colombia, the United Kingdom, South Korea, Norway, Pakistan, Italy, and Canada established networks and platforms for research collaboration. The Norway NPHI established a rapid research review process, which identified evidence needs and conducted evidence reviews in 1–3 days to inform guideline development. All work of this NPHI is published on the Live Map of COVID-19 Evidence, which contained 18,000 publications as of February 2020 (*23*).

NPHIs also conducted research, clinical trials, and published papers related to COVID-19. We found 105 studies with NPHI support, defined as funding (n = 25), data (n = 35), or direct study implementation (n = 13). For example, NPHIs in Colombia, Jordan, and Tanzania conducted seroprevalence studies. NPHIs in Brazil and South Korea conducted clinical trials on treatment, immunization, and mental health effects on healthcare workers as well as epidemiologic studies. NPHIs also made datasets available for other researchers, nationally and internationally.

Prevention Programs and Health Promotion

NPHIs were further involved in COVID-19 prevention efforts through support for vaccination reporting and risk communication. For example, the US NPHI helped manage 2 vaccine reporting systems to obtain efficacy and safety data on COVID-19 vaccines: the Vaccine Adverse Events Reporting System, which aggregates self-reported adverse vaccine events from patients and clinicians, and the Vaccine Safety DataLink, which gathers hospital data from ≈10 million patients. Both systems enable monitoring of vaccine safety and further studies on rare and severe adverse events. The Colombia NPHI created standard operating procedures for healthcare workers to identify and report vaccine adverse events and register cases with surveillance systems.

NPHIs were involved in risk communication through websites, social media, routine briefings to the public, situational reports, and engagement with communities and multisectoral partners. Health promotion messages and risk communication targeted disproportionately affected populations, such as traditional fishing communities (Brazil), religious

congregants (South Korea and Canada), and employees in occupational settings (England). NPHIs' COVID-19 risk communication activities more commonly focused on a general audience (Italy); restaurants, schools, and nursing homes (Sweden); and other government agencies and clinic settings (United States). In Nigeria, the most popular source of COVID-19 information cited during the pandemic was the NPHI.

NPHIs also worked closely with other sectors and communities to advance their public health messages. The Jordan NPHI started a multisectoral risk-communication campaign on mental health and COVID-19, through partnerships with nongovernmental organizations, academia, public and private media outlets, social media, and religious leaders. The Tanzania NPHI worked with municipalities and local communities to develop a risk communication plan that included relevant media outlets to disseminate culturally appropriate COVID-19 preventive measures. The South Korea NPHI repurposed a 24-hour hotline created for risk communication during the MERS outbreak to support COVID-19 health communication.

Quality Assurance in Personal and Population-based Healthcare Services

Some NPHIs also supported population access to COVID-19 healthcare services, managed surge capacity, and ensured quality of service delivery. The Brazil NPHI, in partnership with the Ministry of Health, built a rapid assembly hospital on its campus, with 200 beds to treat critically ill COVID-19 patients. The South Korea NPHI established a tiered patient-severity index and supported the repurposing of nonhospital facilities for case-patients with mild illness. Private dormitories and training centers were converted into isolation centers for those with severe illness.

NPHIs also provided national guidance and support for infection prevention and control (IPC) procedures in healthcare and public settings. The Italy NPHI participated in a multisectoral working group that provides guidance on IPC measures against COVID-19 transmission in healthcare facilities and maintained a unit dedicated to the management of IPC initiatives. The South Korea NPHI sterilized and fumigated public places such as public transit settings and theaters.

NPHIs also supported risk assessment in healthcare settings by establishing tools for clinicians and occupational health practitioners. For example, the South Korea NPHI developed standard, mandatory symptom screening of all hospital visitors and staff via a smartphone application. It further reduced hospital-based infections by managing supply and demand of face masks through social networks and smartphone applications.

Human Resources Development and Training

As part of the COVID-19 response, NPHIs routinely engaged in human resources development, which included training and deploying staff and forming platforms and working groups to coordinate workforce development activities. Ethiopia, Colombia, Liberia, Pakistan, and South Korea NPHIs conducted workshops and training for laboratorians based in universities and hospitals nationwide. NPHIs commonly partnered with other sectors to advance this training. For example, the South Korea NPHI trained private hospitals and laboratories to use the diagnosis kits in partnership with the Korean Society for Laboratory Medicine Practice; the Pakistan NPHI, together with multiple academic partners, provided online training for laboratory technicians.

NPHIs from Canada, Colombia, Italy, Liberia, and Ukraine also built human resource capacity in case identification and management, contact tracing, surveillance, and IPC. The Liberia NPHI leveraged its experience from the Ebola virus disease response to recruit, train, and deploy contact tracers early in the response. The Jordan NPHI and other partners trained ≈400 healthcare workers nationwide on COVID-19 vaccination.

The US NPHI deployed staff to subnational units to assist in the COVID-19 response. It created a dedicated COVID-19 response section to support state, tribal, local, and territorial health departments. The system deployed hundreds of teams to support subnational teams with data collection, epidemiologic investigations, contact tracing, and more.

Two NPHIs managed training platforms and working groups. The Ethiopia NPHI and partners launched the COVID-19 Ethiopia Health Worker Training Platform, a smartphone-based digital learning platform for healthcare workers responsible for COVID-19 diagnosis and treatment. The Italy NPHI supported a multisectoral COVID-19 training working group that designs standardized training methods, conducts needs assessments, evaluates training, and organizes scientific meetings to share knowledge and best practices.

Discussion

Our literature review revealed that NPHIs played an active role in the COVID-19 response. This role was normative (e.g., setting quarantine policy) and involved implementation (e.g., providing COVID-19

testing). NPHIs rarely acted alone but instead commonly partnered with government authorities at national and subnational levels (including health, education, security, and emergency services); private industry (including private manufacturers, laboratories, and airlines); and civil society (including training institutions, professional associations, and community groups). They also sponsored novel digital health technologies to support contract tracing, quarantine, and population health data analytics.

The engagement of NPHIs in surveillance, public health research, and public health prevention and promotion is consistent with the literature with regard to what are considered core NPHI capabilities (*22*,*24*). However, the active role reported for NPHIs in quality assurance reflects a special role played by NPHIs during an epidemic, in which triaging hospital access and containing hospital-based infections is paramount. Of note, NPHIs routinely leveraged personnel, infrastructure, practices, and policies established in response to previous epidemics (e.g., MERS, HIV, and Ebola) to respond to COVID-19, which illustrates the value of sustained development of epidemic response capability by NPHIs over time.

Limitations of our review included the lack of documentation for 61% of the countries searched and the skew of available articles toward 10 countries, which prevented generalizability of the study findings. It is noteworthy that the highest number of relevant articles was identified by searching NPHI websites and social media, followed by conducting electronic searches by using proper name of the NPHI. Many articles that we screened described the government response to COVID-19 but omitted the role of NPHIs. Few articles offered any comparisons between NPHI activities.

We conclude that there is a gap in the systematic comparison of these institutions with respect to COVID-19, which could elucidate trends, challenges, and best practices in the manner called for by Jakab et al. (*25*). A study by Binder et al., published after our review, contributes to this end (*26*). Those authors conducted a literature review and listening sessions comprising leaders from 10 Africa NPHIs and documented common challenges faced by these NPHIs and innovations. However, they report that their methods did not systematically document NPHI activities with regard to COVID-19, and the article does not document the role of NPHIs outside of Africa (*26*).

To obtain consistent and comprehensive data on the role of NPHIs with regard to COVID-19 globally, we recommend direct data collection through surveys and interviews. Those activities would fill gaps in data by public health function and geography and allow for cross-country comparisons and measuring the degree or intensity of NPHI activities. Survey findings also open up the potential for quantitative analysis of the relationship between NPHI activities and COVID-19 outcomes, such as confirmed cases, mortality rates, and social distancing. Such analyses would benefit from additional information that would enable stratification based on characteristics of NPHIs, such as size, maturity, and funding. Together, this information could build on other analyses that attempt to explain country COVID-19 outcomes (*15*,*16*; C.T. Lee et al. unpub. data, https://www.medrxiv.org/content/10.1101/2021.02.02.21251013v1) and could identify key areas for shoring up public health capacity to improve the response to future epidemics.

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Adapting Longstanding Public Health Collaborations between Government of Kenya and CDC Kenya in Response to the COVID-19 Pandemic, 2020–2021

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Kenya's Ministry of Health (MOH) and the US Centers for Disease Control and Prevention in Kenya (CDC Kenya) have maintained a 40-year partnership during which measures were implemented to prevent, detect, and respond to disease threats. During the COVID-19 pandemic, the MOH and CDC Kenya rapidly responded to mitigate disease impact on Kenya's 52 million residents. We describe activities undertaken jointly by the MOH and CDC Kenya that lessened the effects of COVID-19 during 5 epidemic waves from March through December 2021. Activities included establishing national and county-level emergency operations centers and implementing workforce development and deployment, infection prevention and control training, laboratory diagnostic advancement, enhanced surveillance, and information management. The COVID-19 pandemic provided fresh impetus for the government of Kenya to establish a national public health institute, launched in January 2022, to consolidate its public health activities and counter COVID-19 and future infectious, vaccine-preventable, and emerging zoonotic diseases.

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In December 2019, cases of pneumonia of unknown origin were reported in Wuhan, China (*1*). The disease, COVID-19, was caused by betacoronavirus SARS-CoV-2; the World Health Organization (WHO) declared the COVID-19 outbreak a public health emergency of international concern on January 30, 2020, and a pandemic on March 11, 2020 (*2*). By December 23, 2021, a total of 276.4 million persons had received a confirmed SARS-CoV-2–positive test and ≥5.4 million persons had died from COVID-19 (*3*).

Countries in sub-Saharan Africa, including Kenya, conducted enhanced surveillance activities before their first documented COVID-19 cases (*4*). Early surveillance activities in Kenya used platforms established by Kenya's Ministry of Health (MOH) and Kenya Medical Research Institute that are supported by external partners, including the WHO, US Centers for Disease Control and Prevention in Kenya (CDC Kenya), US Agency for International Development, US Department of Defense, Wellcome Trust (*5*), and Africa Centres for Disease Control and Prevention. COVID-19 prevention, detection, and response efforts in Kenya began in mid-January 2020 and included laboratory strengthening, deployments to the national public health emergency operations center (PHEOC), training healthcare workers on infection prevention and control (IPC), enhanced surveillance, and screening persons arriving at ports of entry (POE). On March 13, 2020, the President of Kenya announced the country's first laboratory-confirmed COVID-19 case, which was detected by the National Influenza Center (NIC) Reference Laboratory. By

December 26, 2021, Kenya had experienced 5 epidemic waves (July and November 2020 and March, August, and December 2021); a total of 282,554 laboratory-confirmed COVID-19 cases, 5,361 related deaths, and a case fatality rate of 1.9% were reported (Figure 1) (*6*). In addition, 64% of the population in Kibera, a densely populated informal settlement in Nairobi, were exposed to SARS-CoV-2 by June 2021 (*7*).

For >40 years, CDC Kenya has partnered with Kenya's MOH to support developing workforce capacity, infrastructure, and systems to prevent, detect, and respond to multiple disease threats. We describe longstanding collaborations between CDC Kenya and the government of Kenya that were adapted to respond to the COVID-19 pandemic in 2020 and 2021. In addition, we briefly describe some new initiatives for controlling COVID-19. The experience in Kenya illustrates how existing public health assets can be adapted and mobilized for new epidemics.

CDC Kenya's Technical and Financial Assistance to MOH COVID-19 Response

As of December 2021, CDC Kenya had 26 staff from the United States, 124 staff from Kenya, and offices in Nairobi and Kisumu. In January 2020, CDC Kenya formed an internal COVID-19 response team that was aligned to Kenya MOH's outbreak response pillars: surveillance, laboratory diagnostics, finance and logistics, IPC, clinical care, and emergency management. In March 2020, in coordination with Kenya MOH, CDC Kenya deployed 53 Kenya-based technical experts across the country to support the COVID-19 response (9 staff were US citizens and 44 were Kenya citizens). By December 2021, 32 CDC Kenya staff remained deployed to support Kenya's COVID-19 response. Upon detection of COVID-19 in Kenya, CDC Kenya allocated funds to implementing partners to support COVID-19 activities through the Global Health Security Agenda, US President's Emergency Plan for AIDS Relief, and other CDC Kenya programs, such as the Influenza Program. By December 2021, CDC Kenya had awarded nearly $40 million to implement COVID-19 response activities in support of the MOH and 17 select counties in Kenya (Appendix Table, https://wwwnc.cdc.gov/EID/article/28/13/21-1550-App1.pdf).

Workforce and Emergency Management and Response

The Kenya MoH established PHEOC in 2016 with support from CDC Kenya and WHO. Initial technical and financial support included equipping the physical space, drafting standard operating procedures, and training staff in the incident management system and outbreak response. From 2013 through Novem¬ber 2022, a total of 6 citizens of Kenya attended CDC's Public Health Emergency Management fellowship training program (8), 4 of whom completed the pro¬gram in 2020-2021. The fellowship includes a rotation in the CDC Emergency Operations Center (EOC) in Atlanta, Georgia, USA (*9*). The previous PHEOC incident manager in Kenya completed

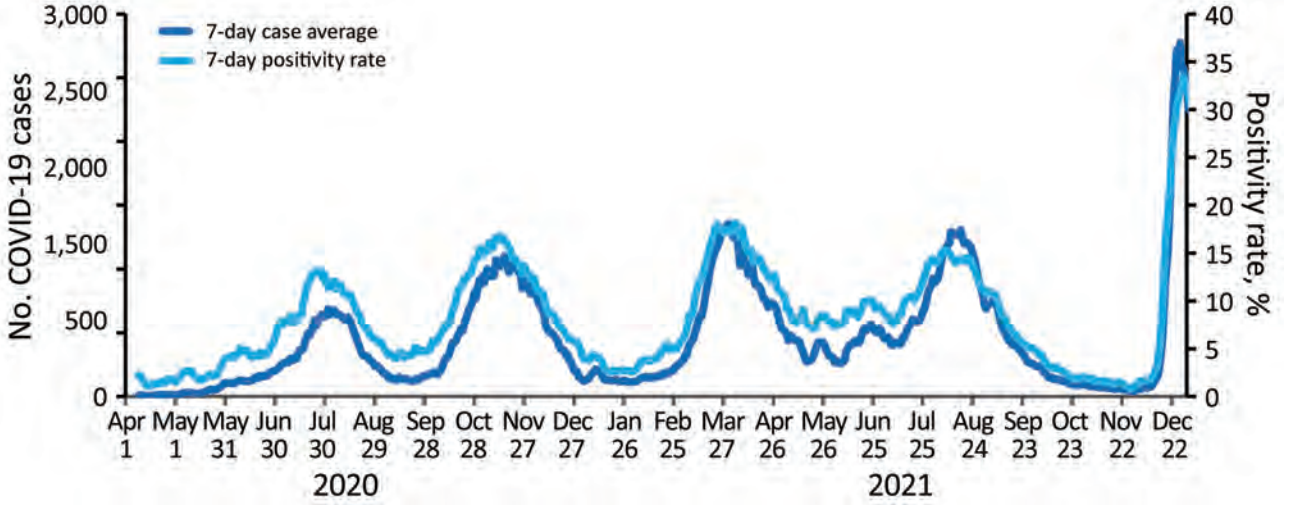

Figure 1. Average number of laboratory-confirmed COVID-19 cases and SARS-CoV-2 positivity rates in Kenya from April 1, 2020, through December 26, 2021, in a review of longstanding public health collaborations between the government of Kenya and CDC Kenya in response to the COVID-19 pandemic. The US Centers for Disease Control and Prevention in Kenya supports the Kenya Ministry of Health with COVID-19 data analysis and visualization. By December 26, 2021, Kenya had experienced 5 epidemic waves during July and November in 2020 and March, August, and December in 2021; a total of 282,554 laboratory-confirmed COVID-19 cases, 5,361 related deaths, and a case fatality rate of 1.9% were reported. The graph shows the 7-day averages for the number of COVID-19 cases and positivity rates.

this fellowship; 2 additional fellows joined Kenya's COVID-19 response team immediately after completing the fellowship and applied their expertise to finalize PHEOC's national strategic plan and framework documents. Three more citizens of Kenya participated in the program in 2022.

Since 1980, CDC has trained >18,000 epidemiologists in >80 countries through the CDC Field Epidemiology Training Program (*10*). The Kenya MOH launched the Kenya Field Epidemiology and Laboratory Training Program (FELTP) in 2004, providing training in basic, intermediate, and advanced field epidemiology to 850 graduates over the past 16 years. The MOH relies on FELTP graduates as lead responders during public health emergencies. For example, by the end of 2021, a total of 79% (173/220) of graduates from the 2-year advanced FELTP worked in 40 of Kenya's 47 counties. During 2020–2021, a total of 22 FELTP residents were deployed to counties to provide mentorship to rapid response teams, and 20 FELTP residents were deployed to POEs to screen 145,275 travelers from >2,000 international flights. The MOH asked CDC Kenya to double the number of residents in the FELTP in 2022 to rapidly expand the workforce. Although FELTP residents were critical assets, early assignments, such as screening travelers, did not optimize their highly technical skill sets. After the government of Kenya increased frontline staff, FELTP residents were able to focus on data analyses and use.

CDC Kenya provided in-person support to Jomo Kenyatta International and Moi International airports and Busia, Malaba, Namanga, Isebania, and Lunga Lunga 1-stop border posts. They trained >1,000 nonhealth workers using a RING (Recognize, Isolate, Notify, and Give support) card as job aid. In June 2020, ≈1,000 truck drivers crossed the Kenya–Uganda border daily, creating a 50-km backup at the border that attracted international media attention (*11*). A coordinated effort by several partners, including CDC Kenya, helped resolve those delays through the deployment of additional human resources and an information system that enabled the MOH to process truckers efficiently, while a CDC Kenya-supported laboratory processed specimens.

A primary responsibility of PHEOC is to integrate data from multiple sources to provide timely information for decision makers. In partnership with the Kenya MOH, CDC Kenya supported the development of PHEOC's integrated dashboard that displayed outbreak information. In addition, the Kenya MOH guided the adaptation of 3 CDC Kenya-supported information systems: Kenya electronic medical records system (*12*), an online client management system that was expanded from its HIV program support origins to enable COVID-19 case investigation, contact tracing, and management of quarantined contacts; viral load database, an automated HIV laboratory database that was adapted to track COVID-19 real-time reverse transcription PCR (RT-PCR) testing, cycle threshold values, and indirectly track commodities; and Jitenge, a mobile application that enabled POE travelers and quarantined clients to self-report daily on their health status in a national database (*13*).

By early 2021, the Kenya MOH, supported by CDC Kenya and WHO, began decentralizing emergency management and established county-led EOCs. With initial seed funding of $750,000 from CDC Kenya, those 17 new EOCs established an incident management system and produced routine situation reports that guided the county-level response (Figure 2). County EOCs managed local outbreaks, including implementing isolation and quarantine measures during the SARS-CoV-2 outbreak. The EOCs coordinated their COVID-19 vaccination campaigns, tracing thousands of persons who did not report for their second vaccine, and integrated programs to improve uptake among clinically vulnerable populations, such as persons living with HIV.

Diagnostic Laboratory Support

Building capacity for laboratory diagnostics has been a pillar of the Kenya MOH and CDC Kenya partnership (*14*). WHO emphasized that timely SARS-CoV-2 testing was the foundation of each country's response (*15*). In the early stages of the COVID-19 epidemic in Kenya, the MOH focused on testing persons returning from international travel. However, once local transmission was well-established in mid-2020, after which >50% of patients had no international travel history, the MOH adopted a strategy to use human resources for tracing contacts and testing persons in high-risk settings, such as healthcare workers.

RT-PCR remains the definitive assay to detect SARS-CoV-2 RNA in Kenya. National laboratory diagnostics for the COVID-19 response were coordinated by the NIC, which was established in 2017 partly through support from CDC Kenya, who aided in the procurement and installation of equipment, preparation for WHO accreditation (granted in 2019), and building staff capacity for respiratory pathogen testing using RT-PCR. Coordination of partners by the Kenya MOH enabled the NIC to achieve testing capacity for SARS-COV-2 in early February 2020. The Africa Centres for Disease Control and Prevention procured RT-PCR primers and reagents, CDC Kenya

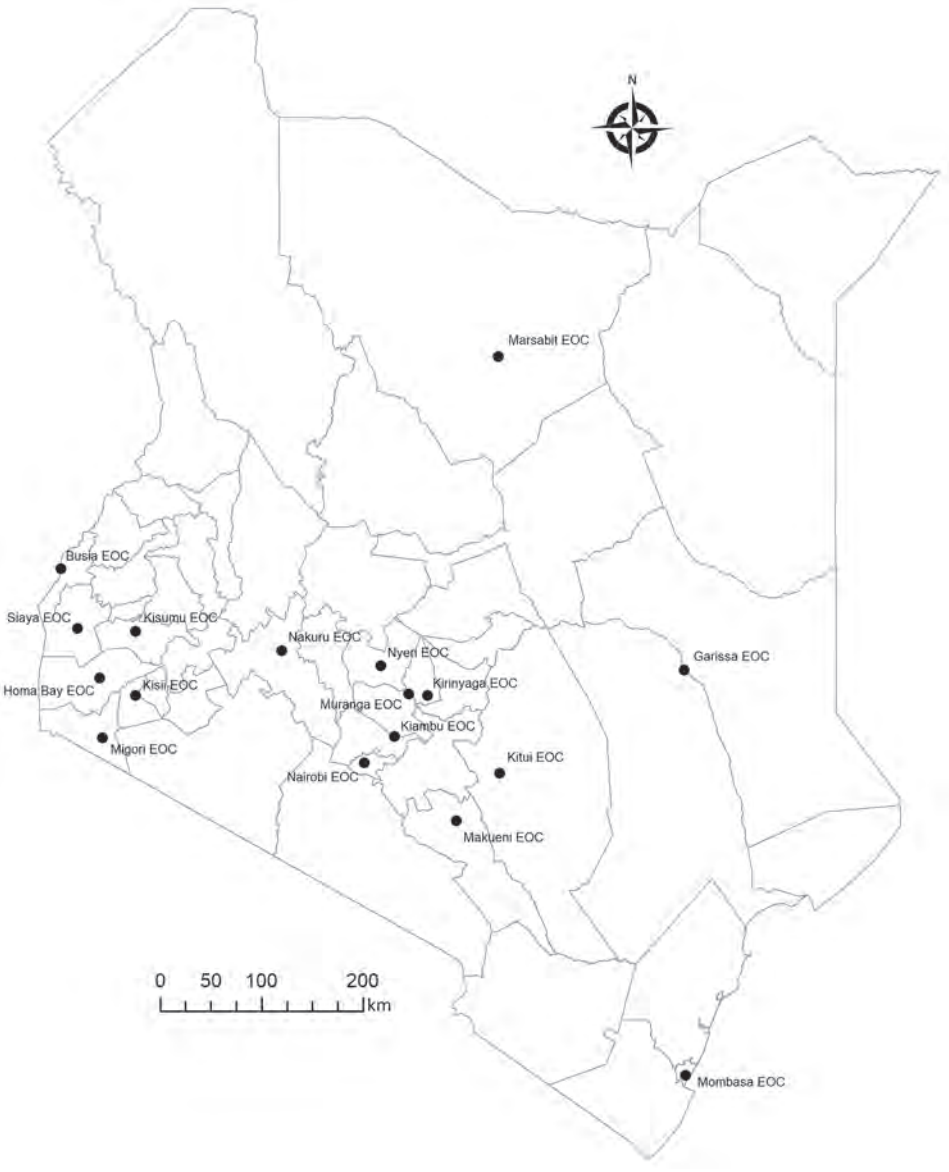

Figure 2. Locations of county EOCs supported by CDC Kenya in a review of longstanding public health collaborations between the government of Kenya and CDC Kenya in response to the COVID-19 pandemic. By early 2021, the Kenya Ministry of Health, US Centers for Disease Control and Prevention in Kenya, and World Health Organization began decentralizing Kenya's emergency management. As of December 2021, a total of 17 county-led EOCs had been established in Kenya. Those 17 new EOCs established incident management systems and produced routine situation reports that guided the county-level response to the COVID-19 epidemic in Kenya. EOC, Emergency Operating Center.

collaborated with NIC staff to validate the assay, and WHO confirmed Kenya's testing capacity within 24 hours of receiving the reagents. Throughout the COVID-19 pandemic, the NIC coordinated the diagnostics of 50 laboratories that test for SARS-CoV-2.

CDC Kenya's laboratory support focused on commodity and personal protective equipment (PPE) procurement, specimen transport, test verification, salary support for additional laboratory personnel, genomic sequencing, and repurposing high-throughput RT-PCR–based HIV testing platforms for SARS-CoV-2. CDC Kenya supported 45% of SARS-CoV-2 testing in Kenya in 2020, decreasing to 34% in 2021 after additional MOH laboratories were established. Also in 2021, Kenya MOH and CDC Kenya collaborated on a field evaluation of an antigen rapid diagnostic test (RDT) kit, and 2 CDC-supported laboratories were among the 5 laboratories performing genomic sequencing. The CDC-supported laboratory in Kisumu was the first to detect the SARS-CoV-2 Delta variant in Kenya at the beginning of the fourth wave; sequencing results were used for the first time to inform mitigation measures coordinated by the county EOC, including quarantine and isolation measures and intensified case and contact tracing.

Epidemic Intelligence

Kenya MOH and CDC Kenya have collaborated on surveillance initiatives for >2 decades. In January 2020, leveraging surveillance platforms for early

detection and mitigation of SARS-CoV-2 was identified as a priority activity by the MOH. CDC's surveillance platforms are protocol-driven and including COVID-19 testing required an amendment. To improve the responsiveness of these platforms in the future, CDC Kenya added language to health security protocols that increase flexibility when the PHEOC is activated.

CDC Kenya's longstanding support of several surveillance systems created geographically diverse opportunities for COVID-19 monitoring. Kenya first implemented severe acute respiratory illness surveillance in 2006 (*16*); the platform currently operates in 8 sites that receive CDC Kenya support to conduct active hospital-based surveillance. By December 2021, a total of 5,162 patients had samples tested for SARS-CoV-2 of which 509 were positive (9.9% positivity rate). Also, since 2006, Kenya Medical Research Institute and CDC Kenya have conducted population-based infectious disease surveillance (PBIDS) in Kibera in Nairobi County, one of the largest informal urban settlements in Africa, and rural Asembo in Siaya County (*17*,*18*). The PBIDS platform includes health facility and household components for a population of >25,000 persons per site. The first COVID-19 case in Kibera was detected on May 8, 2020, by using the PBIDS platform. By December 2021, a total of 1,572 cases (14.0% positivity rate) in Kibera and 628 cases (6.1% positivity rate) in Asembo were reported. Furthermore, in Kibera, CDC Kenya supported 3 rounds of a SARS-CoV-2 seroprevalence survey. The overall weighted individual seroprevalence increased from 43.3% (95% CI 37.4%–49.5%) in December 2020 to 63.9% (95% CI 59.5%–68.0%) in June 2021 (*7*). In 2019, CDC Kenya supported the introduction of a pilot event-based surveillance platform in 4 counties. Similar to the Ebola virus disease response in Guinea (*19*), the core feature of event-based surveillance was a toll-free telephone line to report unusual events for investigation. Activity on the toll-free line reached a peak of 100,000 calls/day after the onset of the COVID-19 epidemic in Kenya.

CDC Kenya supports Kenya MOH with data analysis and visualization (Figure 1), including monitoring populations of interest such as truck drivers and healthcare workers. CDC Kenya participates in the MOH-directed COVID-19 national task force and contributes substantially to the modeling committee that generates analyses briefs for policy makers, including recommendations for implementing nonpharmaceutical interventions. For example, during the first COVID-19 wave, all patients were directed to isolate in facilities, and travel between all 47 counties was suspended, regardless of county epidemiology. The MOH rapidly revised guidance to enable patients with mild COVID-19 to recover at home. During the

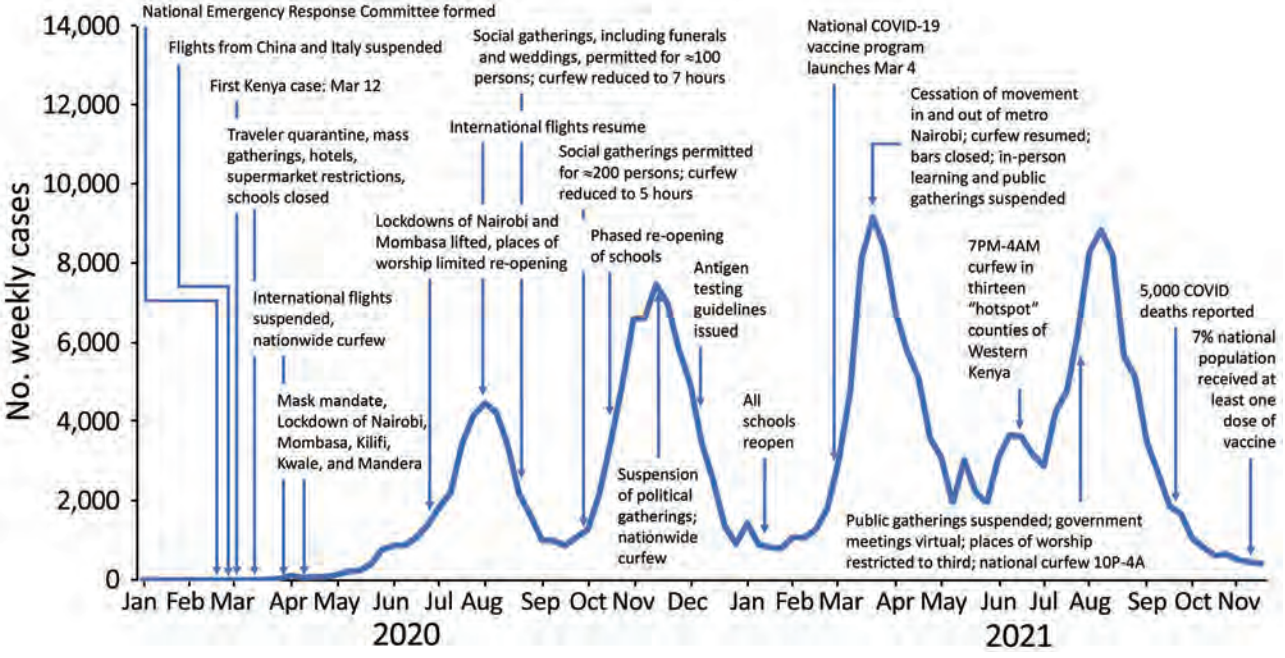

Figure 3. Government applied nonpharmaceutical interventions during the COVID-19 pandemic in Kenya from February 2020 through November 2021 in a review of longstanding public health collaborations between Government of Kenya and CDC Kenya in response to the COVID-19 pandemic. Examples of nonpharmaceutical interventions utilized in Kenya include traveler quarantine, restrictions on mass gathering, school closures, mask mandates, curfews, and phased lifting of restrictions in response to case levels. The graph indicates the number of weekly cases and the period in which the specific nonpharmaceutical and pharmaceutical interventions were implemented.

third wave, when most transmissions occurred in 5 counties, the MOH prohibited travel in and out of those counties, while leaving travel open for residents in the remaining 42 counties. Additional examples of nonpharmaceutical interventions used in Kenya included traveler quarantine, mass gathering restrictions, school closures, mask mandates, curfews, and phased lifting of restrictions in response to case levels (Figure 3). In March 2021, one year after the first COVID-19 case was detected in Kenya and in the absence of available data visualization, CDC Kenya partnered with WHO and Kenya MOH to launch a public dashboard that integrated and displayed COVID-19 epidemic information to support data-informed decision making. This dashboard filled a gap and was used to guide the acute response phase; the country now relies on daily situation reports and the WHO COVID-19 dashboard (*3*).

County Engagement and Response in Kisumu County

In 2019, CDC Kenya assisted the Kisumu County Department of Health in conducting an outbreak readiness assessment in the event that the Ebola virus outbreak in the Democratic Republic of the Congo spread to Kenya. This assessment exercise established a foundational partnership before the first COVID-19 case was detected in Kisumu County in June 2020. Compared with Nairobi County, Kisumu County had 3 extra months to prepare for COVID-19 cases and conducted mass procurement of PPE and test kits. CDC Kenya and Kisumu County Department of Health implemented the WHO's First Few X Cases protocol used to track community transmission among the first 150 cases and their close contacts (*20*). In addition, CDC Kenya supported the installation of the county EOC; trained staff on the incident management system; equipped the EOC physical space; developed guidance on PPE use, waste management, patient flow modifications, and facility and isolation preparedness assessments; and participated in community education opportunities. In May 2021, the Kisumu EOC coordinated the initial response to the first cases of the SARS-CoV-2 Delta variant in Kenya with support from FELTP residents.

Health System

The Kenya MOH partnered with CDC Kenya to establish the patient and health worker safety unit >10 years ago. CDC Kenya and WHO supported the MOH IPC guideline development, training, and policy development and dissemination. One of CDC Kenya's major activities during 2020–2021 was providing technical and financial support to train >8,500 MOH, rapid response team, POE, county health, and healthcare workers on screening procedures, IPC, case and contact tracing, risk communication, sample collection, and biosafety and biosecurity. Biosafety and biosecurity scored particularly low in the 2017 WHO Joint External Evaluation (*21*). Training was adapted to a virtual environment in February 2020, and virtual components became available on the Project ECHO platform (*22*) to all 47 counties by September 2021.

For ≈2 decades, CDC Kenya provided technical assistance to the Kenya Prisons Service. Because of prison overcrowding, Kenya MOH prioritized testing inmates for SARS-CoV-2 to improve early identification and case management. By December 2021, a total of 10,925 cases of COVID-19 were identified among staff and 85,229 inmates. Test positivity rates of up to 90% were observed during outbreaks among new inmates in some prisons. In 2020, CDC Kenya worked with Kenya Prisons Service to develop COVID-19 control plans, integrate COVID-19 and tuberculosis screening for new inmates, train employees on IPC, and analyze data. In 2021, CDC Kenya and Kenya Prisons Service launched an EOC to help control COVID-19 and other outbreaks in prison settings, and, by December 2021, 94.5% of inmates had received at least one COVID-19 vaccine dose (Kenya Prisons Service, pers. comm., email, 2021 Dec 26).

The Kenya MOH focused on COVID-19 vaccine distribution after administering the first dose on March 5, 2021. As of December 24, 2021, a total of 5.6 million persons had received their first dose, and 3.9 million persons were fully vaccinated (14.4% of the goal) (*6*). Of the 23.3 million vaccine doses donated to Kenya by December 2021, the US government donated 7.4 million doses (31.8%) through the COVAX (COVID-19 vaccines global access) initiative and was the largest bilateral donor of COVID-19 vaccines. In late 2020, the government of Kenya established a multisectoral COVID-19 vaccination deployment task force to develop a national vaccination deployment plan that prioritized certain groups to receive the vaccine, including healthcare workers, teachers, security personnel, and persons ≥58 years of age. By September 2021, CDC Kenya and partners trained >2,500 healthcare workers on vaccine administration in 8 priority counties, which comprised 26% of the national vaccination objective. CDC Kenya also supported Kenya's Pharmacy and Poisons Board to strengthen passive and active surveillance of adverse events following immunization.

Discussion

By December 2021, Kenya had experienced 5 COVID-19 epidemic waves. Kenya MOH leveraged its partnership with CDC Kenya, and the multidisciplinary CDC Kenya response team was deployed to support the COVID-19 response. The country's COVID-19 Intra-Action Review noted that Kenya MOH ability to adapt and utilize longstanding health security activities for the COVID-19 response was a strength (S.H. Matendechero, Kenya MOH, pers. comm., email, 2021 Dec 7). Examples of those activities were incorporating SARS-CoV-2 testing into existing surveillance platforms, strengthening the national PHEOC while installing 17 county-level EOCs, deploying 42 FELTP residents across the country to contribute to response activities, using CDC Kenya–supported laboratories to perform 45% of nationwide COVID-19 testing in 2020 and 34% of testing in 2021, and using the PBIDS platform to detect the first case in Kibera.

Because of the demonstrated importance of workforce development and the PHEOC during the COVID-19 pandemic, in August 2020, the president of Kenya announced that the government would establish a national public health institute (NPHI). The institute would integrate essential public health pillars that were already performing well according to the WHO Joint External Evaluation score (Appendix Table) (*21*); surveillance and laboratory platforms would be connected further to enable the national PHEOC and county EOCs to monitor and respond to diseases of public health interest in a timely and appropriate manner. The NPHI was legally launched in January 2022, and its design and resources are being established by the government of Kenya.

Although laboratory capacity and epidemiologic surveillance form the foundation of a public health response (*23*), Kenya was chronically on the verge of running out of laboratory commodities during most of 2020. Relying heavily on donor procurement during 2020, the MOH used 15 different test kits, which met the testing demand but also complicated commodity management. Until testing eased between waves, the Kenya MOH promoted commodity sharing between laboratories according to test platforms and volume, which was monitored by the viral load database. Considering these realities, the MOH and CDC Kenya concluded a field evaluation of an antigen RDT kit in July 2021 that demonstrated adequate sensitivity only among symptomatic patients who had high viral loads (*24*). Those unexpected results were used by Kenya MOH to clarify that antigen RDTs should be used in high-transmission settings or in locations where RT-PCR testing was not easily accessible, and negative RDT results should be confirmed by RT-PCR.

Although CDC Kenya contributed to Kenya's health security, the MOH's routine coordination of donors and partners through the national task force and the Development Partners for Health in Kenya was identified as a strength during the COVID-19 Intra-Action Review (S.H. Matendechero, Kenya MOH, pers. comm., email, 2021 Dec 7). This coordination continues to be essential to ensure that dedicated COVID-19 resources are used appropriately and critical areas are optimally managed. As vaccine distribution has increasingly become the focus, broad national task force coordination has decreased in frequency, which has resulted in reduced management of communication, laboratory, and surveillance functions. The COVID-19 Vaccination Intra-Action Review identified the need to strengthen human resources, cold chain capacity, and surveillance data management to optimize vaccine distribution (S.H. Matendechero, Kenya MOH, pers. comm., email, 2021 Dec 7).

The COVID-19 response has provided the Kenya MOH–CDC Kenya partnership the opportunity to evolve. The 2017 WHO Joint External Evaluation (*21*) noted that CDC Kenya predominantly financed the FELTP. CDC Kenya and Kenya MOH are committed to shared support for this program, and the MOH increased its funding for the FELTP, while also seeking additional funding from the Global Fund. Joint financial ownership has led to improved collaboration, including reviewing the FELTP curriculum for health informatics in response to the COVID-19 Intra-Action Review findings that there were inadequate electronic data management systems in Kenya (S.H. Matendechero, Kenya MOH, pers. comm., email, 2021 Dec 7).

The main limitation of our review is that some aspects of program monitoring and vaccine defaulter tracing were constrained because health information systems were not interoperable. For example, Chanjo KE, Kenya's COVID-19 vaccine registration system, was not interoperable with other systems used by the MOH and PHEOC. Emerging from the COVID-19 pandemic, the Kenya MOH is pursuing an ambitious vision for a digital health platform, a clinical system built on interoperable modules linked by a unique patient identifier. This system would link laboratory and clinical data enabling improved program and patient monitoring.

Containing the pandemic will require continued and increased coordination by national and

county leadership to maintain increased vaccination coverage, improve access to testing, ensure quality healthcare availability, and use nonpharmaceutical interventions wisely (*25*,*26*). The activities implemented by Kenya MOH and CDC Kenya over the past 4 decades were adapted and used to strengthen the COVID-19 response, which focused specifically on 5 core capabilities of CDC: data and analytics, laboratory capacity, public health expertise, outbreak response, and global capacity building (*27*). As Kenya establishes its NPHI, along with support from WHO and the Africa Centres for Disease Control and Prevention, CDC Kenya's partnership with the MOH will continue to reinforce ongoing efforts to prepare for and respond to health threats in the country and region.

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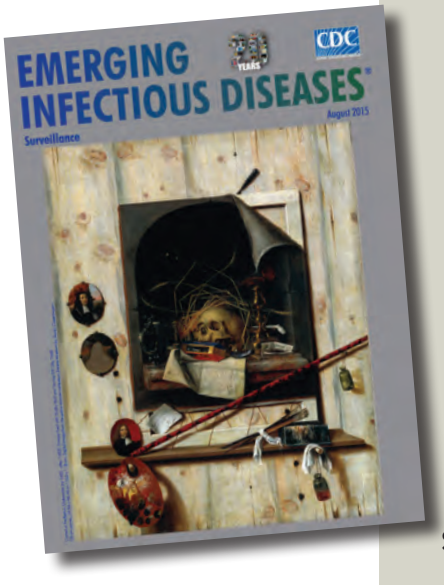

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Escherichia coli

[esh"ə-rik'e-ə co'lī]

A gram-negative, facultatively anaerobic rod, *Escherichia coli* was named for Theodor Escherich, a German-Austrian pediatrician. Escherich isolated a variety of bacteria from infant fecal samples by using his own anaerobic culture methods and Hans Christian Gram's new staining technique. Escherich originally named the common colon bacillus *Bacterium coli commune*. Castellani and Chalmers proposed the name *E. coli* in 1919, but it was not officially recognized until 1958.

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Effect of Nigeria Presidential Task Force on COVID-19 Pandemic, Nigeria

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Nigeria had a confirmed case of COVID-19 on February 28, 2020. On March 17, 2020, the Nigerian Government inaugurated the Presidential Task Force (PTF) on COVID-19 to coordinate the country's multisectoral intergovernmental response. The PTF developed the National COVID-19 Multisectoral Pandemic Response Plan as the blueprint for implementing the response plans. The PTF provided funding, coordination, and governance for the public health response and executed resource mobilization and social welfare support, establishing the framework for containment measures and economic reopening. Despite the challenges of a weak healthcare infrastructure, staff shortages, logistic issues, commodity shortages, currency devaluation, and varying state government cooperation, high-level multisectoral PTF coordination contributed to minimizing the effects of the pandemic through early implementation of mitigation efforts, supported by a strong collaborative partnership with bilateral, multilateral, and private-sector organizations. We describe the lessons learned from the PTF COVID-19 for future multisectoral public health response.

After COVID-19 emerged in China, and before the first case in Nigeria was confirmed, the Nigeria Centre for Disease Control (NCDC) established the multisectoral National Coronavirus Preparedness Group (NCPG) to coordinate the country's preparedness and response efforts (*1*). The Federal Ministry of Health (FMOH) established the Inter-Ministerial Committee on COVID-19 on January 31, 2020 (*1*).

On February 28, 2020, NCDC confirmed the first COVID-19 case in Nigeria. After that confirmation, the NCPG transitioned to an NCDC-led national multisectoral Emergency Operations Centre (EOC), activated at level 3, the highest level of response in the country intended for public health emergencies, requiring national coordination and use of all available resources (*1*). On March 17, 2020, the country's president established the Presidential Task Force (PTF) on COVID-19 (*2*) with a mandate to coordinate and oversee Nigeria's multisectoral intergovernmental efforts to contain the spread and mitigate the impact of COVID-19 in Nigeria. The Secretary to the Government of the Federation chaired PTF, and a national coordinator supervised day-to-day management. The membership included leaders from 13 key ministries, departments, and agencies (MDAs); members were the Honorable Ministers of Health, State for Health, Aviation, Humanitarian Affairs, Disaster Management and Social Development, Education, State for Education, Foreign Affairs,

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Information and Culture, Interior, and Environment; the directors-general of NCDC and Directorate of State Services; the executive director of the National Primary Health Care Development Agency (NPHCDA); and the World Health Organization (WHO) Country Representative. Cabinet-level membership enabled the PTF to focus on high-level political engagement and decision-making.

The PTF coordinated and developed multisectoral frameworks, established budgets, identified funding sources, developed key policy and enforcement measures, ensured national security throughout the response, coordinated response activities with state governments, and managed negative economic effects of the COVID-19 pandemic in Nigeria. The PTF tenure was originally 6 months; it was extended to December 31, 2020, and then to March 31, 2021. In April 2021, PTF activities were streamlined (by reducing number of MDAs) and transitioned to a Presidential Steering Committee (PSC) on COVID-19, focused on sustaining the multisectoral response as the pandemic waned; this structure freed resources for other health and social issues.

To achieve its mandate, the PTF developed the National COVID-19 Pandemic Multisectoral Response Plan (NPRP) (*3*). Its strategic objectives were to provide a coordinated national and subnational multisectoral response to the COVID-19 pandemic; to reduce COVID-19–related illness and deaths; to mitigate pandemic-related impacts on critical, economic, and health infrastructure; and to support postpandemic recovery and rehabilitation. We describe lessons learned from the Nigeria PTF-guided multisectoral COVID-19 response that may be applicable for future public health responses.

The National Pandemic Response Center

The PTF established the National Pandemic Response Centre (NPRC), the technical coordinating structure responsible for providing strategic guidance on the national response, estimating MDA resource needs and allocations, and coordinating all response stakeholder efforts. Stakeholders included MDAs, donors, development partners, nongovernment organizations, and civil society. The organized private sector established the Coalition Against COVID-19 (CACOVID) to coordinate their engagement. The NPRC, led by the PTF national coordinator, included Secretariat, led by a chief of secretariat (CoS) and an incident manager, who coordinated 9 functional pillars. Each pillar was led by different government MDAs with mandate and oversight for their pillar; for example, NCDC oversaw surveillance and laboratory and FMOH led case management (Table 1; Figure 1). Staff from the US Centers for Disease Control and Prevention (CDC), US Agency for International Development (USAID), WHO, UNICEF, e-Health Africa, CREDO, and the Bill and Melinda Gates Foundation supported the NPRC.

The PTF convened a multidisciplinary advisory group to provide evidence-based briefing papers, informing real-time decision making. The group comprised health policy and service experts, including

Table 1. National Pandemic Response Center pillars, by lead agency and focal area, Nigeria, 2020

Thematic area	Lead agency	Area of focus
Epidemiology and surveillance	Nigeria Centre for Disease Control	Improve surveillance, early detection and timely reporting of community transmission of COVID-19
Laboratory	Nigeria Centre for Disease Control	Strengthen laboratory testing and performance
Point of entry	Federal Ministry of Health; Port Health Services	Expand border security patrol and ensure every entry point are equipped for sample collection for testing
Case management	Federal Ministry of Health	Provide technical assistance and epidemiological support to states to improve case management
Infection, prevention, and control	Nigeria Centre for Disease Control	Embed and strengthen functional infection prevention and control programs across the country
Risk communication and community engagement	Federal Ministry of Information and Culture	Strengthen communication around COVID-19 and continuously work with partners to undertake research to address key drivers of behavior change
Security, logistics, and mass care	Federal Ministry of Humanitarian Affairs, Disaster Management, and Social Development	Develop standards and criteria for enforcement of protocols and sanctions
State coordination and government relations	Nigeria Governor's Forum	Strengthen state engagement and ownership of the COVID-19 response efforts
Resource mobilization	Office of the Secretary of the Federation	Ensure sustainable funding for the COVID-19 response
Research	Federal Ministry of Health	Conduct scientific, clinical, anthropological and socio-economic research to provide the evidence base for guiding decision making in COVID-19 planning and response in Nigeria
Sustainable production subgroup	Federal Ministry of Industry, Trade and Investment	Ensure long-term uptake and availability of COVID-19 supplies and products from Government and credible investors

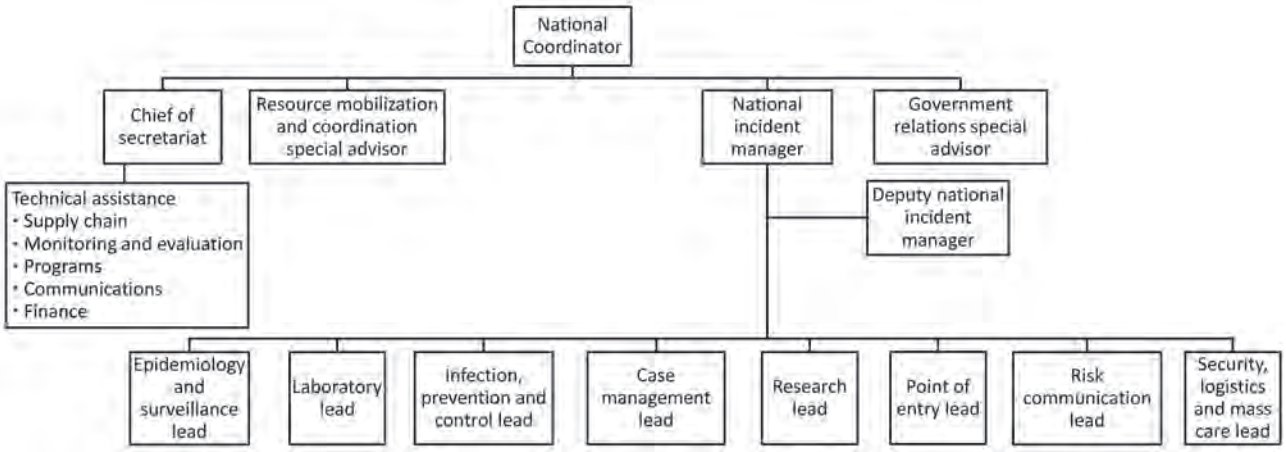

Figure 1. National Pandemic Response Center organizational chart, Nigeria, 2020. Technical assistance comprises staff from various agencies and government who helped oversee each of the specified area listed—supply chain, monitoring and evaluation, programs, communication, and finance.

epidemiologists, modelers, public health experts, social scientists, foreign and domestic academicians, and NPRC staff. This group produced >44 papers supporting PTF decision making by modeling the epidemic trajectory, including potential number of expected cases, deaths, and bed space, and recommended policies and interventions required to reduce transmission risk (*4*).

The NPRC

To provide effective technical guidance and direction, the NPRC developed a comprehensive pandemic response plan (PRP), the blueprint for the coordinated national COVID-19 strategy (*3*), in addition to the NCDC-developed public health incident action plan. The PRP included activities beyond health, such as disaster management, humanitarian affairs, information, security, finance, trade, and investment. The PRP described complementary response roles of national and state governments (Table 2), private sector, and development partners. The PRP divided the response into 6 phases based on the national and WHO epidemic response plans (Table 3), with specific tasks for each phase following specific trigger events.

The PTF Midterm Review

In July 2020, four months after it began, the NPRC implemented a midterm review (MTR) to assess PTF

Table 2. COVID-19 multisectoral MDAs, by sector and role, Nigeria, 2020

Sector	National MDAs and roles	State MDAs and roles
Health	NCDC: Lead on epidemiology, surveillance laboratory, and IPC FMOH: Lead on case management port health management, research on COVID-19 Nigeria Primary Healthcare Development Agency: Community centers and vaccination Nigeria Institute of Medical Research: Research around COVID-19	The state Emergency Operations Center, which comprises members from the State Ministry of Health, State Primary Healthcare Development Agency, and State Health Management Board liaise with the FMOH and NCDC in their day-to-day operations
Nonhealth	Ministry of Information and its agencies take the lead on risk communication Ministries of Interior, Aviation, and Transportation and their agencies, such as Nigeria Immigration Service, Customs, Nigeria Civil Aviation Authority, Federal Airports Authority of Nigeria, Nigerian Ports Authority, Nigerian Maritime Administration and Safety Agency, run the ports of entry Ministry of Humanitarian Affairs and its agency, National Emergency Management Authority, lead mass care Ministry of Defense and the Police, Nigeria Security and Civil Defence Corp, and Federal Road Safety Corp support security and logistics Ministry of Industry, Trade, and Investment oversee and coordinate local production of personal protective equipment Ministry of Finance is involved in economic impact and recovery activities	The state task force, led by the governor or his designate, includes representatives from line MDAs similar to those in the national MDAs—these include the ministries of information and finance, the State Emergency Management Authority, the security agencies, and others

*FMOH, Federal Ministry of Health; MDA, ministries, departments, and agencies; NCDC, Nigeria Centre for Disease Control.

Table 3. Summary of the national pandemic response plan phases, Nigeria, 2020

Phase	Description	Response
1	No cases	Monitoring global trends, surveillance, early detection of high-risk passengers for follow-up, isolation of symptomatic cases
2	Sporadic cases	Increased surveillance, set up of quarantine and isolation procedures, cancellation of gatherings, public sensitization, forecasting and quantification of commodities and personal protective equipment
3	Cluster of connected cases	Intensified surveillance towards containment, expedited sample collection, testing; isolation and management of suspected/confirmed cases, mass care
4	Community transmission	Declaration of a national emergency activation of triage sites and alternative treatment sites. Increased stock of supplies. Mass care. Allocation of resources for public safety and order
5	Postpeak	Continued surveillance, testing, case management, and infection prevention and control measures. Provision of social protection services
6	Recovery	Deactivation and decontamination or triage and treatment sites. Reviewed and modified risk communication. Authorization for opening of public spaces

achievements and challenges and adapt the response for the remaining PTF term (*5*). To complement ongoing public telephone and online surveys and data from each pillar, we conducted an online survey with key stakeholders from MDAs, multilateral organizations, donors, and civil society to assess and score perceptions on the PTF's performance. The survey revealed an aggregate 4.0/5.0 score for the PTF's role in coordinating the national COVID-19 response and collaboration with stakeholders. The lowest score was 2.5 for mitigating the socioeconomic impact (*5*).

During the MTR, MDAs and pillars presented performance reports and received feedback from stakeholders including cabinet ministers, legislators (including the chairmen of the relevant committees on health in the Senate and House of Representatives), representatives from the Office of the Vice President, the Nigeria Governors' Forum (NGF), donors and partners, the diplomatic community, civil society, and Health Sector Union representatives.

The MTR findings (*5*) revealed PTF achievements, with collaboration of NCDC and FMOH, that included the setup of 39 laboratories nationwide and of 131 treatment centers with 7,040 total bed capacity and 256 ICU beds. A total of 138,462 persons were tested and treated, representing a 40% increase in testing from March to June 2020 (*5*). Challenges identified in the MTR included delays in international border closures, negative socioeconomic effects including access to essential services and resources for livelihood, insufficient contact tracing, and low testing rates (<1% of the population had tested by the time of the MTR) (*5*). MTR findings were used to update the NPRP, guiding the national COVID-19 response through detailed action plans for implementation by pillars over the subsequent 6 months.

The PTF End-of-Year Review

In December 2020, the PTF conducted an end-of-year review to assess performance, identify how to sustain the gains made to date, and plan for PSC initiation. An online survey was distributed to key stakeholders to gather feedback on the government of Nigeria's pandemic response. The survey revealed that stakeholders were satisfied with the PTF's performance and commitment to the COVID-19 response. By the end-of-year review, key achievements included developing the Nigeria International Travel Portal (NITP); ramp-up of testing; enhanced infection, prevention, and control (IPC) practices for healthcare workers; reduced infections in healthcare workers; sufficient bed space for case management;, and resumption of economic activities. Challenges included poor enforcement of nonpharmaceutical preventive measures, low community-level testing, and slow economic recovery (*6*).

End-of-Year Review Findings

During March–December 2020, the PTF, through different pillars and the Secretariat, continued fund mobilization, policy formulation, and public- and private-sector collaboration to improve laboratory testing capacity, preventive measure enforcement, healthcare infrastructure improvement, and capacity development. We organized PTF achievements into 8 categories (Figure 2).

Funding

A total of ₦178,800,260,723 (458,462,207 USD) was mobilized for the COVID-19 response (Figure 3). Local and international donors/partners contributed >70% of funds. To promote fiduciary transparency, donors were encouraged to provide direct support to state-led activities based on state plans to avoid funds passing through PTF or national government accounts. This support did not include funds spent directly by donors, e.g., building isolation centers, hiring staff, and deploying rapid-response teams.

Healthcare

By December 31, 2020, the PTF, through NCDC and other partners, had successfully supported 975,786

Figure 2. Depiction of the Presidential Task Force on COVID-19 end-of-year review categories, Nigeria, 2020.

COVID-19 tests, a 600% increase from the 138,462 tests recorded at the MTR in June 2020. PTF reported 13,798 active cases and 1,311 deaths for a case fatality rate of ≈2% (*7*). Daily COVID-19 trends were reported, and weekly epidemiologic profiling guided allocation of resources.

Facility and Laboratory Capacity Building

At the beginning of the pandemic, frontline HCWs were trained and provided with infrastructure for managing suspected cases while adhering to safety protocols and procedures. Capacity development focused on 3 categories: isolation and treatment facilities, COVID-19 testing capacity, and training. The PTF, in collaboration with NCDC, private-sector partners (especially CACOVID), and some state governments, successfully set up and accredited 131 isolation and treatment centers with a total capacity of 7,040 beds across the country over a period of 6 months.

The NCDC led development of decentralized COVID-19 testing laboratory capacity to ensure nationwide geographic coverage and improve 24-hour test turnaround time. By December 31, 2020, Nigeria had 98 operational laboratories, 68 government-owned and 30 private/corporate owned, a 151% increase since the MTR. Molecular testing platforms varied, some, such as TB GeneXpert (Cepheid, https://www.cepheid.com), were repurposed for COVID-19 testing; genomic sequencing was instituted in 3 laboratories. Through December 5, 2020, more than 35,500 HCWs were trained on appropriate IPC practices, including proper use of personal protective equipment. FMOH led case management and developed protocols for establishment of isolation and treatment centers with federal tertiary hospitals as training hubs. Training protocols for frontline HCWs on treatment guidelines and capacity building of biomedical engineers on ventilators and other devices were established. Regular national case reviews of state situations became standard.

Social Welfare

To ensure support for those in need, a national economic recovery plan was created in June 2020 (*8*). The government developed programs to aid vulnerable persons and households. Donors/partners (e.g., CACOVID), MDAs (e.g., Federal Ministry of Humanitarian Affairs, Disaster Management, and Social Development), supported provision and distribution of palliative packages to those in need, including low-income internally displaced and physically challenged persons and women, children, and elderly, that were intended to cushion socioeconomic and psychological effects of the COVID-19 pandemic. Palliatives were either food items delivered to frontline states (a total of 70,000 megatons distributed to 8,827,129 households in 24 states) or cash transfers (1,289,405 beneficiaries in 34 states and the Federal Capital Territory [FCT]).

The distribution of palliatives coincided with a period of social unrest and protests against police brutality (the #EndSARS [Special Anti-Robbery Squad] movement). The harsh economic environment due to the pandemic and public mistrust of government intentions further exacerbated the unsettled mood in the country. Widespread looting of relief items from storage sites and warehouses followed. State governments were widely criticized for not distributing the relief items earlier; however, CACOVID had not completed the delivery of some palliatives and had to halt the process when protests started. Furthermore, the size of the country and level of poverty meant that relief items were insufficient to reach all in need.

Communication

The risk communication pillar maintained regular communication with stakeholders, engaging partners and donors, MDAs, and the public. The PTF leveraged traditional and social media for communication and advocacy materials to build awareness of the COVID–19 pandemic and Nigeria's response. Communication was highlighted as a success of the PTF in >24 rounds of nationwide and state weekly telephone polls and surveys conducted by NOI Polls during May–November 2020, assessing citizens' perception of national and state government's COVID-19 response. State-specific sample sizes ensured states were proportionately represented in surveys of >36,000 citizens. The surveys assessed citizens' perception in 5 key areas: trust/concern, communication monitoring, preventive measures/palliatives, misinformation, and testing. Topics covered included adherence to COVID-19 prevention protocols (e.g., mask-wearing, handwashing, physical distancing); burial protocol, school and National Youth Service Corps (NYSC) reopening, and exposure to and effect of COVID-19 messages. Data collected revealed that PTF successfully maintained regular communication with relevant stakeholders and the public. Challenges included delayed release of guidelines, government mistrust, noncompliance with COVID-19 protocols, and poor testing uptake. As vaccines came into sight, PTF worked with NPHCDA to update the communication strategy to address vaccine uptake and hesitancy.

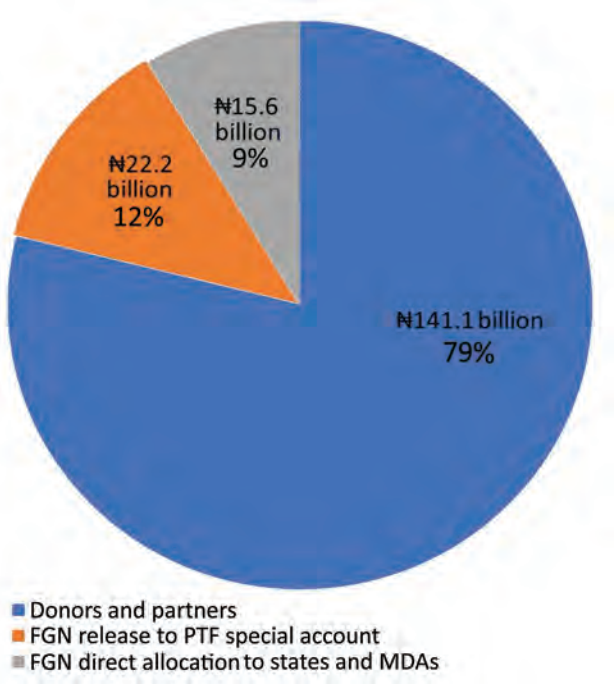

Figure 3. Percentage contribution in naira (₦) and source of funds for COVID-19 response, Nigeria, March–December 2020. FGN, federal government of Nigeria; PTF, Presidential Task Force; MDAs, ministries, departments, and agencies. Source: United Nations Development Program dashboard, Office of the Secretary to the Government of the Federation, Resource Mobilization pillar.

Economic Support

To cushion the effect of lockdowns and restrictions in movement, the federal government's economic program provided loans for individual persons and small and medium-size businesses (Table 4). In addition, at the beginning of the pandemic, travel and tourism, education, worship centers, restaurants, and other sectors were closed at different periods to minimize the risk for transmission and safeguard the health of citizens. Stay-at-home orders and cessation of nonessential movements and activities were initially mandated for Lagos, Ogun, and FCT. Subsequently, other states adopted varying degrees of lockdown strategies, including school closure, movement restriction, and cessation of interstate and international travel (*6*). As lockdowns eased and businesses, schools, and other places for social gatherings began to operate, guidelines for the safe and efficient reopening of the Nigeria economy were developed and released in tandem with the Economic Sustainability Plan (*8*).

The PTF worked closely with the Federal Airports Authority, Nigeria Immigration Service, the Nigerian Civil Aviation Authority, and other international aviation partners and authorities to develop best-practice protocols and measures for resuming air travel. The NITP was updated with changes in travel policies based on the epidemiology in Nigeria and other countries.

NYSC, a national service for new university and college graduates, reopened orientation camps on

Table 4. COVID-19 economic support, Nigeria, March–December 2020

Government Enterprise and Empowerment Program (GEEP)	Trader and market Moni loans	Rapid expansion of the National Social Register
Sensitized over 5 million small scale traders listed in the GEEP database about COVID-19 pandemic. Granted 3 months moratorium on payments owed to 2.2 million existing GEEP beneficiaries and completed 99% of the loan disbursement target	Disbursed loans to 43,117 beneficiaries in 11 states (Lagos, Ogun, Plateau, Bauchi, Yobe, Zamfara, Katsina, Edo, Cross River, Enugu, and Imo) and the Federal Capital Territory	Updated the National Social Register to include previously unidentified vulnerable citizens, now including 3.6 million households in 36 states and the Federal Capital Territory

May 17, 2020. To ensure the safety of the staff and volunteers, PTF, NCDC, and NYSC teams assessed COVID-19 control measures before opening the camps that could host >1,000 participants. Public health guidance for safe reopening of the NYSC camps was distributed across the country. With support from NCDC, all participants underwent COVID-19 PCR or rapid antigen testing before or upon arrival at the camp. Trained staff were assigned to NYSC camps to monitor and support compliance with COVID-19 preventive measures. NYSC camp residents were placed in bubbles, with minimal outside contact after COVID-19 screening to reduce risk for COVID-19 transmission; persons testing positive were not admitted.

After the PTF announced reopening of places of religious and social gatherings, NCDC published guidelines to reduce the risk for infection in places of worship, social gathering centers, hotels, and event centers. Guidelines included mandatory use of face masks, temperature screening, denial of entry for sick persons, provision of hand hygiene stations, attendance limited to a third of the seating capacity, physical distancing of ≥2 m, and no physical contact (*9*). Enforcement proved to be challenging and depended on state governments to implement and sanction organizations and entities that did not comply with the guidance.

Surveillance

The PTF surveillance and epidemiology pillar, led by NCDC, intensified surveillance activities for early COVID-19 case detection, timely reporting of cases, and coordination of the outbreak response. The pillar provided daily epidemiologic updates, weekly profiling, trend analysis, and summaries to aid the PTF in informed decision making. The response was conducted in 3 phases: prevention and preparedness, containment, and control and mitigation.

Prevention and Preparedness

The NCDC's surveillance and epidemiology pillar trained and deployed staff to support preparedness for all states. Working with FMOH Port Health Services leadership, they identified point-of-entry sites, developed guidelines and data collection tools, and put the tools into use. They designated treatment centers and conducted simulation exercises with multiple stakeholders.

Containment

The national preincident action plan NCDC developed and referenced in the NPRP was adapted by states. Rapid response teams deployed by NCDC supported affected states with screenings at points of entry and contact tracing activities in high-priority states. States followed travel restrictions and lockdown protocols for nonessential activities.

Control and Mitigation

The pillar revised the national COVID-19 case definition and enabled community active-case search, which increased identification of COVID-19 infected individuals based on symptoms and testing. COVID-19 treatment centers were strengthened to ensure mandatory institutional quarantine and testing for international travelers was enforced. In addition, policies on home-based care for COVID-19 drastically reduced bed occupancy in isolation centers and increased the capacity of healthcare workers to manage patients who needed emergency care. However, when self-isolation and IPC were not strictly adhered to, home-based care increased the risk for transmission of COVID-19 among family members and the community (*10*). Hotspots were identified across local government areas, and efforts were intensified to contain community transmission.

Resource Management

Funds and resources were received from public and private-sector organizations including national and state governments, CACOVID, WHO, UNICEF, the US government (CDC, USAID, US Department of State, Walter Reed Army Institute of Research WRAIR), the UK Department for International Development, the European Union, the Government of Japan, and other partners (*5*). Mobilized donor funds came from the One UN COVID-19 Response Basket Fund. Resources included technical support and expertise to ensure comprehensive COVID-19 response. Areas supported were technical guidance on IPC measures, training healthcare workers on case management and outbreak response, risk communication to mitigate disease spread, community engagement and awareness of COVID-19 prevention measures, civil society organization mobilization to sustain essential health services, strengthened state level surveillance operational capacity, data analysis, and logistics. By December 6, 2020, the partner agencies allocated ₦19,500,000,000 (US $50,000,000) for technical support. Partners donated materials to MDAs and state governments, including medical equipment, consumables, and infrastructure. Although the PTF worked closely with donors to prioritize and implement projects, no donor funds were directly disbursed or spent by the PTF. All data on mobilized resources were shared on the PTF dashboard for accountability and public access (*5*).

Coordination and Partnership at National and Subnational Levels

The PTF's collaboration with the donors, partners, and the private sector, especially CACOVID, enabled resources and technical support, such as setting up the NITP and isolation centers at the state level, to be provided in a timely manner. In addition, the National Assembly played a key role in passing legislation for a national COVID-19 budget, and the NGF, made up of governors of all 36 states and FCT, served as a crucial platform for the PTF and Secretariat to get standardized messages and protocols to all for prompt implementation at the subnational level.

At the end of the PTF term in March 2021, the roles and responsibilities were transitioned to the PSC until the end of 2021, mandated to build on the PTF achievements and work with NPHCDA to ensure the successful rollout of COVID-19 vaccines across Nigeria. Despite the success recorded over the period of operation, the PTF had several challenges. Nigeria started the pandemic with a weak healthcare infrastructure, including insufficient intensive care units, isolation centers, and other critical needs to provide care for a disease with potential high hospitalization rates. For example, the country had 293 ventilators, far less than the projected estimated need of 1,769. However, level of hospitalization was significantly less than anticipated; hence, hospitals did not run out of ventilators. Logistic bottlenecks, compounded by COVID-19 mitigation lockdowns and shortages of PPE and COVID-19 test kits or components, were common during the early weeks of the pandemic, decreasing COVID-19 testing capacity when it was critical to increase testing. The PTF formed partnerships with key stakeholders and donors to mitigate these challenges. COVID-19 stigma led to difficulty testing suspected persons and eliciting contacts. Effective risk communication and stakeholder engagements were required to address this challenge. A key lesson learned was the importance of mobilizing and responding quickly to the pandemic as well as reinforcing collaborative work with MDAs, including NCDC and other federal ministries, state governments, and donors/partners. The mode of distribution of palliatives provided by the private sector was challenging because of delays in distribution and #EndSARS protests, resulting in palliatives not reaching all in need. Using a health and demographic surveillance system (HDSS) tool could have addressed some gaps in palliative distribution (*11*).

In addition, better monitoring of travelers and enforcement of nonpharmaceutical interventions, such as mask-wearing, could have improved COVID-19 mitigation efforts. Although the NG served as a platform to interact with state governments, occasional differences in opinion created challenges for standardization of recommendations. Finally, the Nigeria COVID-19 response was dynamic as knowledge continued to emerge about the disease. However, the strength of the coordination enabled rapid mobilization and deployment of resources nationwide to address the emergency.

Conclusion

The PTF provided oversight for the multisectoral Nigeria COVID-19 response. Through pillars and functional working groups, the PTF supported coordination and policy formulation, resource mobilization from donors and the private sector, establishment of COVID-19 infrastructures and services, effective risk communication, capacity building of health workers, and improved humanitarian and social interventions. Through the coordinating platform and the development and implementation of policy documents, the PTF contributed to limiting the spread of the virus and mitigating its impact on the health of Nigerians and on the country's economy. In mid-2021, Nigeria scored 4th of 50 countries on an independent normalcy index reviewing transportation and travel, recreation and entertainment, and retail and work (*12*). To ensure gains were not lost and to continue to have a functioning multisectoral body, the PSC on COVID-19 continued to work closely with key health agencies, including the NCDC and NPHCDA, providing strategic direction and oversight to COVID-19 response efforts. This arrangement not only served the country relatively well amid an extraordinary public health crisis but also strengthened government public health agencies to respond better to future pandemics.

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etymologia revisited

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Streptomycin

strep'to-mi'sin

In the late 1930s, Selman Waksman, a soil microbiologist working at the New Jersey Agricultural Station of Rutgers University, began a large-scale program to screen soil bacteria for antimicrobial activity. By 1943, Albert Schatz, a PhD student working in Waksman's laboratory, had isolated streptomycin from *Streptomyces griseus* (from the Greek *strepto-* ["twisted"] + *mykēs* ["fungus"] and the Latin *griseus*, "gray").

In 1944, Willam H. Feldman and H. Corwin Hinshaw at the Mayo Clinic showed its efficacy against *Mycobacterium tuberculosis*. Waksman was awarded a Nobel Prize in 1952 for his discovery of streptomycin, although much of the credit for the discovery has since been ascribed to Schatz. Schatz later successfully sued to be legally recognized as a co-discoverer of streptomycin.

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Use of Epidemiology Surge Support to Enhance Robustness and Expand Capacity of SARS-CoV-2 Pandemic Response, South Africa

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As COVID-19 cases increased during the first weeks of the pandemic in South Africa, the National Institute of Communicable Diseases requested assistance with epidemiologic and surveillance expertise from the US Centers for Disease Control and Prevention South Africa. By leveraging its existing relationship with the National Institute of Communicable Diseases for >2 months, the US Centers for Disease Control and Prevention South Africa supported data capture and file organization, data quality reviews, data analytics, laboratory strengthening, and the development and review of COVID-19 guidance This case study provides an account of the resources and the technical, logistical, and organizational capacity leveraged to support a rapid response to the COVID-19 pandemic in South Africa.

SARS-CoV-2 was identified in late December 2019, the first cases occurring in Wuhan, China (*1*). A rapid spread of the virus in China, followed by an exponential increase of cases across the globe, resulted in the declaration of a global pandemic by the World Health Organization on March 11, 2020; on March 15, 2020, the president of South Africa declared a national state of disaster (*2*). That declaration resulted in the establishment of a National Coronavirus Command Centre and national implementation of nonpharmaceutical prevention measures, such as closures of nonessential private industries, school closures, restrictions on public gatherings, social distancing, citizen curfews (including household confinements), and restrictions on international and domestic interprovincial travel.

Accurate and timely data are essential to stem an outbreak. As COVID-19 cases increased during the first weeks of the pandemic in South Africa, the National Institute of Communicable Diseases (NICD) requested assistance from the US Centers for Disease Control and Prevention South Africa (CDC-SA) with data capture from laboratory-confirmed cases because the number of paper forms received exceeded existing capacity. A measure of the success of this support was reflected in the ability of the government of South Africa (GOSA) publishing daily COVID-19 related statistics in the media.

Although initial requests for support were received from the NICD, these requests were closely followed by similar requests from the National Department of Health (NDoH) Coronavirus Command Council. As a result, CDC-SA was approached to extend epidemiologic and surveillance support to the national level, especially to the provincial levels buckling under the strain of providing timely and accurate COVID-19 data to the NDoH Coronavirus Command Council (Appendix, https://wwwnc.cdc.gov/EID/article/28/13/21-2522-App1.pdf).

Author affiliations: US Centers for Disease Control and Prevention, Pretoria, South Africa (R. Taback-Esra, D. Morof, M. Briggs-Hagen, H. Savva, S. Mthethwa, D. Williams, J. Drummond, N. Rothgerber, M. Smith, M. McMorrow, M. Ndlovu, A. Adelekan, G. Kindra, J. Olivier, N. Mpofu, K. Motlhaoleng, L. Khuzwayo, D. Makapela, P. Manjengwa, A. Ochieng, S. Porter, J. Grund, K. Diallo, R. Lacson); US Public Health Service Commissioned Corps, Rockville, Maryland, USA (D. Morof, M. Briggs-Hagen, M. McMorrow)

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CDC-SA has a long history of providing public health support to GOSA through the US President's Emergency Plan for AIDS Relief (PEPFAR). Through providing HIV and tuberculosis technical assistance and support of direct service delivery, CDC-SA has developed a close working relationship with NICD and the national and provincial departments of health. CDC-SA staff members bolstered multiple elements of the COVID-19 response, adding to the public health response and surveillance capacity of GOSA. For example, CDC-SA leveraged its existing relationship with the NICD to strengthen national COVID-19 surveillance by supporting data capture and file organization, data quality reviews, and data analytics, laboratory strengthening, and COVID-19 guidance development and review. In addition, CDC-SA supported GOSA with the deployment of senior CDC staff epidemiologists at the national and provincial government levels.

CDC-SA was nimble in providing support when the country was operating under GOSA-authorized COVID-19 lockdown restrictions. CDC-SA supported the NICD by sending a team of staff members, including senior epidemiologic and clinical experts, to support the NDoH Coronavirus Command Council. On March 5, 2020, CDC-SA also deployed a group of epidemiologists and surveillance experts to 7 provinces across South Africa. On March 23, 2020, CDC-SA deployed its first epidemiologist to the KwaZulu-Natal Province, where the COVID-19 outbreak was first identified in South Africa. Provincial support varied depending on need and included providing assistance with developing data management and reporting systems, providing up-to-date clinical guidance and relevant protocol guidelines related to isolation and quarantine regimens, providing geographic outbreak data, and supporting hotspot mapping for response targeting, cluster outbreak investigations, and myriad other technical areas dependent on the needs of the provincial departments of health. Central to this support was the notion of skills transfer from CDC-SA staff to GOSA staff. GOSA staff continue to incorporate these lessons learned by ensuring daily data are disseminated for public circulation.

Internal and external stakeholder coordination was critical to the successful and timely deployment of multiple CDC-SA staff. Identifying a senior CDC-SA staff member to coordinate these efforts enabled senior-level engagement across GOSA and their US Government counterparts. Identifying the needs within each province highlighted the varying epidemiologic and surveillance capacity gaps across the different provinces. Provincial deployers provided various iterations of the following support for a duration of 3–6 weeks per deployment:

- Ensuring case surveillance and timely and complete reporting of cases and contacts to NICD and NDoH
- Assisting with collecting, entering, and managing COVID-19 case report data; data cleaning; providing epidemiologic guidance in the analysis and interpretation of epidemiologic data; and responding to requests from NICD and NDoH (e.g., providing the latest guidance updates on contact tracing and testing)
- Supporting the compilation of various surveillance reports (e.g., death surveillance)
- Providing provinces with technical assistance to evaluate the readiness of health systems and supply chain for key medical equipment, including personal protective equipment, oxygen, and ventilators
- Providing technical support to review and assist in drafting key COVID-19 outbreak and laboratory testing guidance documents and policies, including refining outbreak case definitions
- Providing outbreak mitigation support and recommendations for infection prevention and control initiatives at multiple types of public facilities, including hospitals and correctional facilities.
- Supporting the development of clinical, health promotion, and training guidance and policies
- Advocating for and encouraging the transition from a contact tracing and containment focus to community mitigation strategies as the outbreak progressed throughout 2020

In total, 47 CDC-SA staff joined national and provincial government response teams. This valuable support provided the much-needed capacity to GOSA and enabled skills transfer and sustainability of these skills to GOSA counterparts. Tools, dashboards, and training and health promotion materials continue to be used in the management of COVID-19 in South Africa through support from CDC

Communication between provincial government officials in South Africa with their US Government counterparts was essential. A total of 21 provincial technical support deployments occurred over the 6-month period during March–September 2020 (Table 1). The communication levels and types (Table 2) were an essential aspect of engaging all key stakeholders in CDC-SA staff deployments, thereby ensuring alignment with the larger GOSA COVID-19 response effort and US diplomatic priorities and

ensuring the safety and security of those deployed. In addition, support provided highlights the ability of CDC to be responsive to requests from GOSA.

Nightly check-in meetings with deployers became a fundamental element of the technical support provided to deployers. The check-ins also served as critical psychosocial support during a high-risk and uncertain time. Included in these calls were key CDC-SA clinicians and surveillance and laboratory technical specialists, who provided up-to-date guidance on the technical aspects of the deployments. In addition, CDC-SA provided routine updates to the South Africa PEPFAR Coordinating Office and PEPFAR South Africa, which were implementing partners working in close coordination on COVID-19 efforts with provincial governments.

These deployments in the setting of COVID-19 raised multiple logistical challenges, particularly the provincial deployments. In early March 2020, all provincial travel in South Africa was prohibited. CDC-SA expeditiously coordinated with a CDC-SA team of drivers to transport epidemiologic and surveillance specialists to and within 7 of the 9 provinces across South Africa. All drivers were certified as essential workers and obtained permission to transport CDC-SA staff. The provision of this essential service by the CDC-SA driver team enabled the prompt deployment of CDC-SA staff members during extremely challenging times, including having no operational airports, dealing with interprovincial law enforcement checkpoints, risking exposure to SARS-CoV-2, and limited availability of hospitality services and accommodations because of the national lockdown.

Table 1. CDC-SA COVID-19 response support, South Africa, March–September 2020*

Deployment type	No. personnel
Provincial support	21
NICD data entry, data analytics	9
National Command Center technical assistants	3
Driver support team	6
Logistics support team	5
CDC-SA management support	3

*CDC-SA, US Centers for Disease Control and Prevention–South Africa; NCID, South Africa National Institute of Communicable Diseases.

The ability to respond rapidly and provide support was largely thanks to the efforts of the CDC-SA logistics team. The logistics team was responsible for organizing crucial land transportation to and from the deployment sites for the teams, with transport often occurring outside of curfew, requiring the necessary GOSA approvals.

The success of the rapid scale-up of the CDC-SA deployments can be attributed to the leadership, management, and technical skills of the different team members. In addition, all deployments were based on the notion of volunteerism, which included navigating the unknown risks in the early stages of the pandemic in the first few months of 2020. This aspect was acknowledged by GOSA in various communications to CDC.

By mid-September 2020, the first wave of the COVID-19 pandemic in South Africa had passed. As a result, CDC-SA staff returned to their core tasks of providing technical HIV and tuberculosis support to GOSA. GOSA's capacity to provide epidemiologic and surveillance support has grown stronger in the 18 months since the onset of the pandemic, with demand for support from CDC-SA decreasing in frequency.

Table 2. CDC-SA COVID-19 communications response, South Africa, March–September 2020*

Agency	Communications
National Department of Health	• Head of Department of the Provincial Department of Health: notification of the location, scope of work, and name of each CDC-SA staff member • NICD: notification of the location, scope of work, and name of each CDC-SA staff member to ensure provincial and national cooperation of COVID-19 data flow • Provincial NICD points of contact: notification of the location, scope of work, and name of each CDC-SA staff member to ensure provincial and national cooperation of COVID-19 data flow
US government communications	• Notification to US senior leadership within South Africa, including the nature and scope of support provided by CDC-SA • Notification to provincial consular offices, with formal communications to Consul Generals under which the 7 provinces fall • Weekly calls with consular staff for general COVID-19 updates
CDC-SA deployment team	• Nightly (Monday–Friday) check-in calls for all deployers with the CDC-SA coordination team over the course of the 6-month deployment. These calls provided not only an update on the ever-changing global COVID-19 clinical guidance but provided an essential psychological support to deployers • Coordination calls with the logistic teams, including the driver support team. Because of the challenging nature of the times, including the severe nature of the national lockdown requirements, those engagements became essential in navigating many unknown aspects of travel, personal protective equipment requirements, COVID-19 exposures, and, most important, collegial support

*CDC-SA, US Centers for Disease Control and Prevention–South Africa; NCID, South Africa National Institute of Communicable Diseases.

Currently, the CDC-SA continues to provide much-needed support around HIV and tuberculosis while, simultaneously and proactively integrating dimensions of COVID-19 best practices into the daily work of our implementing partners, where possible and as needed. These include the following lessons learned:

1. Rapid, accurate data on status of the outbreak for developing policy and informing leadership, the public health and clinical communities, and the general public. Providing the tools and expertise to help accomplish robust data dissemination is critical to a successful support effort.
2. Up-to-date guidance and recommendations are critical and often challenging, given insufficient data and expertise and changing situations. Providing expertise and support to complement the local expertise in developing guidance and recommendations is important to supporting the response.
3. Substantial physical and emotional strain afflicts staff responding to a pandemic. Providing personnel support to decrease the workload and emotional support to deal with the stress are important to assisting the response.
4. A pandemic response is complex and ever-changing, making frequent (e.g., daily) communication among participants essential to coordinating a successful support effort.

The need for CDC-SA national and provincial-level deployments is continuously reassessed, taking into consideration national and provincial COVID-19 indicators and ongoing consultation with GOSA. However, CDC-SA remains on standby to respond to the pandemic as the need arises, having gathered greater experience through lessons learned on pandemic response.

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The CDC-SA COVID-19 Deployment Team acknowledges the critical roles the staff at NICD, NDOH, and the provincial departments of health in the Eastern Cape, Western Cape, Mpumalanga, Free State, Limpopo, North West, KwaZulu-Natal, and Gauteng provinces and is grateful for their partnership in epidemic control. The CDC-SA COVID-19 Deployment team thanks the CDC South Africa logistics team for their enormous efforts, including the CDC administration team who supported various data entry efforts and the team of dedicated drivers who supported the deployment efforts, which included CDC-SA administration, travel, and country business office teams. The CDC-SA COVID-19 Deployment Team also acknowledges the support provided by PEPFAR in mitigating the negative impact of the COVID 19 pandemic on HIV and tuberculosis services.

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Building on Capacity Established through US Centers for Disease Control and Prevention Global Health Programs to Respond to COVID-19, Cameroon

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The COVID-19 pandemic has highlighted the need for resilient health systems with the capacity to effectively detect and respond to disease outbreaks and ensure continuity of health service delivery. The pandemic has disproportionately affected resource-limited settings with inadequate health capacity, resulting in disruptions in health service delivery and worsened outcomes for key health indicators. As part of the US government's goal of ensuring health security, the US Centers for Disease Control and Prevention has used its scientific and technical expertise to build health capacity and address health threats globally. We describe how capacity developed through global health programs of the US Centers for Disease Control and Prevention in Cameroon was leveraged to respond to coronavirus disease and maintain health service delivery. The health system strengthening efforts in Cameroon can be applied in similar settings to ensure preparedness for future global public health threats and improve health outcomes.

The ongoing COVID-19 pandemic was declared a public health emergency of international concern by the World Health Organization (WHO) on January 30, 2020 (*1*). As of July 13, 2022, the pandemic had affected >232 countries and territories, resulting in >555.4 million cumulative COVID-19 cases and 6.3 million deaths globally (*2*). The effect of the pandemic has been far-reaching. It has caused major disruptions to essential health services in almost all countries globally, exacerbating gaps in health systems with weak infrastructures and undoing global health gains in nearly all major health areas (*3*).

Cameroon is a low to middle-income country in central Africa that has a limited domestic health expenditure of ≈4% of its gross domestic product and poor outcomes for key health indicators. Concurrent security and humanitarian crises have further affected the health system, including Boko Haram and ISIS-West Africa terrorist attacks in the Far North region (*4*); ongoing civil conflict and worsening violence in the Anglophone Northwest and Southwest regions (*5*); and large settlements of refugees in the Northern and East regions (*6*) from neighboring Central African Republic, Nigeria, and Chad. The country has been greatly affected by the COVID-19 pandemic and accounts for the highest number of COVID-19 cases and deaths in Central Africa (*7*). For much of the first year of the pandemic, the COVID-19 case count and case-fatality rate for Cameroon were among the highest in Africa, and as of March 16, 2022, two years since the start of the pandemic in Cameroon, there were 119,544 confirmed cases, including 1,927 deaths, and a case-fatality rate of 1.6% (*2*). Health personnel accounted for 4,419 confirmed cases and 61 deaths, reflecting the disproportionate effect of the pandemic on the health workforce.

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The US Department of Health and Human Services and Centers for Disease Control and Prevention (CDC) began work in Cameroon during 1998 by establishing an HIV laboratory and research program. The presence of CDC in Cameroon evolved to an established country office in 2004, providing technical expertise and support to the Ministry of Health (MOH) to strengthen disease control efforts and develop sustainable public health capacity. In 2007, an agreement was signed between the US and Cameroon governments, establishing a partnership to prevent and control HIV/AIDS, avian influenza, and other infectious diseases. Consistent with the International Health Regulations (2005) that states WHO member states should develop, strengthen, and maintain their capacity to respond promptly and effectively to public health emergencies of international concern (*8*), Cameroon has focused on strengthening its capacity to respond to public health threats with support from the US government and other partners.

CDC provides technical and financial assistance to the Cameroon MOH at the national and subnational levels and delivers clinical services in >300 health facilities across all 10 regions of the country through implementing partners. Health systems strengthening efforts include building epidemiology, surveillance, laboratory, research, and emergency management capacity and developing a fit-for-purpose workforce to ensure the sustainability of programs. As a key implementing agency of the President's Emergency Plan for AIDS Relief (*9*), CDC has scaled-up HIV prevention, care, and treatment services for persons living with HIV and accelerated progress in controlling the HIV epidemic in Cameroon. Through the Global Health Security Agenda (*10*), CDC has strengthened the capacity of Cameroon to prevent, detect, and effectively respond to disease outbreaks. Implementation by CDC of the President's Malaria Initiative (*11*) to reduce malaria-related illness and death, technical assistance for vaccine-preventable diseases, and support for other global health programs have contributed to health system strengthening in Cameroon.

Leveraging Global Health Programs of CDC for COVID-19 Response

Building on the strong partnership between CDC and Cameroon MOH, Cameroon leveraged the capacity established through US government–funded global health programs to prepare for and respond to the COVID-19 pandemic. With support from CDC, WHO, and other technical partners, the Cameroon MOH initiated outbreak preparedness planning in January 2020 when COVID-19 was designated as a public health emergency of international concern, developed a COVID-19 preparedness and response plan, and conducted trainings for health officials at national and subnational levels. In addition, Cameroon hosted in March 2020 a meeting of the Health Ministers of the Economic and Monetary Community of Central Africa to develop a joint plan for prevention, preparation, and response to COVID-19 in the Central Africa region.

After detection of the first COVID-19 case in Cameroon on March 6, 2020, the National Public Health Emergency Operations Center (PHEOC) was activated for the response. The PHEOC is a state-of-the-art facility constructed and established with support from the US Defense Threat Reduction Agency and CDC and handed over to the government of Cameroon in June 2019 to ensure coordination and management of health emergencies (*12*). Functioning of the PHEOC requires well-trained emergency management experts. To this end, CDC's Public Health Emergency Management Fellowship in Atlanta builds the emergency management capacity of international health officials through specialized training, mentorship, and technical assistance (*13*). Eleven senior Cameroon health officials trained through the fellowship were essential to the stand-up of the PHEOC and lead different aspects of the COVID-19 response. CDC has also strengthened emergency management capacity at the subnational level by supporting the establishment of rapid response teams in the 10 regions of Cameroon, which have responded to multiple disease outbreaks and public health emergencies. After the activation of the National PHEOC, the emergency operations centers and rapid response teams in all regions of Cameroon were activated for the COVID-19 response.

The CDC office in Cameroon organized a COVID-19 Response Team comprising staff who had previously supported the 2014–2016 West Africa Ebola response and other disease outbreaks, applying their outbreak response expertise to support COVID-19 response efforts. CDC developed a response plan aligned with the COVID-19 plan of the Cameroon MOH. CDC public health experts were integrated into the National Incident Management System (IMS), an established command structure to manage emergency responses (*14*), and provided technical leadership and expertise in conjunction with WHO for the response efforts of MOH. The CDC COVID-19 Response Team members provided expert technical support across all pillars of the National IMS, including surveillance, laboratory, case management, and infection prevention and control

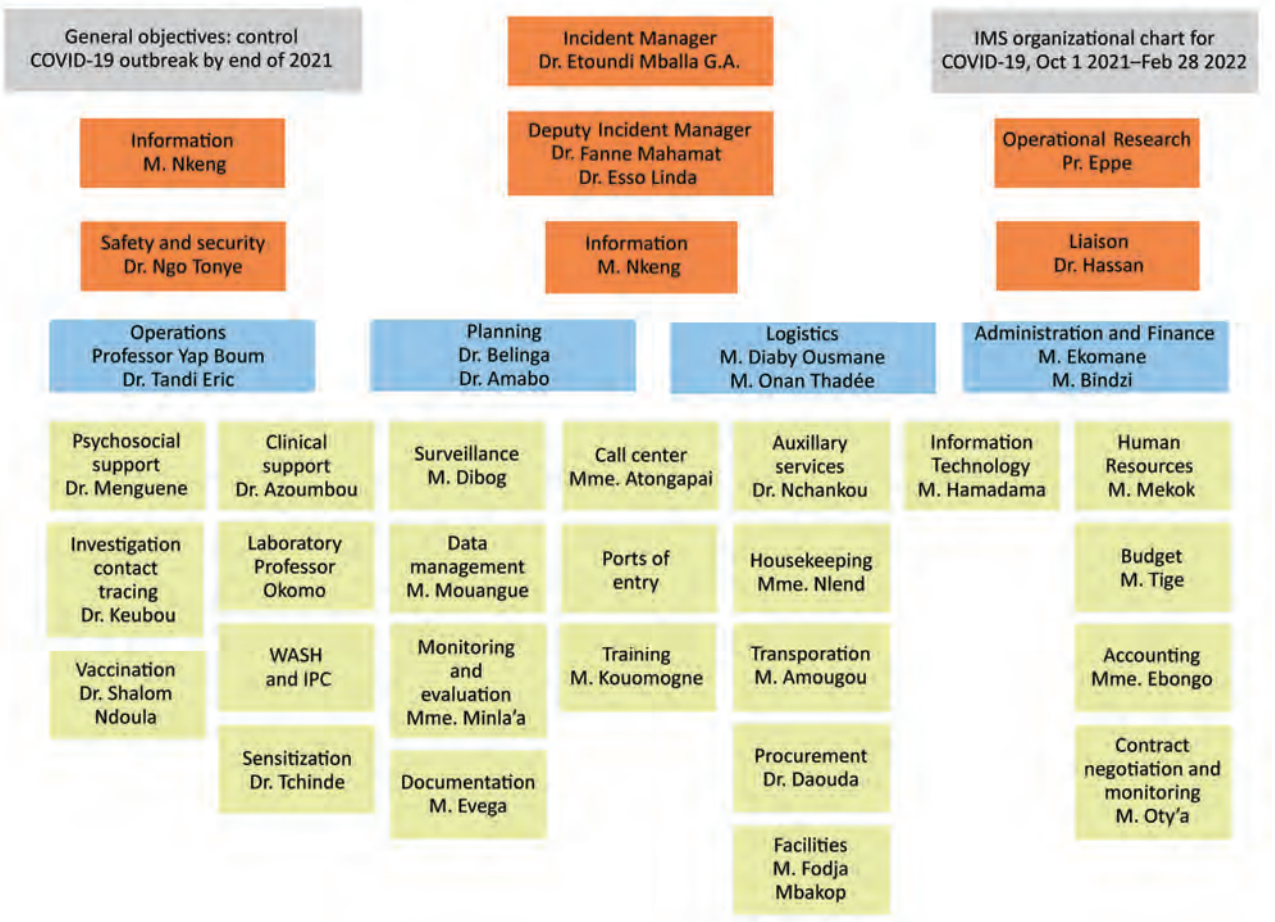

Figure 1. Cameroon Ministry of Health COVID-19 incident command structure and pillars supported by the Centers for Disease Control and Prevention. Source: Cameroon Ministry of Health/Public Health Emergency Operations Center. IMS, Information Management System; IPC, Integrated Phase Classification; WASH, water, sanitation, and hygiene.

(Figure 1). Coordination of partners involved in the response increased efficiencies and helped to address duplication of efforts by multiple stakeholders.

The CDC-established Field Epidemiology Training Program (*15*) developed a trained global public health workforce to collect, analyze, and interpret data for decision making, strengthening countries' capacities to address public health challenges and meet the needs of their population. Established in 2010, Cameroon's Field Epidemiology Training Program (CAFETP) trains health officials in Cameroon and neighboring countries in central Africa to strengthen the public health workforce in the region. More than 1,100 CAFETP graduates and trainees distributed across the country (Figure 2) supported the National and Regional IMS and were the ground force of the COVID-19 response of Cameroon, constituting rapid response teams and conducting disease surveillance, case investigations, and contact tracing. With oversight from the CDC Field Epidemiology Training Program Resident Advisor, CAFETP graduates, and trainees conducted active surveillance, monitored contacts of cases, and enabled early detection and management of COVID-19 cases. The CAFETP also trained health staff working in prisons on case investigation and mitigating transmission risk in congregate settings. Border health measures were put in place at different points of entry to reduce the risk for transmission from travelers to Cameroon. In collaboration with other technical partners, CDC supported the MOH in developing passenger screening protocols; training health officials to conduct screenings at the international airports, seaports, and land border crossings; implementing COVID-19 testing at points of entry; establishing isolation and quarantine measures for passengers upon arrival; and conducting supportive supervision of border health officials.

CDC helped to develop and strengthen the capacity of laboratories in Cameroon by supporting establishment and renovation of the National Public

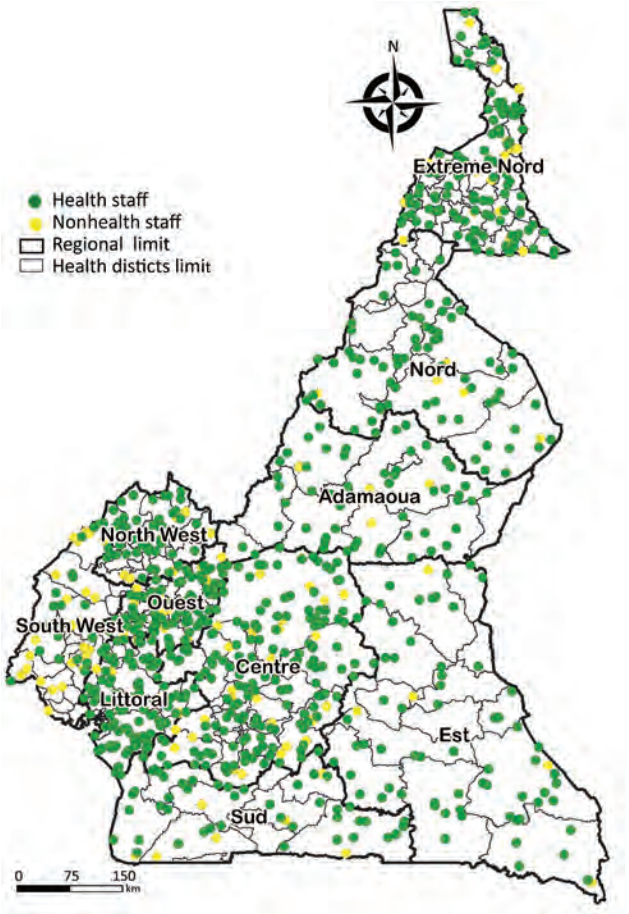

Figure 2. Distribution of Cameroon Field Epidemiology Training Program trainees and graduates by region, Cameroon, July 2022. Source: Cameroon Ministry of Health/Cameroon Field Epidemiology Training Program.

Health Laboratory in 2016, leading the development of the first National Laboratory Strategic Plan in 2018, and leading the implementation of the Strengthening Laboratory Improvement Process Toward Accreditation, a framework for evaluating the progress of laboratories toward international accreditation (*16*). As a result of CDC support, 5 laboratories have received ISO-15189 accreditation (https://anab.ansi.org), meeting international standards for quality management systems and competence for medical laboratories (*17*). Those 5 laboratories were the first internationally accredited laboratories in Cameroon and central Africa. Cameroon was among the first countries in central Africa that had COVID-19 diagnostic capacity. At the start of the pandemic, Centre Pasteur Cameroon was the only reference laboratory for COVID-19 testing, but testing capacity quickly became overwhelmed because of increased testing needs for samples from all regions of the country.

The challenges with testing called attention to the need for enhanced collaboration between the Cameroon MOH and stakeholders to manage human resources and ensure timely procurement and management of reagents and testing commodities. CDC decentralized the response by providing technical support for COVID-19 testing and development of a laboratory strategy in Cameroon and a decentralization plan to expand capacity from the national level to a network of 19 laboratories across the country. The National Public Health Laboratory coordinated the distribution of COVID-19 test kits and received CDC support to procure sample collection and transportation material, improve laboratory supply management, and establish a call center to ensure reporting of results from decentralized laboratories. CDC staff conducted supervisory visits to laboratories to provide technical support on workflow, strengthen biosafety measures, and validate COVID-19 testing algorithms. CDC supported the expansion of testing strategies, mobile testing units for sample collection, and delivering negative test results through text messages, which led to increased access to testing and reduced turnaround time for test results. As of March 16, 2022, PCR testing had been conducted on 608,118 samples and rapid antigen testing on 1,916,552 samples. CDC also supported genomic surveillance to detect new circulating variants of SARS-CoV-2.

The CDC COVID-19 response staff embedded in the National IMS pillar for case management (Figure 1) provided support to improve outcomes for confirmed cases. Efforts included supporting development of case management algorithms, standard operating procedures, and registers; the training of health workers on patient management; and conducting field supervision visits to COVID-19 isolation and treatment centers. Establishing a community of practice among case management physicians resulted in weekly sharing of data and best practices among COVID-19 isolation and treatment centers, leading to improved outcomes. CDC also participated in joint assessments of COVID-19 treatment centers with WHO and the MOH and developed a supportive supervision tool used to assess the functional capacity of treatment centers and provide recommendations to improve gaps. Infection prevention and control (IPC) measures were focused on preventing nosocomial transmission among patients and healthcare workers. CDC provided personal protective equipment and IPC supplies for health facilities and healthcare workers, supported IPC guideline development, conducted trainings for health workers on IPC practices,

and participated in supportive supervision visits with WHO and the MOH.

Risk communication and community engagement are key components of outbreak response (*18*). CDC supported development and implementation of the national communication plan for COVID-19 in Cameroon, developed and disseminated risk communications tools, and established and supported call centers at national and regional levels. CDC also supported the intersectoral approach to achieving community ownership and engagement at all levels and provided technical support for public communication and press briefings on COVID-19 preparedness and response efforts in Cameroon. CDC COVID-19 response staff were integrated into the National IMS communication pillar, and culturally appropriate health messages to counter COVID-19 misinformation were developed for print, broadcast, and social media. CDC also supported revisions of the communication strategic plan and tools to meet the changing communications needs of the outbreak and sensitize the population to COVID-19 vaccines.

After the emergency authorization of COVID-19 vaccines (*19*), Cameroon began preparations for vaccine introduction and implementation as part of its response strategy. Surveys on vaccine acceptance indicated most persons in Cameroon were reluctant to receive a COVID-19 vaccine even if proven to be safe and efficacious (*20*,*21*). CDC supported developing national guidelines for vaccine rollout, a nationwide vaccine deployment plan, and training manuals and communication tools to increase vaccine uptake. Since the introduction of COVID-19 vaccines in Cameroon during April 2021, the MOH has administered vaccines at fixed vaccination sites, conducted mass vaccination campaigns across all 10 regions of the country, and introduced mobile vaccination teams to increase accessibility. However, vaccine coverage remained suboptimal (Figure 3) and substantially lower than global coverage targets (*7*,*22*). Knowledge, attitudes, and practices information obtained by CDC and the MOH during October–December 2021 showed high levels of distrust and limited knowledge about the safety and efficacy of COVID-19 vaccines. To address this issue, CDC provided surge support and additional funding

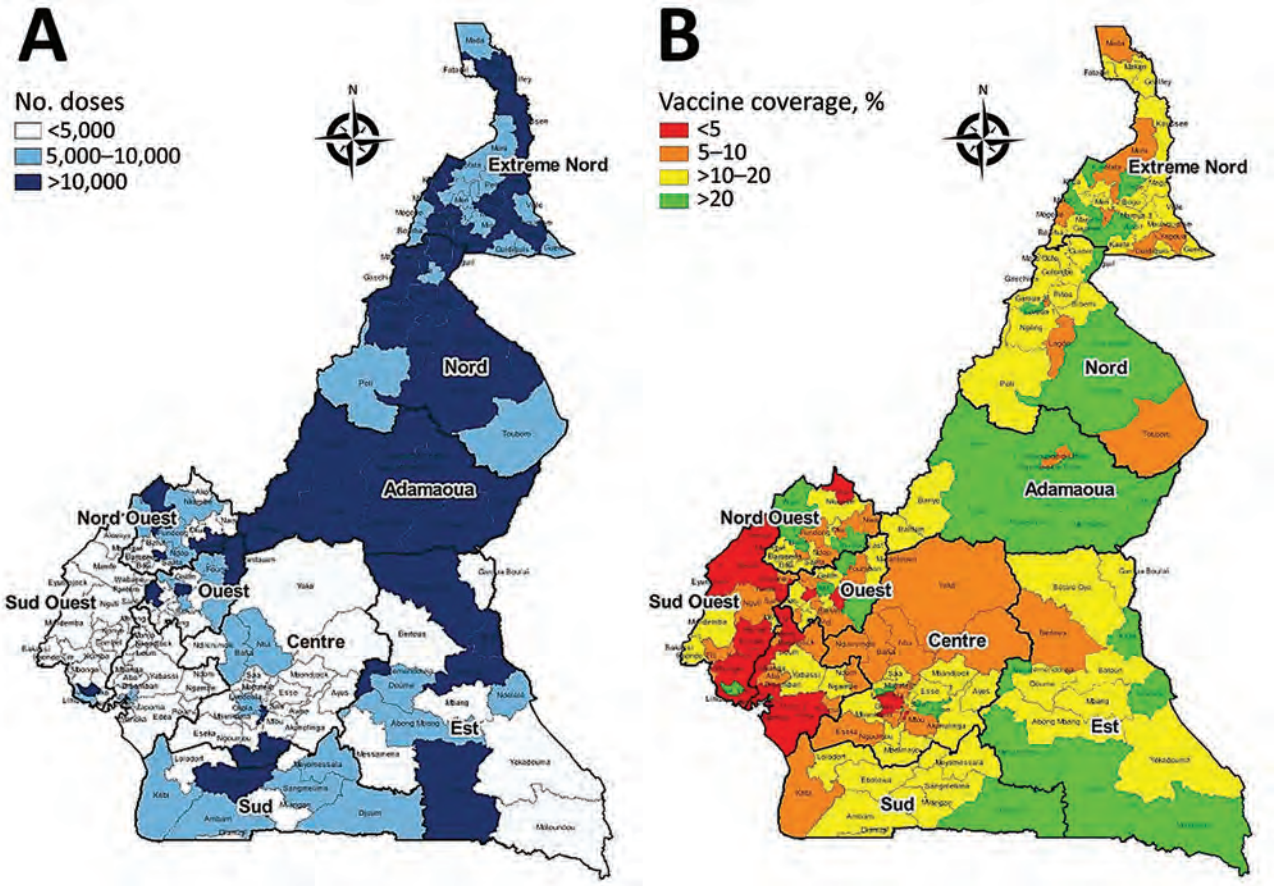

Figure 3. COVID-19 vaccination coverage, by health district, Cameroon, July 2022. A) Number of vaccine doses administered; B) percentage of population that has received ≥1 vaccine dose. Source: Cameroon Ministry of Health/Expanded Programme on Immunization.

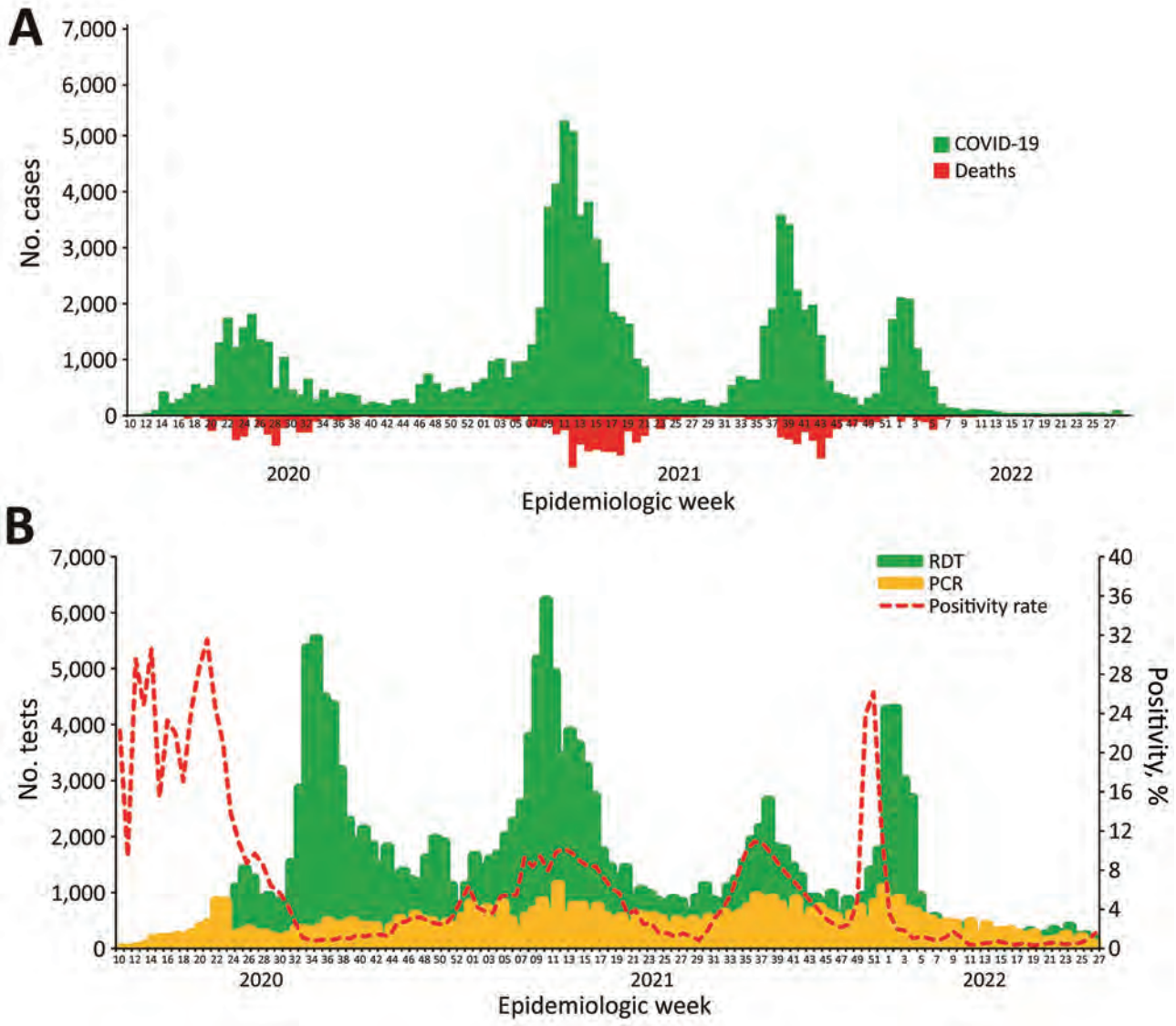

Figure 4. COVID-19 epidemic curve (A) and B) SARS-CoV-2 test positivity (B), Cameroon, through July 2022.Source: Cameroon Ministry of Health/Public Health Emergency Operations Center. RDT, rapid diagnostic test.

for COVID-19 vaccine implementation as part of Global VAX (*23*). Efforts are ongoing to address vaccine hesitancy and increase access to vaccination services, including setting up more vaccination posts, training additional vaccinators and community health workers, and developing strategies to reach priority and hard-to-reach populations.

Surveillance and response for adverse events following immunization are essential for ensuring the safety of vaccines (*24*). With funding and technical support from CDC, the Expanded Program on Immunization in Cameroon is conducting a cohort monitoring study on COVID-19 vaccine adverse events following immunization, which will inform and strengthen vaccination efforts. A major lesson learned was the need for early engagement of community leaders, social groups and faith-based organizations to promote vaccine uptake and to widely disseminate information in local languages, adapted for each target audience.

Epidemiologic data are needed to understand the magnitude and effect of the pandemic, predict future trends, and ensure an effective public health response. Because of limited diagnostic testing during earlier waves of the COVID-19 pandemic and the large number of persons who had asymptomatic or mildly symptomatic infections, the reported number of cases globally is much lower than the actual prevalence (*25*). In collaboration with the Cameroon MOH, CDC conducted a nationwide survey

to determine the seroprevalence of SARS-CoV-2 in Cameroon, identify risk factors for infection, and assess knowledge and attitudes about COVID-19 (*26*). The serosurvey was conducted during October–December 2020 across all 10 regions of Cameroon and showed an overall estimated seroprevalence of 10.5% and regional variation ranging from 7.7% to 12.6%. The results of that survey have informed program planning and guided decision making in Cameroon.

As of July 2, 2022, Cameroon had recorded 120,068 cumulative confirmed COVID-19 cases, including 1,931 deaths (case-fatality rate 1.6%) (*2*). The country has had 4 waves of the epidemic, and surges in cases have been attributable to limited compliance with community mitigation measures, increased congregation and travel during holidays and festive periods, resumption of schools, and circulation of more easily transmissible variants of the virus. After Cameroon hosted the 2021 African Cup of Nations, the largest international soccer tournament on the continent, in January and February 2022, the country fully emerged from the fourth wave of the pandemic and has maintained low community transmission since (Figure 4).

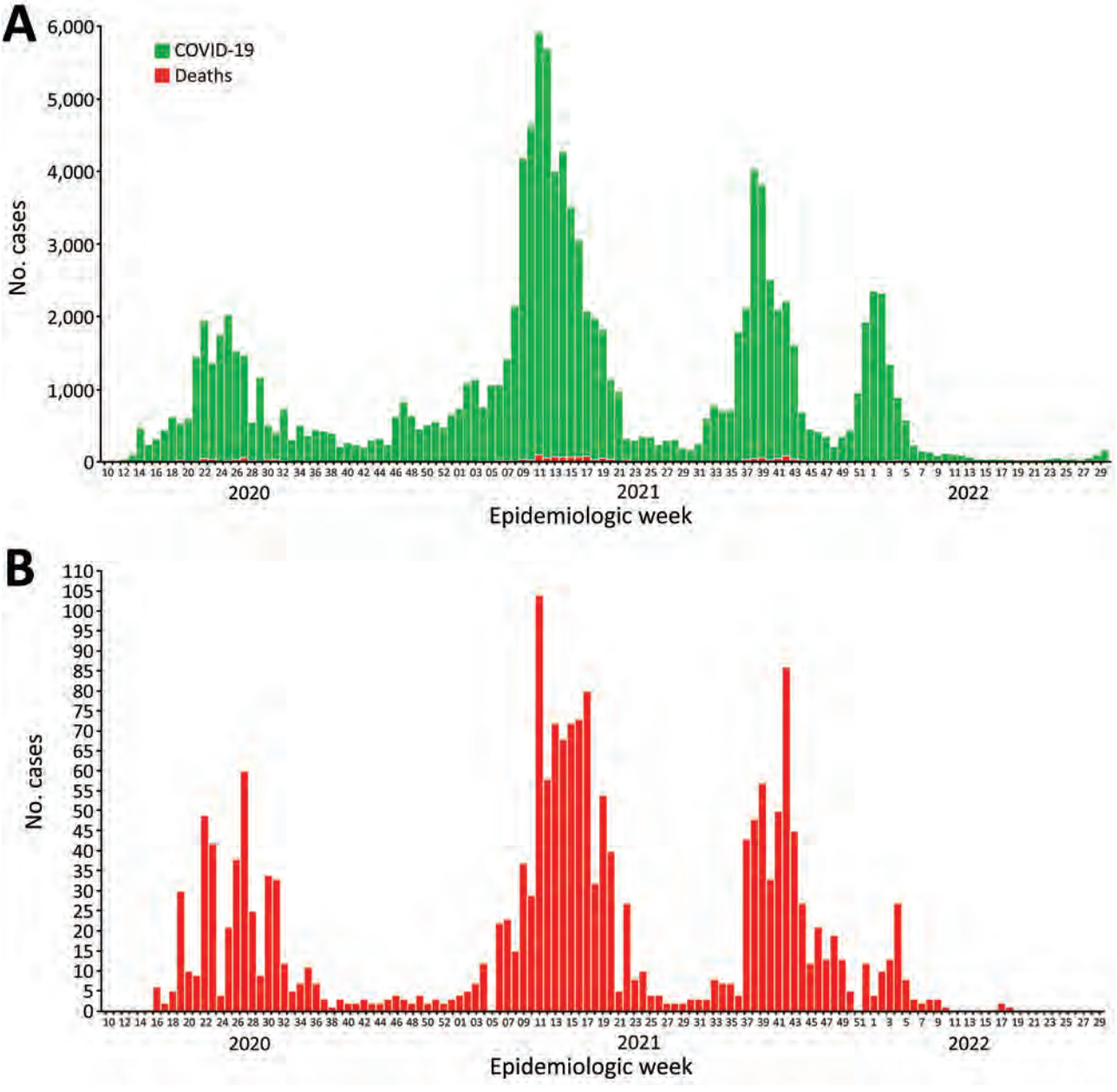

Figure 5. COVID-19 cases (A) and deaths (B), Cameroon, through July 2022.

Rapid test and real-time PCR test positivity is <2%, community transmission remains low (Figure 5), and hospital bed availability and health staffing capacity are sufficient across all 10 regions of the country. On the basis of systems previously in place and capacity strengthened during the pandemic, Cameroon is well-positioned to respond to subsequent waves of the pandemic.

Ensuring Health Service Provision During COVID-19 Pandemic

The COVID-19 pandemic overwhelmed health systems globally and adversely affected health programs because available resources were focused on responding to the pandemic (*3*). In Cameroon, delivery and uptake of health services were reduced because many health facilities were repurposed as COVID-19 treatment centers. To decentralize the response to all regions, the Cameroon MOH designated 78 existing health facilities at the national and subnational levels as COVID-19 isolation and treatment centers, including reference hospitals for management of critical case-patients. This change resulted in reduced delivery of primary care and other services typically provided in health facilities.

In addition, the HIV and tuberculosis programs showed decreases in testing, treatment initiation, and retention because clients were reluctant to come to health facilities because of a fear of becoming infected with SARS-CoV-2. The MOH suspended facility-led community activities to reduce transmission risk. Frontline workers and health service providers given a diagnosis of COVID-19 were put in isolation and persons who were close contacts of case-patients underwent mandatory quarantine, reducing staffing capacity and increasing workloads for other healthcare workers.

Programs developed innovative strategies to ensure continued service delivery for clients, including mobile and satellite clinics, community treatment dispensation, and home-based care to mitigate the effect of the COVID-19 pandemic on the health sector. CDC provided recommendations to the MOH to lift restrictions on community activities and enable differentiated service delivery, including HIV index case testing, antiretroviral (ART) and tuberculosis treatment dispensation, and HIV viral load sample collection in the community. Clinical implementing partners collaborated with community-based organizations and satellite health facilities for HIV testing, linkage, and treatment dispensation. CDC conducted weekly virtual clinical program and data reviews with implementing partners and health facilities and held quarterly virtual sessions to review program performance and share best practices. Establishing virtual trainings and weekly granular site management (*27*) enabled near–real-time monitoring of program activities and addressed some challenges presented by COVID-19 in delivering HIV and tuberculosis services. When feasible, the team conducted site visits, in-person data quality assessments, and partner monitoring while ensuring adequate protection to reduce the risk for COVID-19 transmission.

HIV service provision and program performance decreased in many President's Emergency Plan for AIDS Relief–supported sub-Saharan African countries during the COVID-19 pandemic (*28*,*29*), including decreases in pediatric and adolescent HIV testing and diagnoses. However, by scaling up differentiated service delivery models, implementing weekly monitoring of program performance, and providing virtual technical support to implementing partners and health facilities, Cameroon maintained service delivery to clients and sustained programmatic gains (*30*). Index testing performance and yields increased by 32% for pediatric HIV testing and 6% for pediatric HIV diagnoses. As a result of intensified efforts by CDC to optimize HIV program performance, the clinical program a major increase in transition of patients to receiving tenofovir, lamivudine, and dolutegravir (TLD), the recommended first-line ART regimen. Through high-level advocacy to revise national guidelines and rapidly scale-up use of TLD, the proportion of persons living with HIV (PLHIV) receiving TLD increased from 0.3% in December 2019 to 56% in December 2020 and surpassed the 80% national target by June 2021. The rapid TLD transition led to a major improvement in viral load suppression to 93% nationally. CDC provided expert technical support to Cameroon MOH and partners to scale up effective strategies across the clinical cascade, supporting HIV testing for 1,559,727 persons, identifying 62,340 HIV positive cases, and initiating treatment for 58,122 PLHIV in 2021. As of January 2022, there were 390,100 PLHIV in Cameroon receiving ART. The ART program had attained a clinical cascade achievement of 85–93–93 based on programmatic data, putting Cameroon on track to reach the 95–95–95 targets (95% of PLHIV are aware of their status, 95% of diagnosed PLHIV are receiving ART, and 95% of PLHIV receiving treatment are virally suppressed) before the 2030 timeline and achieve sustained HIV epidemic control (*31*).

Conclusions

The COVID-19 pandemic called attention to health system gaps and underscored the need for resilient

health systems to effectively respond to health threats while ensuring continued health service delivery. The effect of the pandemic has been serious in central Africa and other resource-limited settings, largely caused by the limited health infrastructure and capacity in the region. Building on the strong partnership with the Cameroon MOH, capacity established through global health programs of CDC was leveraged to support the COVID-19 response in Cameroon while implementing innovative strategies such as differentiated service delivery and granular site management to mitigate the effect of the pandemic on health programs. In addition to the need for strengthened disease preparedness and response capacity, key lessons learned from the response in Cameroon to the pandemic include the need for a well-trained and fit-for-purpose health workforce, timely mobilization of resources, and the need for coordination of multiple stakeholders to effectively manage response efforts.

Despite ongoing security and humanitarian crises in Cameroon, efforts of CDC have helped to strengthen the health system and improve health outcomes by ensuring continuity of HIV and tuberculosis services during the COVID-19 pandemic and maintaining programmatic gains. Through support of CDC, Cameroon has accelerated progress to reach the 95–95–95 targets and is positioned to be the first country in West and Central Africa to achieve HIV epidemic control. As part of the mission of the US Government to improve health globally, CDC continues to provide support to Cameroon to respond to the COVID-19 pandemic and prevent and control other public health threats. The lessons learned from Cameroon might be applicable to other resource-limited settings and conflict-affected areas to respond to COVID-19 and prepare for future pandemics.

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Use of Project ECHO in Response to COVID-19 in Countries Supported by US President's Emergency Plan for AIDS Relief

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The US Centers for Disease Control and Prevention, with funding from the US President's Plan for Emergency Relief, implements a virtual model for clinical mentorship, Project Extension for Community Healthcare Outcomes (ECHO), worldwide to connect multidisciplinary teams of healthcare workers (HCWs) with specialists to build capacity to respond to the HIV epidemic. The emergence of and quick evolution of the COVID-19 pandemic created the need and opportunity for the use of the Project ECHO model to help address the knowledge requirements of HCW responding to COVID-19 while maintaining HCW safety through social distancing. We describe the implementation experiences of Project ECHO in 5 Centers for Disease Control and Prevention programs as part of their COVID-19 response, in which existing platforms were used to rapidly disseminate relevant, up-to-date COVID-19–related clinical information to a large, multidisciplinary audience of stakeholders within their healthcare systems.

The onset of the COVID-19 pandemic challenged health systems worldwide, resulting in service delivery disruptions and compromised quality of care of illnesses worldwide. HIV services were no exception to this phenomenon; continuity of HIV prevention and treatment was severely affected (*1*). Approximate excess deaths caused by HIV and AIDS of >400,000 persons in 2020 has been estimated as a result of COVID-19–induced disruptions (*1*). COVID-19 has affected the global response to HIV and AIDS, and countries that implemented adaptive mitigation measures for health services' continuity have reported fewer negative effects than countries that did not (*2*).

Project Extension for Community Healthcare Outcomes (Project ECHO) was launched in 2003 by the University of New Mexico Health Sciences Center (Albuquerque, NM, USA) to expand access to hepatitis C treatment for patients living in remote areas of the state. Through a hub-and-spoke model that connects spoke sites to a centrally located hub of subject matter experts through video conferencing technology, Project ECHO uses case-based learning to build communities of practice and learning among geographically distant providers practicing at different levels of the healthcare system (*3*). Since its inception in 2003, the ECHO model has been adapted to address a variety of healthcare workforce development needs and expanded to multiple geographic locations (*4*). As one of the first countries in Africa to adopt Project ECHO, Namibia connected remote clinical sites with centrally located specialists for HIV and tuberculosis (TB) medical education and care management in 2015. All major district hospitals and high-volume healthcare centers in the country are now connected by this platform.

The COVID-19 pandemic has posed numerous unforeseen challenges to HIV service delivery Programs and sites supported by the US President's Plan for Emergency Relief (PEPFAR) have faced the need to develop and adapt creative solutions for ongoing frontline provider support and HIV service

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quality assurance in this context. Traditional in-person training and site visit approaches were no longer feasible or recommended because of restrictions on in-person gatherings and the priority of preserving the safety of providers and beneficiaries and limiting COVID-19 spread. We describe national and regional examples of how the Project ECHO platform was used to build capacity, rapidly and regularly disseminate evolving information on COVID-19 prevention and treatment in people living with HIV, and mentor frontline providers in resource-poor health settings supported by PEPFAR.

Methods

Respondents from a convenience sample of 9 PEPFAR-supported countries known to have implemented Project ECHO for their HIV and TB programs before the COVID-19 pandemic completed a template to capture whether and how Project ECHO was being used for COVID-19–related topics, session frequency, number of participants, cadre type, and geographic location. The study team entered the data into a Microsoft Excel (https://www.microsoft.com) spreadsheet for data organization and descriptive

Table 1. Characteristics of projects Incorporating COVID-19 topics in HIV/TB Project ECHO programs*

Project ECHO characteristics	Coordinating organizations	COVID-19 topics covered during ECHO sessions	Main COVID-19 topics
South Sudan HIV ECHO: first session Mar 11, 2020, and occurred weekly; range 219–322 participants.	ICAP South Sudan, College of Physicians and Surgeons of South Sudan, Juba Teaching Hospital (Central Equatoria State)	1) Introduction to COVID-19; 2) protecting frontline healthcare workers to ensure continuity of services; 3) case management 1: mild/moderate and severe cases; 4) case management 2: critical cases and special populations; 5) infection prevention and control; 6) patient screening, triage, isolation, and contact tracing; 7) rational use of PPE; 8) cleaning and waste/dead body management	1) Case management 1: mild/moderate and severe cases; 2) case management 2: critical cases and special populations; 3) infection prevention and control
Namibia ECHO: first session Mar 17, 2020, and occurred weekly; range 172–390 participants	Namibia Ministry of Health and Social Services	1) COVID-19 and patients on ART; 2) HIV patient management in the COVID-19 context; 3) overview of infection prevention and control measures in COVID-19 pandemic; 4) national update on COVID-19 developments; 5) pediatric HIV disclosure in the context of COVID-19; 6) how to prepare ART clinics for COVID-19	1) Case management 1: basics of COVID-19, management of mild/moderate and severe cases 2) case management 2: advanced management of critical cases and special populations; 3) infection prevention and control; 4) Introduction and planning for IPC: WHO Tabletop Exercise
Zambia Project ECHO TB/HIV: first session Jan 29, 2020, and occurred weekly with ad hoc sessions; range 64–65 participants	Zambia Ministry of Health	1) Clinical update on the Novel Coronavirus (2019-nCoV); 2) COVID-19 orientation for HCWs; 3) COVID-19 pandemic response; 4) COVID-19 in children; 5) PPE donning and doffing; 6) clinical features of COVID-19; 7) COVID-19 pandemic literature review; 8) psychological aspects of the COVID-19 pandemic; 9) COVID-19 management – experiences from China and Italy; 10) COVID-19 and management of noncommunicable diseases and comorbidities; 11) ensuring quality HIV services during COVID-19 pandemic; 12) COVID-19 in Zambia: "What We Should Know"; 13) TB/TPT guidance during the COVID-19 pandemic; 14) COVID-19 vaccine	1) Sustaining quality HIV services amidst COVID-19; 2) clinical features of COVID-19; 3) COVID-19 vaccination
Kyrgyzstan HIV ECHO Project: first session Sep 23, 2016, and occurred biweekly and weekly; range 30–60 participants.	Kyrgyz State Medical Institute for Postgraduate Education	Introduction to COVID-19	1) Outpatient COVID-19 management; 2) COVID-19 diagnosis, clinical features, and management; 3) etiology, clinical features; 4) diagnostics and treatment
Central America HIV Treatment ECHO: first session Oct 9, 2020, and occurred weekly; range 31–87 participants.	SE-COMISCA El Salvador	COVID-19 and HIV co-infection	COVID-19 and HIV co-infection

*ART, antiretroviral therapy; ECHO, Extension for Community Healthcare Outcomes; IPC, infection prevention and control; PPE, personal protective equipment; SE-COMISCA, Secretaría Ejecutiva del Consejo de Ministros de Salud de Centroamérica y República Dominicana; TB, tuberculosis; TPT, tuberculosis preventive treatment; WHO, World Health Organization.

Table 2. COVID-19 Project ECHO program characteristics from 4 regions and countries, 2020–2021*

Project ECHO COVID-19 characteristics	Coordinating organization (Hub)	No. participants	Participant cadre	Participant location
Regional Central America Laboratory COVID-19 Project ECHO: in Spanish; first session held Jun 9, 2020; 6 biweekly sessions.	SE-COMISCA El Salvador	101–224	Laboratory staff	Member states of the SICA region (Belize, Costa Rica, Guatemala, El Salvador, Honduras, Nicaragua, Panama, Dominican Republic), Bolivia, Ecuador, Mexico, Peru, United States
Regional Central America Clinical COVID-19 Project ECHO: in Spanish; first session held Apr 15, 2020; 31 weekly sessions.	SE-COMISCA El Salvador	127–328	Medical doctors, nurses, clinical officers/medical licentiates, pharmacists	Member states of the SICA region (Belize, Costa Rica, Guatemala, El Salvador, Honduras, Nicaragua, Panama, Dominican Republic), Bolivia, Ecuador, Mexico, Peru, Spain, United States
Kenya COVID-19 Project ECHO: in English; first session held Apr 3, 2020; 5 monthly sessions.	National AIDS and STI Control Council Hub, Kenyatta National Hospital Hub	300–1,037	Physicians, medical officers, clinical officers, nurses, pharmacists, pharmaceutical technologists, laboratory staff, infection prevention teams	Kenya
Southern Africa Regional COVID-19 Project ECHO (SARE): in English with Portuguese translation; first session held Dec 3, 2020; 11 biweekly sessions.	Zambia Ministry of Health Project ECHO	61–264	Medical doctors, nurses, clinical officers/medical licentiates, pharmacists	Botswana, Eswatini, Lesotho, Malawi, Mozambique, Zambia

*ECHO, Extension for Community Healthcare Outcomes; SE-COMISCA, Secretaría Ejecutiva del Consejo de Ministros de Salud de Centroamérica y República Dominicana; SICA, Sistema de la Integración Centroamericana; STI, sexually transmitted infection.

analyses. Respondents implementing COVID-19 Project ECHO sessions answered a separate open-ended questionnaire about implementation challenges, program facilitators, and lessons learned from the use of the ECHO model to address COVID-19 (Appendix, https://wwwnc.cdc.gov/EID/article/28/13/22-0165-App1.pdf). The study team entered responses in Microsoft Word and grouped common themes related to implementation-enabling factors and challenges and perceived public health benefits. This project was reviewed in accordance with US Centers for Disease Control and Prevention (CDC) human research protection procedures and was determined to be nonresearch.

HIV Project ECHO Programs Incorporating COVID-19 Topics

In 4 countries and 1 region (South Sudan, Namibia, Zambia, Kyrgyz Republic, and Central America), existing HIV Project ECHO programs were used to incorporate COVID-19 topics (Table 1). Although most of these programs targeted doctors and nurses, some also included other healthcare workers. For example, in South Sudan, ECHO sessions included participants from multiple cadres, such as clinical monitoring and evaluation staff, psychosocial counselors, laboratorians, and community health workers. Namibia included laboratorians; Zambia, pharmacists; and Kyrgyz Republic, general practitioners. Project ECHO sessions began including COVID-19 topics between January and December 2020; most started in March, around the time countries and regions began to report COVID-19 cases.

COVID-19–Focused Project ECHO Programs

In total, 4 ECHO programs (2 in Central America and 1 each in Kenya and Southern Africa) were focused on COVID-19–related content (Table 2). COVID-19 Project ECHO programs in Central America addressed laboratory-specific and clinical-specific topics. Of those 4 programs, 3 catered to audiences within the broader geographic region (2 in Central America and 1 in southern Africa). ECHO session frequency varied from weekly in the Central America COVID-19 Clinical ECHO program to biweekly for the COVID-19 Laboratory ECHO program in Central America and southern Africa and monthly for the Kenya national COVID-19 ECHO program. Similar to the HIV Project ECHO programs that incorporated COVID-19 topics, almost all programs that were COVID-19–focused included multidisciplinary participants (physicians, nurses, clinical officers, pharmacists, and laboratory staff); the exception was the Central America COVID-19 laboratory ECHO program, which only targeted laboratorians.

Results

Enabling Factors for Implementation

Country programs using Project ECHO during the COVID-19 pandemic cited several key enabling factors for implementation. Three of four COVID-19–focused Project ECHO programs launched from existing national ECHO hubs; in doing so, those programs capitalized on previously established information technology networks, equipment, and staff knowledge of ECHO. The Central America CDC program had an existing partnership with the regional ECHO hub that hosts both the TB- and HIV-focused Project ECHO programs, which provided a foundation to rapidly launch the COVID-19–focused ECHO program. Through its established network of ECHO participants, the Central America clinical COVID-19 ECHO program quickly connected to almost 4,000 healthcare providers who had participated in HIV- and TB-focused ECHO sessions over the previous year. This immediate network enabled rapid and broad dissemination of evolving COVID-19 diagnosis and management information. Similarly, the South Sudan HIV Project ECHO hub, established in 2018, built on its existing network to incorporate COVID-19 topics into their existing HIV Project ECHO program and expanded their reach to medical teams in 40 health facilities. Zambia respondents cited the ECHO hub location within the national Ministry of Health and its connection with 10 provincial health offices throughout the country as a key enabling factor in reaching healthcare providers across the country. In Central America, support from the Executive Secretary of the Regional Ministries of Health partner (SE-COMISCA) was critical to establish regional support for Project ECHO. The CDC Central America COVID-19 Project ECHO noted that its previous experience drawing on the expertise of diverse local and national health experts from the Pan American Health Organization, ministries of health, and large hospitals, as well as local healthcare personnel, for planning, facilitation, and capacity building contributed to high attendance and reported satisfaction with sessions, which was assessed through anonymous polling at the end of sessions.

Table 3. Topics, gaps and participant concerns and questions in COVID-19 Project ECHO sessions conducted in countries supported by US President's Emergency Plan for AIDS Relief, 2020–2021*

Topics covered	Gaps identified by participants	Examples of main concerns and common questions
COVID-19 case management	1) Principles of oxygen escalation/de-escalation; 2) innovative therapies for mild/moderate cases	1) What parameters are used in the decision to use supportive oxygen?; 2) mild/moderate COVID-19 case management; 3) how long does immunity to COVID-19 last?
Co-infection and comorbidities	1) Warning signs and management of cardiovascular manifestations of COVID-19; 2) management of patients with hypertension and COVID-19; 3) COVID-19 management in patients with comorbidities	1) How to standardize treatment for patients; 2) the role of steroid management in COVID-19 management
Infection prevention and control, PPE	1) PPE principles and use/reuse scenarios; 2) infection prevention and control in the context of community service delivery; 3) SARS-CoV-2 modes of transmission	1) Principles of donning and doffing PPE for frontline HCWs and standards for reuse in resource-limited settings; 2) mask use according to clinical service delivery points; 3) community behavior change strategies in infection prevention
Vaccines/immunization	1) Vaccine development processes and mechanisms of action; 2) COVID-19 vaccine demand creation strategies	1) Vaccination guidance for pregnant patients, other vulnerable populations, and persons previously infected with COVID-19; 2) management and reporting of vaccine-related adverse events during vaccination campaigns
Mental health	1) Specialists available and equipped to address HCW needs; 2) strategies to address mental health issues and build resilience among front-line HCW	1) Addressing mental health needs of HCWs during the pandemic; 2) HCW support systems and lack thereof; 3) insufficient expertise in diagnosing Mental Health issues leading to a growing number of undiagnosed health issues
Surveillance	1) SARS-CoV-2 surveillance methods and best practices; 2) acute febrile disease surveillance in a COVID-19 pandemic	1) Role of community health workers for COVID-19 disease surveillance; 2) harnessing digital technologies to improve Health Information systems
Laboratory	1) Role of public health laboratories in the pandemic response; 2) SARS-CoV-2 detection kit evaluation and validation; 3) SARS-CoV-2 diagnostic testing expansion and decentralization	1) Diagnostic test result (molecular and antigen) interpretation; 2) COVID-19 test positivity and duration of infectivity?; 3) serologic tests' utility in the diagnosis of acute COVID-19

*ECHO, Extension for Community Healthcare Outcomes; HCW, healthcare worker; PPE, personal protective equipment.

Other factors identified by country teams that aided in implementation included the virtual delivery method and reasonable time requirements of Project ECHO. Respondents in Zambia described the weekly, 60-to-90–minute format of Project ECHO sessions as "ideal to minimize disruptions in clinical duties" and noted "the flexibility of tailoring ECHO sessions to meet the specific healthcare worker COVID-19 topic needs as opposed to strict adherence to a predetermined curriculum."

Public Health Benefit

Respondents described the perceived public health benefits of using Project ECHO to respond to COVID-19. One common theme emerged regarding the benefit of bidirectional information sharing between geographically distant frontline providers and health system leaders, which helped provide insight into the public health policy and broader service delivery challenges and ability to disseminate evolving guidelines and policies for more rapid adoption. Respondents from the Project ECHO Laboratory program in Central America indicated question-and-answer sessions were helpful in fostering dialogue between facility-level laboratory staff and national-level persons who might be responsible for influencing COVID-19 laboratory policies and procedures. The South Sudan respondents highlighted how including COVID-19 topics in their HIV Project ECHO program was "crucial to information dissemination in an extremely challenging operating environment where public health programs and impact otherwise suffer from poor physical access, limited human resource capacity, insecurity and limited-service quality oversight and supervision."

Challenges to Implementation

Countries noted several challenges to implementing Project ECHO during and with COVID-19. Those included lack of time to identify the quantity and quality of experts who were needed to present or assist with sessions, the large volume of rapidly evolving and often difficult-to-navigate information on COVID-19 prevention and clinical management (Table 3), limited ability to maintain interactive discussion-oriented sessions while disseminating large quantities of information within the allocated time, and difficulty with long-term session planning.

Country and regional programs reported variable participation in Project ECHO sessions. In addition, CDC country staff noted information technology connectivity challenges and session-timing conflicts with clinical duties as barriers to consistent participation.

Limitations

One of the limitations of this analysis is the lack of a systematic review of all Project ECHO programs globally that were implemented in response to the COVID-19 pandemic. We used a convenience sample, limiting the generalizability of observations or conclusions beyond the contributing countries. The tool to capture Project ECHO program characteristics for this analysis was limited, and a more in-depth comprehensive tool to systematically evaluate Project ECHO programs during COVID-19 is likely needed. In addition, observing the development of communities of practice, a core function of any ECHO program, might have been limited by variable participation across ECHO programs.

Conclusions

The COVID-19 pandemic heightened existing concerns over disruptions in healthcare service delivery and essential public health functions during public health emergencies. Project ECHO might help address some of these concerns by enabling the consistent delivery of clinical and public health updates and engaging communities of providers. The ability to connect multiple stakeholders could help strengthen service quality and system resilience in the face of new challenges such as COVID-19 and lead to potential long-term positive outcomes. Evaluating ECHO programs formally to establish implementation best practices and recommendations for the use of this platform could benefit the larger public health community in its response to future public health threats.

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Faith Community Engagement to Mitigate COVID-19 Transmission Associated with Mass Gathering, Uman, Ukraine, September 2021

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Annually, ≈30,000 Hasidic and Orthodox Jews travel to Uman, Ukraine, during the Jewish New Year to pray at the burial place of the founder of the Breslov Hasidic movement. Many pilgrims come from the northeastern United States. The global health implications of this event were seen in 2019 when measles outbreaks in the United States and Israel were linked to the pilgrimage. The 2020 pilgrimage was cancelled as part of the COVID-19 travel restrictions imposed by the government of Ukraine. To prepare for the 2021 event, the National Public Health Institute, the Public Health Center of Ukraine, organized mitigation measures for pilgrims arriving in Uman, and the CDC COVID-19 International Task Force assisted with mitigation measures for pilgrims coming from the United States. We describe efforts to support COVID-19 mitigation measures before, during, and after this mass gathering and lessons learned for future mass gatherings during pandemics.

The World Health Organization (WHO) characterized the spread of SARS-CoV-2, the virus that causes COVID-19, as a pandemic in March 2020 (*1*). At the onset of the pandemic, WHO recognized transmission risks during gatherings and subsequently issued guidance and policy documents for gatherings during the COVID-19 pandemic (*2*). Mass gatherings are defined by WHO as events involving large numbers of attendees at a specific location, for a specific purpose, over a specific duration of time (*3*). Given the high density and mobility of participants, mass gatherings can be associated with increased transmission of SARS-CoV-2. These gatherings can create conditions conducive for SARS-CoV-2 transmission, given crowding, challenges with physical distancing, and prolonged and frequent contact among mass gathering participants. Therefore, the WHO recommended that, during the pandemic, gatherings "should not take place unless the basic precautionary measures to prevent and control infection are strictly applied and adhered to by all attendees" (*2*). These basic precautionary measures include physical distancing, regular handwashing, adherence to mask guidance issued by local health authorities, staying outdoors and avoiding crowding, and ensuring proper ventilation when indoors.

Orthodox Jewish communities in New York City (NYC), New York, USA, have been disproportionally affected by COVID-19. In the early fall of 2020, the incidence of COVID-19 in Orthodox Jewish neighborhoods was 4 times higher than the citywide average (*4*). As of April 2020, the Hasidic neighborhood of Borough Park in Brooklyn had the second-highest number of COVID-19 cases in NYC, and the predominantly Orthodox County of Rockland County, New York, experienced the second-highest number of COVID-19 cases per capita in the United States (*5*).

Each year, ≈30,000 Hasidic and other Orthodox Jews travel to Uman, a city that has 86,900 persons

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in the Cherkasy Region of central Ukraine, during the Jewish new year, Rosh Hashanah, and subsequent high holy days, as part of a pilgrimage to pray at the burial place of Rabbi Nachman, an 18th century luminary who founded the Breslov Hasidic movement (*6*). During the Uman pilgrimage, pilgrims gather in tight quarters when praying in synagogues, as well as when sleeping and eating. Thousands of pilgrims travel to Uman from the United States, particularly from NYC (Amudim Community Resources, https://amudim.org). The global health implications of this event were seen in 2019 when measles outbreaks in the United States and Israel were linked to the pilgrimage (*7*,*8*). Cases of infection with SARS-CoV-2 in Ukraine were reported in March 2020 (*9*).

As of September 6, 2021, the beginning of Rosh Hashanah, 2,578,394 SARS-CoV-2 cases and 59,523 deaths had been reported in Ukraine (*10*). As part of the travel restrictions put in place by the government of Ukraine to prevent the spread of COVID-19, international travelers were not allowed to enter the country for the Uman pilgrimage in 2020 (*11*). Travel restrictions were lifted in 2021, enabling international travelers to participate in the Rosh Hashanah pilgrimage during September 6–8, 2021. Many pilgrims remained in Uman throughout the Jewish High Holidays that ended on September 29, 2021. Given the disruption of the 2020 pilgrimage, a larger number of pilgrims was expected for the 2021 Uman pilgrimage.

The Public Health Center of the Ministry of Health of Ukraine (UPHC), through the US Centers for Disease Control and Prevention (CDC) Ukraine Office, requested technical assistance from the CDC COVID-19 International Task Force in supporting mitigation efforts for this mass gathering, including specifically for pilgrims traveling from the United States.

The purpose of this report was to describe COVID-19 mitigation measures for the 2021 Rosh Hashanah Pilgrimage to Uman, Ukraine; report the number of COVID-19 cases in NYC and Uman; and assess whether there were any signals of increased COVID-19 transmission in NYC linked to the Uman pilgrimage. The activities of the study, and the partnerships involved herein, exemplify the Supplement theme of Leveraging and Adapting Global Health Systems and Programs During the COVID-19 Pandemic.

This activity was reviewed by CDC and determined to be nonresearch. It was conducted consistent with applicable federal law and CDC policy (see, e.g., 45 C.F.R. part 46, 21 C.F.R. part 56; 42 U.S.C. §241(d); 5 U.S.C. §552a; 44 U.S.C. §3501 et seq.).

The CDC COVID-19 International Task Force engaged multiple groups, including influential American Hasidic leaders, to develop a comprehensive mitigation and communications strategy for the Uman pilgrimage targeting pilgrims in Ukraine and the United States. The project was coordinated by CDC in partnership with UPHC, the Rabbinical Alliance of America, Amudim, and the NYC Department of Health and Mental Hygiene (NYC DOHMH). CDC has been partnering with UPHC since its inception in 2017. During the COVID-19 pandemic, UPHC received funds from CDC to support faith-community engaged contact tracing and mitigation during the Rosh Hashanah pilgrimage. The Rabbinical Alliance of America and Amudim did not receive governmental funding for this study.

Together, project partners developed a fact sheet based upon WHO and CDC COVID-19 guidelines, addressing the need for COVID-19 vaccinations before travel, and mitigation measures during the pilgrimage and upon return to the United States. The fact sheet was translated into Hebrew, Yiddish, and Ukrainian. Forward and backward translation in all languages was conducted in the United States and Ukraine by certified translators. Cognitive testing of the fact sheet was conducted with religious leaders and other community consultants to ensure cultural appropriateness.

Funded by the NYC DOHMH, the fact sheet was disseminated by full-page inserts in 5 major Orthodox publications (Hamodia, Flatbush Jewish Journal, Yated, Der Yid, and Di Tzeitung/News Report) in NYC for 5 days each during August 5–September 3, 2021, reaching an estimated daily readership of 321,000 persons. The fact sheet was also sent out by various WhatsApp groups. Furthermore, a weekly YouTube show hosted by Rabbi Dr. Glatt, sponsored by Young Israel of Woodmere, New York and promoted by the Rabbinical Alliance of America and other national rabbinical organizations, regularly featured CDC mitigation guidance and reached over 6,000 viewers weekly. The Rabbinical Alliance of America also shared the fact sheet with its listservs, comprising >950 Orthodox rabbis and 1,500 additional congregational and community leaders.

In Uman, concerted COVID-19 mitigation efforts were made by UPHC (Table 1) and the US-based Orthodox Jewish faith-based organization, Amudim (Table 2). UPHC produced 2 videos aimed at the Hasidic Jewish community conveying recommendations for the safe celebration of Rosh Hashanah that were broadcast at the international airports in Kyiv and Lviv, large international airports used by most pilgrims traveling into Ukraine, and in hotels and refectories in Uman. A

Table 1. COVID-19 mitigation measures implemented by UPHC and associated with mass gathering, Uman, Ukraine, September 2021*

Mitigation measure	Location	Quantity
Safe celebration of Rosh Hashanah video in English and Hebrew	International airports of Kyiv and Lviv, hotels and refectories in Uman, and central billboard on Pushkina Street, the main thoroughfare for the pilgrimage	2 videos: 1 in English with Hebrew subtitles, 1 in Hebrew with English subtitles
Safe celebration of Jewish high holidays web content	UPHC Web site, Visit Ukraine Web site (principle tourist information portal for travelers)	
Distribution of CDC-developed fact sheet	Rabbi Nachman of Breslov International Charitable Foundation and pilgrimage in Uma	19,000 fact sheets distributed
COVID-19 mitigation posters	Kyiv and Lviv airports, hotel lobbies, Red Cross tents, local synagogues, and Rabbi Nachman's burial place	30 posters
COVID-19 hotline: Hebrew language option	Nation	1 national hotline
CLINITEST Rapid COVID-19 antigen tests† distributed	Uman	50,000
Hand sanitizer	Distributed to pilgrims in Uman	19,000
Disposable masks	Distributed to pilgrims in Uman	190,000

*CDC, Centers for Disease Control and Prevention; UPHC, National Public Health Center of the Ministry of Health of Ukraine.
†Siemens (https://www.siemens.com).

central billboard was also used on Pushkina Street, the main thoroughfare for the pilgrimage. "Safe Celebration of the Jewish High Holidays" web content was posted across the UPHC website; on the Visit Ukraine Web site, the principal tourist information portal for travelers to Ukraine and Ukrainians planning travel abroad; and through various social media outlets. Recognizing the need to immediately diagnose cases and isolate persons who had COVID-19, UPHC provided 50,000 CLINITEST Rapid COVID-19 antigen tests (Siemens, https://www.siemens.com) to Uman for use during the pilgrimage.

Because the immediate goal was preventing the spread of COVID-19 during the Uman pilgrimage through multiple interventions in the United States and Ukraine, an evaluation of the interventions was not planned as part of the study. However, efforts were made to assess the effect of the study by comparing different data sources.

During the 2021 Uman pilgrimage, UPHC collaborated with the Uman branch of the Uman district of the Cherkasy Central Committee of the Ministry of Health to provide the number of PCR tests used and rapid antigen tests conducted in Uman, as well as the number of positive test results. UPHC also provided the number of COVID-19 cases among service workers in Uman during the pilgrimage and 2 weeks after the pilgrimage.

US Customs and Border Protection (USCBP) provided data regarding the number of travelers returning to NYC from Ukraine after Rosh Hashanah and other high holy days. CDC subsequently provided traveler data to the NYC Test and Trace Corps program (T2). Travelers were advised on quarantine and offered testing and vaccination resources.

COVID-19 incidence in Ukraine for the epidemiologic week starting September 6, 2021, was 6.3 cases/100,000 persons and increased to 10.4 cases/100,000 persons the next epidemiologic week (*10*). Pilgrims entering Ukraine were required to show a negative COVID-19 PCR test result for a test that was conducted no more than 72 hours before entering Ukraine. According to information received from the Head of the Situational Center of the Main Department of National Police in the Cherkasy region, 34,069 pilgrims came to Uman in 2021 to celebrate Rosh Hashanah, many of whom were US citizens. (Information was received on September 15, 2021, from the Head of the Situational Center of the Main Department of National Police in the Cherkasy region of Serhiy Kovalenko.) That center was created in Uman for the pilgrimage and included representatives of the State Emergency Service of Ukraine, the National Guard, the National Police, and the Border Guard Service. Information about the number of pilgrims was collected through various sources: the Border Guard Service, the International Charitable Rabbi Nachman Fund, and in the 7 points of entry to Uman (by the National Police). COVID-19 vaccination coverage among pilgrims is not known.

Table 2. COVID-19 mitigation measures implemented by Amudim and associated with mass gathering, Uman, Ukraine, September 2021

Mitigation measure	Location	Quantity
COVID-19 mitigation banners and posters	Banners placed on the exterior of building on Pushkina Street and throughout dining and prayer areas	120 posters
COVID-19 mitigation cards	Distributed to pilgrims in Uman	250,000
Limiting capacity in the dining halls and at individual dining tables was limited to 50%	Uman	
Hand sanitizer and sanitizing hand wipes	Distributed to pilgrims in Uman	5,000 bottles of sanitizer, 100,000 wipes

Although more pilgrims than usual were expected, given that international travelers were denied entry to Uman in 2020, official reports registered 34,069 pilgrims, a number similar to previous pilgrimages. Amudim reported less crowding in dining facilities than in previous years even if persons did not maintain 2 meters of physical distancing. For example, instead of having 14 persons at dining tables, table wardens ensured that only 6–8 persons used a table at a time. Temporary synagogues and areas of study were set up in Uman to decongest established synagogues that restricted prayers at 50% normal capacity.

During September 6–10, 2021, laboratories in Uman performed 13,267 PCR tests for symptomatic and asymptomatic persons and found 93 positive specimens (0.7% positivity), all among pilgrims. Rapid antigen tests (n = 3,467) were also performed, and none showed positive results. According to the Uman District Department of the Cherkasy Central Committee of the Ministry of Health, 11 additional positive COVID-19 PCR results were identified among pilgrims during predeparture screening at Kyiv Boryspil International Airport. As of September 21, 2021, no COVID-19 cases were registered among Rosh Hashanah service workers or the population in the pilgrimage zone for whom testing was readily available. The Situational Center of the Main Department of National Police in Cherkasy reported that as of September 22, 2021, there were 3,315 pilgrims remaining in the city of Uman. However, no additional testing data were provided during September 6–10, 2021.

The US government imposed COVID-19 mitigation measures for international travelers arriving in the United States, including mask mandates on all US airlines. All air passengers, including US citizens and fully vaccinated persons, were required to have a negative COVID-19 test result within 3 days before date of travel or documentation of COVID-19 recovery in the previous 3 months. A total of 9,936 international air passengers arrived in the United States from Ukraine the week after the pilgrimage, September 8–15, 2021. Most of those passengers were indirect arrivals with connections through airports in Europe. Slightly more than half (n = 5,219, 52.5%) of the total international air passengers from Ukraine arrived at John F. Kennedy (n = 3,661, 36.8%) and Newark (n = 1,558, 15.7%) airports as US First Ports of Entry (*12*). (Note that cited CBP data are US government–controlled information and, because of legal restrictions, may not be shared beyond provision of this manuscript without explicit written permission; written requests for information may be submitted to DHS-SPS-RFI@hq.dhs.gov). Given the potential for COVID-19 exposure during the Uman pilgrimage, T2 proactively reached out to 471 contactable travelers returning to NYC from Ukraine during September 8–15, 2021, the period after Rosh Hashanah, and an additional 404 contactable travelers returning to NYC from Ukraine during September 30–October 7, after the end of the high holy days, on the basis of lists provided by CDC using data supplied by USCBP. Travelers were called and given information about quarantine and offered resources on testing and vaccination. Passengers arriving during September 16–29 were not tracked by USCBP because stakeholders reported that the preponderance of pilgrims would return to the United States either after Rosh Hashanah or after the end of all high holy days.

In addition to the proactive call made to travelers, T2 performed case investigations on NYC residents who had positive laboratory-based or point-of-care SARS-CoV-2 test results, at which point contacts were elicited and details about recent travel were captured. During September 8–October 8, 2021, T2 identified 15 persons who had COVID-19 and reported recent travel to Ukraine. These case-patients provided 22 contacts. T2 investigators observed lower than normal completion rates on case investigations and reluctance to respond to the question "have you traveled?" Although there was increased incidence of COVID-19 in 2 Hasidic neighborhoods in Brooklyn (Borough Park and Williamsburg) during September 2021, T2 determined the increase in Borough Park was unrelated to the pilgrimage because it began before the return of pilgrims; the cause for the increase in Williamsburg is unclear. We compiled COVID-19 incidence rates for these 2 communities (Table 3) (*13*).

The COVID-19 mitigation efforts for the Uman pilgrimage were a unique collaboration between the CDC COVID-19 International Task Force; Ukraine's Public Health Center; the CDC Ukraine Office; the CDC COVID-19 State, Tribal, Local, and Territorial Task Force; Orthodox and Hasidic leaders in the United States; and the NYCDOHMH. These efforts highlight the opportunities to mitigate COVID-19 transmission associated with mass gathering events by focusing on mitigation before, during, and after an event. These efforts also highlight the critical need for early planning to coordinate the efforts and interests of diverse participants as it relates to mass gatherings.

Collaborations take time to develop, and cross-border collaborations can take even longer. We also learned that modified data systems might be needed to measure the effect of mitigation efforts during a mass gathering.

Ensuring that culturally appropriate and relevant communications materials were developed and disseminated by trusted entities was the cornerstone to programmatic success. Identifying and developing relationships with key Hasidic leaders in Uman and the United States was critical to mitigation efforts for the Uman pilgrimage. Planning started in February 2021 and required coordination across countries and jurisdictions. Creating culturally appropriate resources for diverse communities required extensive community consultation and piloting. Limited internet uptake among the target population required the of nontraditional communication channels, such as the use of WhatsApp groups, and printing communication materials for distribution. Partnerships enabled multiple communication touchpoints, including Orthodox Jewish print publications and hotlines, videos shown in airports and on major airlines, fact sheets, and COVID-19 hygiene kits and billboards. Mitigation measures focused on vaccination before travel, social distancing and mask wearing during the pilgrimage, and symptom monitoring, as wells as COVID-19 testing and contact tracing.

Future mass gatherings might consider supplementing routine data collection tools with tools specific to the mass gathering to better enable disaggregating test results between host community members and mass gathering participants. A registration system could also assist with active follow-up of mass gathering participants upon their departure and help identify COVID-19 cases associated with the mass gathering.

The positive outcomes of the mitigation efforts for the 2021 Uman pilgrimage were strengthening the partnership between CDC and the UPHC, the collaboration between CDC and the NYCDOHMH, and developing relationships and collaboration with Orthodox and Hasidic leaders in the greater NYC metropolitan area. This program underscored opportunities for future research for enhancing and targeting COVID-19 surveillance efforts to help identify where to focus mitigation efforts for future mass gatherings during pandemics.

Table 3. COVID-19 incidence rates in Brooklyn, New York, USA, associated with mass gathering in Uman, Ukraine, during September 2021

Location	Beginning of epidemiologic week	Incidence, cases/100,000 persons
Borough Park, postal code 11219	Sep 6	79.93
	Sep 13	134.32
	Sep 20	164.29
	Sep 27	153.19
	Oct 4	167.62
	Oct 11	185.39
Williamsburg, postal code 11211	Sep 6	103.12
	Sep 13	131.79
	Sep 20	159.17
	Sep 27	134.35
	Oct 4	142.06
	Oct 11	155.32

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Effects of COVID-19 on Vaccine-Preventable Disease Surveillance Systems in the World Health Organization African Region, 2020

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Global emergence of the COVID-19 pandemic in 2020 curtailed vaccine-preventable disease (VPD) surveillance activities, but little is known about which surveillance components were most affected. In May 2021, we surveyed 214 STOP (originally Stop Transmission of Polio) Program consultants to determine how VPD surveillance activities were affected by the COVID-19 pandemic throughout 2020, primarily in low- and middle-income countries, where program consultants are deployed. Our report highlights the responses from 154 (96%) of the 160 consultants deployed to the World Health Organization African Region, which comprises 75% (160/214) of all STOP Program consultants deployed globally in early 2021. Most survey respondents observed that VPD surveillance activities were somewhat or severely affected by the COVID-19 pandemic in 2020. Reprioritization of surveillance staff and changes in health-seeking behaviors were factors commonly perceived to decrease VPD surveillance activities. Our findings suggest the need for strategies to restore VPD surveillance to prepandemic levels.

Routine immunizations are among the most effective interventions to reduce illnesses, hospitalizations, and deaths from vaccine-preventable diseases (VPD) (*1*). The COVID-19 pandemic has directly affected services in health systems, including routine vaccine delivery, disease detection, laboratory confirmation of suspected cases, and outbreak responses (*2*–*4*). While the COVID-19 pandemic continues to disrupt routine immunization services, maintaining high-quality VPD surveillance is even more critical for detecting and responding effectively to VPD outbreaks, particularly in geographic areas with populations known to be vulnerable or low immunization coverage (*5*,*6*).

Recent assessments have suggested that COVID-19 mitigation measures (e.g., social distancing, country border lockdowns, delays in specimen transportation) may have hindered detection and timely notification of VPD cases (*5*,*7*). It is unknown if the decrease in reported surveillance indicators and cases were because of interruptions in surveillance systems, decreases in disease occurrence, or both. This lack of data includes which specific activities of VPD surveillance were most disrupted by the COVID-19 pandemic at national and subnational levels and to what extent these disruptions varied by disease, location, or severity of impact. Information from frontline workers at the operational levels of VPD surveillance systems, such as STOP Program consultants, can serve as a foundational source to identify specific surveillance components affected by the COVID-19 pandemic.

Since 1999, the STOP (originally Stop Transmission of Polio) Program has supported the Global Polio Eradication Initiative (GPEI) and national ministries of health to strengthen routine immunization and surveillance programs to reduce global VPD morbidity and mortality (*8*). STOP consultants are deployed through the World Health Organization (WHO) in 1 of 3 roles (communications specialist, data manager, or field epidemiologist) at national, provincial, district, and subdistrict levels (*8*). To help document the effect of the COVID-19 pandemic on general VPD surveillance, as well as on 3 priority surveillance systems—measles, rubella, and acute flaccid paralysis (AFP) for poliovirus—we solicited information from STOP consultants on disruptions they observed to

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VPD surveillance programs while deployed during 2020. We considered insights from STOP consultants relevant because of their field presence and direct involvement in immunization and VPD surveillance activities throughout the COVID-19 pandemic.

Methods

We developed a web-based survey to determine how surveillance activities across different health system levels changed because of the COVID-19 pandemic. We distributed the survey in May 2021 to all 214 STOP consultants deployed to 44 countries across the 6 WHO regions who were on assignment from January 2020 through June 2021. Our report focuses on the WHO African Region, where 75% (160/214) of all STOP consultants were deployed. The survey questions primarily focused on their perceptions and observations about how COVID-19 had affected surveillance for poliovirus, measles, rubella, and other VPDs (pertussis, yellow fever, and neonatal tetanus) and asked STOP consultants to recall changes to their work in 2020 compared with 2019. The survey, developed in both English and French, included categorical responses and free-text fields and was sent to respondents by email with 2 weeks for completion.

We used R version 9.1.3 (The R Project for Statistical Computing, https://www.r-project.org) to conduct descriptive analyses to summarize the quantitative survey findings by calculating the proportion of responses to each question. We then reviewed qualitative information provided through the free-text responses to identify trends and themes that provided more context and descriptive information about the disruptions to VPD surveillance activities observed by the STOP consultants.

Results

Of the 160 STOP consultants in the African Region, 154 (96%) completed the survey (Table 1). Seventy percent (107/154) were epidemiologists, with 42% (64/154) stationed at the district level. All (154/154) African Region STOP consultants who responded were involved to some extent in COVID-19 activities in 2020, most often supporting response activities related to active surveillance and contact tracing; coordinating state-, district-, or local-level COVID-19 response efforts; engaging communities to implement preventive measures; and developing and disseminating COVID-19 weekly reports.

Among respondents, 97% observed that the COVID-19 pandemic either somewhat (54%; 83/154) or severely (43%; 66/154) affected measles or rubella surveillance in 2020. Themes from free-text responses suggested movement restrictions implemented to mitigate the risk of COVID-19 transmission affected the ability of surveillance staff to conduct supervisory visits, active case searches, suspected case investigations, community-based surveillance, and capacity-building activities and impeded collection and transportation of blood samples. About two thirds of the African Region STOP respondents (61%; 94/154) suggested that COVID-19 mitigation efforts also potentially disrupted the detection, notification, and reporting of measles or rubella cases.

Almost all of the African Region STOP consultants surveyed observed that AFP surveillance for poliovirus was either somewhat (55%; 84/154) or severely (43%; 66/154) affected by the COVID-19 pandemic during 2020 (Table 2). Some respondents suggested that country lockdowns and the reassignment of polio program staff to the COVID-19 response contributed to the decrease in AFP surveillance activities in 2020. Surveillance activities delayed by COVID-19 mitigation measures commonly mentioned by respondents included active case investigations and transporting samples to national laboratories for processing.

African Region STOP consultants noted the number of active AFP surveillance activities they

Table 1. Characteristics of 154 STOP Program consultants in the World Health Organization's African Region who responded to a survey on the effects of COVID-19 on vaccine-preventable disease surveillance systems, 2020*

Characteristics	Value†
Number of countries with STOP respondents	27 (57)
Median number of STOP respondents per country (IQR)	4 (2–8)
STOP consultant administrative level of assignment‡	
National	30 (19)
Provincial	53 (34)
District	64 (42)
Local	7 (5)
STOP consultant role	
Field epidemiologist	107 (70)
Communication specialists	26 (17)
Data manager	21 (14)

*Values are no. (%) except as indicated. IQR, interquartile range.
†Percentages may not equal 100% because of rounding.
‡Deployment location at time of survey response.

Table 2. Impact of COVID-19 on measles and rubella, AFP/polio, and other VPD surveillance systems according to 154 STOP Program consultants in the World Health Organization's African Region, 2020*

Category	No. (%) respondents		
	Measles and rubella	AFP/polio	Other VPDs
Compared to 2019, in 2020 did COVID-19 impact surveillance overall?			
Severely impacted	66 (43)	66 (43)	38 (25)
Somewhat impacted	83 (54)	84 (55)	92 (60)
Not at all impacted	3 (2)	3 (2)	15 (10)
Does not know	2 (1)	1 (1)	9 (6)
Missing response	0	0	0
Compared to 2019, in 2020 did you conduct active surveillance?			
Increased active surveillance	3 (2)	1 (1)	2 (1)
Same level of active surveillance	21 (14)	19 (12)	24 (16)
Decreased active surveillance	108 (70)	119 (77)	100 (65)
No active surveillance	20 (13)	13 (8)	24 (16)
Does not know	0	0	0
Missing response	2 (1)	2 (1)	4 (3)
Compared to 2019, in 2020 did staffing change for surveillance at your level of responsibility?			
Staffing increased	4 (2)	11 (7)	4 (3)
No change in staffing	103 (67)	89 (58)	107 (69)
Staffing decreased	23 (15)	31 (20)	24 (16)
Does not know	23 (15)	22 (14)	18 (12)
Missing response	1 (1)	1 (1)	1 (1)
Compared to 2019, in 2020 did COVID-19 impact adversely the detection, notification and reporting of cases?			
Yes	94 (61)	106 (69)	94 (61)
No	37 (24)	40 (26)	39 (25)
Does not know	22 (14)	7 (5)	20 (13)
Missing response	1 (1)	1 (1)	1 (1)
For responses indicating an adverse impact on the detection, notification, and reporting of VPD cases, identify the health care level impacted (select all that apply)			
At the national level	24 (26)	37 (35)	29 (30)
At the province level	40 (43)	50 (47)	45 (48)
At the district level	75 (80)	81 (76)	72 (77)
At the local level	86 (92)	92 (87)	85 (90)
Compared to 2019, in 2020 did COVID-19 mitigation efforts disrupt the transport of specimens of suspected VPD cases to relevant who reference laboratories?			
Yes	50 (32)	73 (47)	42 (27)
No	50 (32)	36 (23)	44 (29)
Does not know	52 (34)	44 (29)	66 (43)
Missing response	2 (1)	1 (1)	2 (1)

*AFP, acute flaccid paralysis, VPD, vaccine-preventable disease.
†Percentages may not equal 100% because of rounding.

conducted decreased (77%; 119/154) or were not completed (8%; 13/154) in 2020 compared with 2019. Respondents also noted that lockdowns to mitigate the transmission of COVID-19 often reduced the public's access to and use of local healthcare facilities and services, which may have allowed AFP cases to go undetected.

Most respondents felt that COVID-19 either somewhat (60%; 92/154) or severely (25%; 38/154) affected surveillance of other VPDs, such as pertussis, yellow fever, and neonatal tetanus, in 2020. Specifically, 65% (100/154) of respondents suggested that active surveillance conducted for other VPDs decreased in 2020 compared with 2019; 16% (24/154) noted they did not conduct any active surveillance for these other VPDs in 2020. However, African Region STOP consultants did observe some improvements in measles or rubella surveillance in 2020, including the integration of VPD surveillance activities into COVID-19 response activities; using phone, WhatsApp, and similar technologies for communication when field access was limited; improving community-based surveillance; and implementing VPD surveillance refresher trainings for health facility staff.

Discussion

As the number of undervaccinated children increases because of disruptions in routine immunization services, understanding how VPD surveillance systems have fared during the COVID-19 pandemic becomes critical (*1*). Descriptions collected from WHO African Region STOP consultants support general observations that the COVID-19 pandemic adversely affected implementation of VPD surveillance activities in 2020 and that COVID-19 mitigation strategies and staff reassignments may have been substantial disrupting factors. Further efforts are needed to directly associate observations from our survey with changing

trends in indicators of disease surveillance systems in the WHO African Region and across other WHO regions during 2020.

STOP consultants spend most of their time at local or district levels, and results from this survey suggest that certain VPD surveillance activities such as detection, notification, and reporting were affected primarily at those levels; however, some effect was observed on regional and national activities in many WHO African Region countries because the COVID-19 response was prioritized. Respondents also noted that measles and rubella surveillance staff were often shifted to COVID-19–related activities. In countries where staffing and funding are limited, integrating VPD surveillance functions across systems, instead of relying on standalone systems, could be a mechanism to address resource limitations, even moreso as COVID-19 becomes endemic in countries.

In addition, some respondents indicated that country lockdowns and movement restrictions contributed to delays in suspected case investigations and transportation of samples to reference laboratories. Although the Global Polio Eradication Initiative had published interim guidance on how to continue conducting polio surveillance with COVID-19 mitigation measures in place (*9*,*10*), survey responses seem to corroborate existing reports of decreased AFP surveillance indicators during the COVID-19 pandemic (*7*). Although AFP surveillance for poliovirus may have been adversely affected in many countries by the pandemic, it is notable that AFP surveillance systems were still able to identify circulating vaccine-derived and wild poliovirus in the African Region (*11*).

Among limitations in our survey, consultant-respondents were asked to respond to questions based on their personal knowledge and experience, which is likely to have varied depending on location, length of time in assignment, and type of assignment, and should be considered a collection of observations or case series. These responses provide a valuable starting point to generate hypotheses for future public health investigations and research into impacts of VPD surveillance systems during the COVID-19 pandemic. Second, each STOP consultant surveyed was contracted through WHO to work in partnership with the Ministry of Health in their country of assignment. Thus, responses might not represent observations of the COVID-19 pandemic's effect on VPD surveillance activities among private sector or non–Ministry of Health immunization and surveillance staff, or in countries without STOP consultants.

Conclusions

Since 2020, the COVID-19 pandemic has disrupted or delayed many aspects of both aggregate and case-based VPD surveillance systems in Africa. A conscientious effort should be made to connect COVID-19 response activities to existing public health surveillance systems, especially where substantial investments have been made towards strengthening VPD contact tracing, active surveillance, and specimen collection and transportation. Efforts to integrate systems across diseases would promote and facilitate efficient restructuring, integration, and coordination of surveillance systems globally.

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CDC's COVID-19 International Vaccine Implementation and Evaluation Program and Lessons from Earlier Vaccine Introductions

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The US Centers for Disease Control and Prevention (CDC) supports international partners in introducing vaccines, including those against SARS-CoV-2 virus. CDC contributes to the development of global technical tools, guidance, and policy for COVID-19 vaccination and has established its COVID-19 International Vaccine Implementation and Evaluation (CIVIE) program. CIVIE supports ministries of health and their partner organizations in developing or strengthening their national capacities for the planning, implementation, and evaluation of COVID-19 vaccination programs. CIVIE's 7 priority areas for country-specific technical assistance are vaccine policy development, program planning, vaccine confidence and demand, data management and use, workforce development, vaccine safety, and evaluation. We discuss CDC's work on global COVID-19 vaccine implementation, including priorities, challenges, opportunities, and applicable lessons learned from prior experiences with Ebola, influenza, and meningococcal serogroup A conjugate vaccine introductions.

In March 2020, the World Health Organization (WHO) characterized COVID-19 as a global pandemic, driving a race to develop vaccines against SARS-CoV-2, the virus that causes COVID-19. Nine months later, the first COVID-19 vaccine was approved for widespread use in the United Kingdom; the vaccination program there launched on December 8, 2020 (*1*). In rapid succession, the United States issued an emergency use authorization for, recommended, and began administration of COVID-19 vaccines as well (*2*), and WHO issued the first emergency use listing (EUL) and policy recommendations for COVID-19 vaccines (*3*). As of April 2022, >11 billion doses of COVID-19 vaccines have been administered worldwide (*4*), and a total of 10 COVID-19 vaccines have been issued under EUL from WHO (*5*).

The Access to COVID-19 Tools (ACT) Accelerator is the coordinated global effort to develop diagnostic, treatment, and prevention tools to fight COVID-19 (*6*). COVID-19 Vaccines Global Access (COVAX) is the vaccines pillar of the ACT Accelerator and aims to accelerate development and manufacture of COVID-19 vaccines and to guarantee fair and equitable access for every country in the world (*7*). WHO; the Coalition for Epidemic Preparedness Innovations (CEPI); and Gavi, the Vaccine Alliance, co-lead COVAX. As of April 2022, a total of 145 countries were participating in COVAX (*8*), including both funded and self-financing economies (*9*). The US government is the largest contributor to COVAX and has committed US $4 billion in funding (*10*) and committed to donating >1.1 billion vaccine doses (*11*) as of October 2021; the Centers for Disease Control and

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Prevention (CDC) contributes assistance to COVAX as a key technical partner. Although COVAX is the single largest mechanism for COVID-19 vaccine procurement globally, countries may also gain access to doses via national production, bilateral agreements with vaccine manufacturers, or bilateral donations.

CDC supports international COVID-19 vaccination efforts and COVAX by participating in global-level technical working groups, collaborating with global immunization partners to create tools and guidance, and gathering and synthesizing evidence to support new policy and global guidance. CDC also supports global COVID-19 vaccine implementation as a key component of CDC's Strategy for the Global Response to COVID-19 (*12*). CDC anticipates these activities will reduce the COVID-19 burden in partner countries while strengthening partner countries' capacities to vaccinate their populations against future vaccine-preventable diseases that pose an epidemic or pandemic threat.

To support ministries of health in developing or strengthening their national capacities for the planning, implementation, and evaluation of COVID-19 vaccination programs, CDC established the COVID-19 International Vaccine Implementation and Evaluation (CIVIE) program. We describe the CIVIE program; challenges and opportunities with global COVID-19 vaccine implementation; and applicable lessons learned from prior experiences with Ebola, influenza, and meningococcal serogroup A conjugate vaccine introductions.

CIVIE

CDC established the CIVIE program in 2020 to help country ministries of health and their partner organizations effectively introduce, deploy, manage, and evaluate COVID-19 vaccines, with the additional goal of establishing sustainable programs for the delivery of immunizations throughout the life-course (*13*). CIVIE initially prioritized specific low- and middle-income countries (LMICs) for potential CDC support for COVID-19 vaccine implementation. CIVIE evaluated each country by factors including level of interest, the presence of a CDC office or staff in that country, the existence of CDC-supported programs, and eligibility to receive donor-funded COVID-19 vaccines through COVAX (Figure 1).

CIVIE supports countries in implementing their national deployment and vaccination plans for COVID-19 vaccines (*14*) by working with the countries' ministries of health to identify specific activities that would benefit from CDC technical or financial support. In countries with in-country CDC staff, CIVIE primarily works with ministries of health through CDC staff; in countries without in-country CDC presence, CIVIE either engages directly with ministries of health or supports them via regional CDC offices, CDC-funded implementing partners, or WHO offices at the country or regional level.

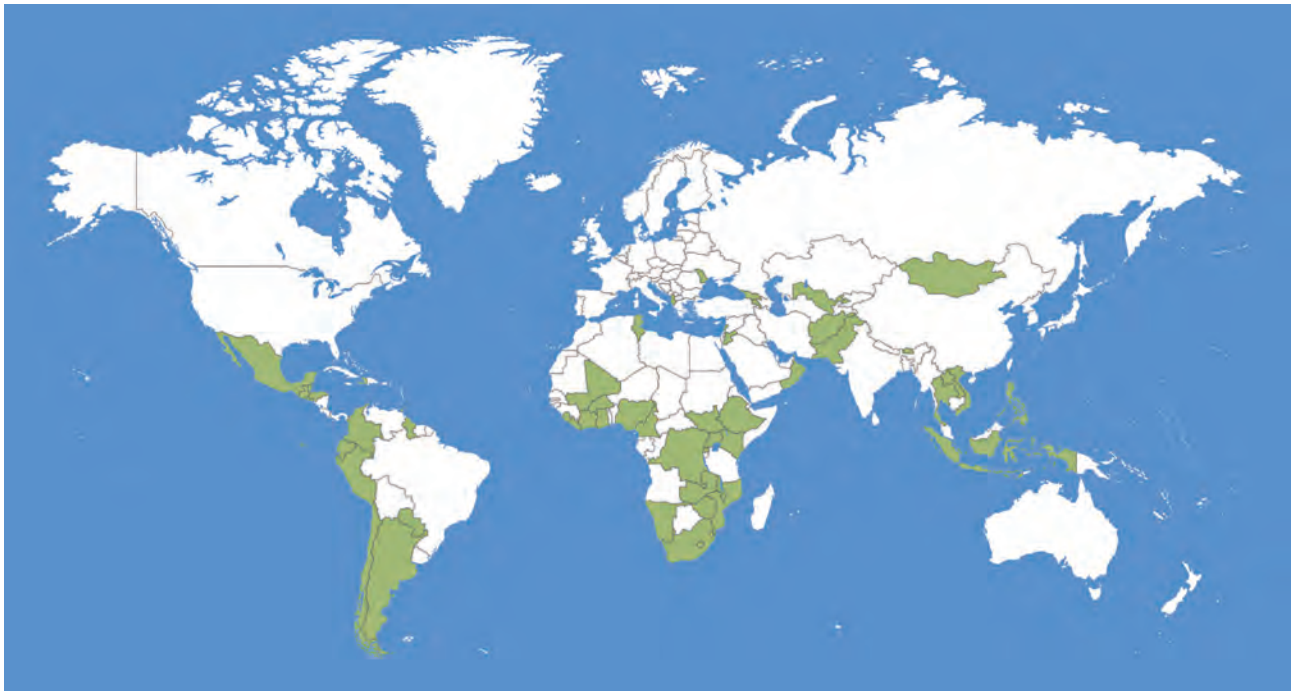

Figure 1. Green shading indicates the 55 countries supported by the Centers for Disease Control and Prevention's COVID-19 International Vaccine Implementation and Evaluation program in fiscal year 2021.

CIVIE's 7 priority areas for country technical assistance are vaccine policy development, program planning, vaccine confidence and demand, data management and use, workforce development, vaccine safety, and evaluation (Table 1). CIVIE chose these technical areas to leverage CDC's technical expertise and comparative advantages for supporting country-level vaccine implementation and evaluation (*15*), on the basis of lessons learned from other vaccine introductions. In fiscal year 2021, CIVIE supported 55 countries, representing 27% of the world's population (Figure 1); vaccine confidence and demand and vaccine safety were the most commonly requested areas for CDC country support (Figure 2).

To carry out this work, CDC received funding from both the Coronavirus Aid, Relief, and Economic Security Act in 2020 and the American Rescue Plan in 2021. CDC has awarded funds to the Task Force for Global Health (TFGH) as a main implementing partner; TFGH then subawards funding to in-country partners. In addition, CIVIE has provided funding to the WHO headquarters and regional offices to indirectly support global, regional, and country-level COVID-19 vaccine implementation. CDC's support for COVID-19 vaccine implementation and evaluation in fiscal year 2021 was coordinated with support provided to countries from other US government entities, such as US Agency for International Development (USAID) (*10*) and the US President's Emergency Plan for AIDS Relief (PEPFAR), as well as from multilateral partners such as WHO (*7*), Gavi (*8*), UNICEF (*16*), and other global partners. Specific examples of CDC's coordination with partners and technical activities in countries to accelerate progress toward widespread and equitable access to safe and effective COVID-19 vaccines have been published (*17*,*18*).

Challenges

The COVID-19 vaccine rollout faced many challenges. Although COVID-19 vaccines were rapidly developed and manufactured, getting the vaccines delivered to countries, distributed within countries, and administered worldwide is a complex interdependent effort (*7*). Challenges we observed during the initial rollout were insufficient manufacturing capacity, supply constraints, the overwhelming and simultaneous demand for vaccination, inequitable vaccine distribution and access, partner coordination challenges, a complicated and evolving vaccine product landscape, multidose schedules, a limited evidence base for some vaccine products, staffing shortages, and overburdened healthcare workers. In addition, many countries were inadequately prepared to monitor vaccine safety and address public concerns about COVID-19 vaccines, and an overabundance of information, including misinformation (*19*), contributes to low vaccine confidence in many populations.

Unlike childhood vaccination programs, which are present in all countries, 38% of countries lacked adult vaccination programs in 2018 (*20*), and specific immunization programs for healthcare workers are not present in many countries. The COVID-19 vaccine rollout began by targeting healthcare workers, older adults, and other special populations who are most at

Table 1. CDC priority technical areas to support global COVID-19 vaccine implementation through the COVID-19 International Vaccine Implementation and Evaluation (CIVIE) program

Technical area	Examples of CDC-supported activities
Vaccine policy development	Assist with data review to inform prioritization and planning for vaccination of risk groups Support and strengthen national-level decision making and National Immunization Technical Advisory Groups via trainings and workshops
Program planning	Support microplanning for populations targeted for vaccination Help design logistical and distribution plans for different vaccination scenarios or products
Vaccine confidence and demand	Develop and provide standard tools for country-level adaptation to collect data on behavioral and social barriers to vaccine uptake Provide support to assess and manage the effect of infodemics* on vaccine confidence and uptake Provide messaging and communications technical assistance, materials, and tools
Data management and use	Provide technical assistance to rapidly assess, develop, implement, and monitor data management systems and tools used for COVID-19 vaccine introduction and safety monitoring
Workforce development	Conduct rapid performance assessments to understand workforce-related barriers and facilitators to delivering COVID-19 vaccine Provide evidence-based tools and techniques for improving supervision
Vaccine safety	Strengthen passive or enhanced surveillance for adverse events following immunization Use active surveillance or special studies to address key questions on COVID-19 vaccine safety Ensure preparedness to respond to safety events through vaccine-related event response planning
Evaluation	Support post-introduction evaluations using standard WHO tools Conduct targeted evaluations of vaccine effectiveness to address key global evidence gaps

*Infodemic, "overabundance of information during a disease outbreak" (*17*).

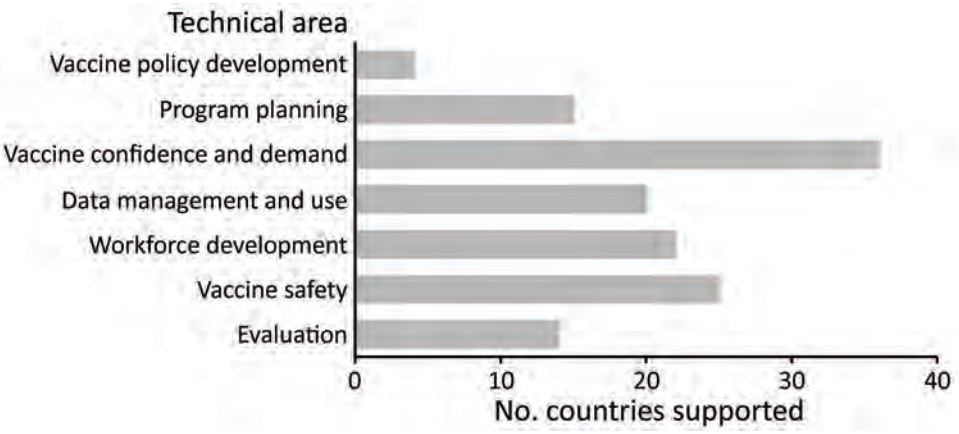

Figure 2. Technical areas of support provided to countries by the Center for Disease Control and Prevention's COVID-19 International Vaccine Implementation and Evaluation (CIVIE) program in fiscal year 2021

risk for severe disease or death from COVID-19, followed by other members of the general adult population (*21*). This process required devising and communicating new strategies for vaccine implementation that were different from the typical routine childhood immunization programs. Furthermore, these new strategies had to be tailored to individual countries and target populations for vaccination, which required continuous evaluation and adaptive communication strategies.

Opportunities

Despite these challenges, the global introduction of COVID-19 vaccine presented opportunities for improving and modernizing immunization programs. Vaccination provides a path out of the COVID-19 pandemic; the world's current focus on immunization can be leveraged to ensure a successful COVID-19 vaccine rollout and strengthen the demand for and confidence in vaccination against all vaccine-preventable diseases. Because the COVID-19 vaccines were made available for adult populations first and were subsequently approved for younger age groups, COVID-19 vaccination provides an excellent opportunity to emphasize the life-course approach to vaccination (*22*), a key element of the WHO Immunization Agenda 2030 (*13*).

CIVIE's financial and technical support to ministries of health for rapid implementation and evaluation of COVID-19 vaccines offers many benefits, including the strengthening of existing partnerships and the formation of new collaborations beyond the traditional immunization partner organizations. With continued support, the resulting evidence-based improvements in immunization systems could lead to long-term benefits such as the establishment of new adult and healthcare worker vaccination platforms, strengthened national immunization programs, introductions of non–COVID-19 vaccines that were placed on hold during the pandemic, and improved country readiness for future vaccine introductions, including those in response to public health emergencies.

Because the CIVIE program was created very early in the COVID-19 vaccine introduction process, it provided a foundation upon which new activities could be launched as vaccine rollout progressed. In the second year of the program, CIVIE continued to respond to the evolving needs of global COVID-19 vaccination implementation, such as increased vaccine supply and the need to address growing inequities in vaccination coverage, by continuing system-strengthening activities and further expanding support in the areas of postintroduction evaluations, vaccine effectiveness studies, vaccine campaigns or high-throughput vaccination planning and implementation, and vaccination in humanitarian settings.

Lessons Learned from Previous Vaccine Introductions

Despite the unprecedented nature of the COVID-19 pandemic and the resulting global COVID-19 vaccination effort, the CIVIE program found applicable lessons in previous introductions of Ebola, influenza, and meningococcal serogroup A vaccines (Table 2). Although many lessons, both positive and negative, have been learned through experiences with prior vaccine introductions, we have chosen to focus on these particular vaccines given the CIVIE team's collective background experience. We selected illustrative examples that informed the strategy for COVID-19 vaccine implementation and high-level lessons learned, although certainly county-level and subnational lessons have been learned as well.

Ebola Vaccine

Experience with the Ebola vaccine has highlighted some of the difficulties associated with the introduction of new vaccines during public health emergencies (e.g., vaccine supply constraints, identification and vaccination of healthcare workers, and the importance of strong community engagement to build trust and vaccine confidence). During the large West Africa Ebola virus disease (EVD) outbreak in 2014–2016, Ebola vaccine development was expedited, driven by the gravity of the public health emergency and the need for rapid access to a safe and effective vaccine against Ebola viruses (*23*–*26*). Since then, >300,000 persons have been vaccinated with rVSVΔG-ZEBOV-GP (ERVEBO; Merck & Co., Inc., https://www.merck.com) during multiple EVD outbreaks in the Democratic Republic of the Congo (DRC), Guinea, Uganda, South Sudan, Burundi, and Rwanda, using a vaccination strategy targeting EVD case contacts, contacts of contacts, healthcare workers, and frontline workers (*27*–*29*). A second Ebola vaccine option, the 2-part regimen of Ad26.ZEBOV (Zabdeno; Janssen, https://www.janssen.com) and MVA-BN-Filo (Mvabea; Janssen), is now recommended as preventive vaccination for at-risk persons, such as healthcare workers and frontline workers in neighboring countries where EVD outbreaks may spread (*30*).

As we have seen with COVID-19 vaccines, supply constraints have limited the use of the Ebola vaccine during outbreaks. Limited quantities meant that vaccination strategies had to be tailored based on the vaccine and disease characteristics, risk-benefit analyses for different target populations, and country-specific contexts. WHO developed the Strategic Advisory Group of Experts on Immunization (SAGE) roadmap for prioritizing use of COVID-19 vaccines in the context of limited supply as a tool for countries to optimize the benefits from COVID-19 vaccines, based on public health goals, vaccine access, and various vaccination coverage scenarios (*21*). Ebola vaccination strategies have similarly prioritized most-at-risk populations, such as healthcare workers. However, preventive Ebola vaccination activities in Uganda, Rwanda, South Sudan, Burundi, Sierra Leone, and Liberia highlighted the challenges associated with quickly defining, identifying, and vaccinating healthcare worker populations. These challenges included unknown population estimates; high turnover of facility-based healthcare workers, which limits knowledge accumulation and makes it difficult to maintain high vaccination coverage; and the fact that EVD outbreaks often occur in rural areas where traditional healers and community health workers are more difficult to identify (*31*). These challenges necessitated strong microplanning and developing a healthcare worker registry to ensure accurate estimates of vaccine doses (*31*), both which are applicable to COVID-19 vaccination efforts. The Ebola vaccine experience also presaged the need to rapidly develop and distribute locally appropriate job aids and just-in-time training, as access and acceptance of technology continue to increase; similarly, workforce development is a strong area of focus for COVID-19 vaccine.

The experience with the Ebola vaccine has reinforced the crucial role of social and behavioral science in immunization programs, generating many lessons learned about the importance of communication and strong community engagement to build vaccine trust (*32*–*34*). Of note, Ebola vaccine prioritization efforts led to confusion and mistrust in the community because of concerns about vaccine equity, thereby undercutting vaccine confidence (*35*,*36*). In addition, rumors about Ebola vaccine eligibility and safety circulated on both traditional and social media, which likely reduced vaccine uptake (*34*–*36*). In DRC, rapid surveys were conducted to monitor community perceptions, vaccine acceptance, and misinformation; in addition, local partners regularly compiled community feedback from focus groups and key informant interviews to inform response interventions and improve vaccination uptake (*35*,*36*). Similar strategies for understanding community perceptions of COVID-19 vaccines (e.g., knowledge, attitudes, and

Table 2. Applicable lessons for global COVID-19 vaccine implementation learned from prior vaccine introductions

Vaccine	Lessons learned
Ebola	Experience with vaccine prioritization in the setting of vaccine supply constraints during an outbreak How to identify and vaccinate healthcare workers The importance of strong community engagement to build trust and vaccine confidence
Influenza	National capacities in microplanning, accessing target vaccination groups, workforce training, and conducting vaccination campaigns strengthened via seasonal influenza programs The Partnership for Influenza Vaccine Introduction program provided a model structure that formed the basis for the COVID-19 International Vaccine Implementation and Evaluation program
Meningococcal serogroup A	Experience with rapid mass vaccination campaigns for adults in low-resource settings The importance of clear communication to the public Methods for ensuring vaccination program sustainability

practices surveys; health communication; and social listening activities) have been a key part of CIVIE's support to partner countries and have been used to develop culturally appropriate materials that convey accurate information and improve local COVID-19 vaccine uptake.

Influenza Vaccine

Seasonal influenza vaccines have been used in immunization programs in high-income countries for decades but remain underused in LMICs. For example, in 2017, countries in the African, Eastern Mediterranean, and South-East Asian WHO regions represented 49% of the global population but received 6% of all manufactured doses of influenza vaccine (*37*). The low uptake of influenza vaccines globally results in a substantial annual preventable disease burden and missed opportunities to strengthen pandemic vaccine preparedness through the annual planning and deployment of influenza vaccines. Seasonal influenza vaccination provides countries annual opportunities to strengthen capacity in microplanning, accessing target groups likely to be included in early pandemic vaccination priorities (e.g., healthcare workers, older adults, pregnant persons), training workforces, and conducting time-limited campaigns. A review of the 2009 influenza A(H1N1) pandemic vaccine deployment found that countries with existing seasonal influenza programs at the onset of the pandemic were able to deploy pandemic vaccines more quickly than those without such programs (*38*). Similar regional reviews confirmed that successful H1N1 vaccination in 2009 required capacities that were built or strengthened through seasonal influenza vaccination (*39*).

To support expanded influenza vaccination, CDC initiated the Partnership for Influenza Vaccine Introduction (PIVI) in 2013 with the TFGH, and in coordination with WHO (*40*). PIVI has supported LMICs to plan, implement, and evaluate influenza vaccination programs by providing access to influenza vaccine doses and targeted technical assistance. PIVI partner countries have reported that invaluable capabilities were developed as part of their influenza programs (e.g., policy development, microplanning, communications, and health worker training), which in turn accelerated the deployment of COVID-19 vaccines. In addition, the PIVI model of bilateral engagements with ministries of health to provide funding and technical assistance has formed the basis for CIVIE's country engagement approach, factored into the initial country prioritization, and enabled rapid provision of assistance. Building on these direct engagements with LMICs, CIVIE is working with WHO, TFGH, and other partners to evaluate whether the presence of seasonal influenza vaccination programs or other adult vaccination programs is associated with more successful national COVID-19 vaccination programs. If the presence of influenza vaccination programs improves national pandemic responses, that evidence strengthens the argument for continued and increased investment in adult and healthcare worker vaccination programs.

Meningococcal Serogroup A Conjugate Vaccine

Meningococcal serogroup A conjugate vaccine (MACV), MenAfriVac, was developed to prevent the predominant cause of meningitis epidemics in the Africa meningitis belt. Starting in 2010, MACV was implemented via mass vaccination campaigns targeting persons 1–29 years of age (*41*). MACV was the earliest known new vaccine to be initially introduced in the WHO Africa region via mass vaccination campaigns instead of routine childhood immunization (*41*); MACV was later integrated into national childhood immunization programs to ensure continued community protection. Some key lessons learned from MACV rollout that help inform global COVID-19 vaccination efforts included how to launch rapid mass vaccination campaigns for adult populations in low-resource settings, the importance of clear communication to the public, and how to ensure vaccination program sustainability.

Conducted in 24 of 26 meningitis-belt countries to date (*42*), MACV mass campaigns were immensely successful. MACV was met with extremely high community acceptance (*43*), evidenced by 98% administrative coverage among the target populations (*41*), and resulted in a near disappearance of *Neisseria meningitidis* serogroup A meningitis from the region (*44*). Some elements that contributed to the success of these mass campaigns that are also crucial components of COVID-19 vaccine rollout were strong global coordination, country engagement, early and adequate microplanning, cascade training, community engagement, deployment of technical assistance staff, intensive supportive supervision, and adequate provision of vaccines and logistics (*41*,*43*).

Another factor contributing to the success of MACV mass campaigns was clear communication from the governments and partners about the risks of the disease versus the benefits of vaccination. Many of the communities that were offered vaccination with MACV had long collective experience with meningitis and personally knew those who had had the disease, which has a high case-fatality ratio. The collective fear of meningitis made the benefits

of vaccination clear, and persons were very willing to seek MACV for themselves and their children. Although COVID-19 has proven itself to be a deadly disease, with >6 million deaths reported worldwide by April 2022 (*4*), it does not have the same severity or case-fatality ratio as meningitis or EVD. Perceptions about the risk of COVID-19 compared with the benefits of COVID-19 vaccination differ (*45*) and can be influenced by misinformation; this variability in risk perception necessitates tailored communication strategies.

Finally, the experience with MACV offered lessons learned regarding vaccination program sustainability. Although MACV was rolled out via mass vaccination campaigns initially, WHO recommends that MACV be introduced into the childhood immunization program for children 9–18 months of age after the completion of a country's mass campaign to sustain population-level immunity, (*46*). However, this next step of childhood immunization has proceeded slowly; only 15 of the 24 meningitis belt countries that conducted mass campaigns have followed through with MACV introduction for children (*47*). This delay may in part be a result of the success of the mass campaigns, which dramatically decreased the disease burden and may thereby have reduced the perceived urgency for MACV introduction for children (*41*). Although the continued need for COVID-19 vaccination beyond this pandemic phase remains unclear, the potential need for ongoing booster doses would require countries to develop sustainable ways to integrate COVID-19 vaccination into their national immunization programs for children, adolescents, and adults.

Conclusion

Although the global COVID-19 vaccine rollout is an unprecedented response to a major global pandemic and is faced with many and ever-changing challenges, applicable lessons have been and can be learned from experience with other vaccine introductions. CIVIE's support to countries builds on lessons learned from other global vaccine initiatives to help LMICs deploy and evaluate COVID-19 vaccines, thereby reducing disease burden and transmission in their countries while also reducing the threat of COVID-19 globally. These activities can help expand sustainable programs for the delivery of immunizations throughout the life-course while strengthening partner countries' capacities to vaccinate their populations against current or future vaccine-preventable diseases.

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Prototheca

[pro”to-the’kə]

From the Greek *proto-* (first) + *thēkē* (sheath), *Prototheca* is a genus of variably shaped spherical cells of achloric algae in the family *Chlorellaceae*. Wilhelm Krüger, a German expert in plant physiology and sugar production, reported *Prototheca* microorganisms in 1894, shortly after spending 7 years in Java studying sugarcane. He isolated *Prototheca* species from the sap of 3 tree species. Krüger named these organisms as *P. moriformis* and *P. zopfii*, the second name as a tribute to Friedrich Wilhelm Zopf, a renowned botanist, mycologist, and lichenologist.

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Effects of Decreased Immunization Coverage for Hepatitis B Virus Caused by COVID-19 in World Health Organization Western Pacific and African Regions, 2020

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The World Health Organization–designated Western Pacific Region (WPR) and African Region (AFR) have the highest number of chronic hepatitis B virus (HBV) infections worldwide. The COVID-19 pandemic has disrupted childhood immunization, threatening progress toward elimination of hepatitis B by 2030. We used a published mathematical model to estimate the number of expected and excess HBV infections and related deaths after 10% and 20% decreases in hepatitis B birth dose or third-dose hepatitis B vaccination coverage of children born in 2020 compared with prepandemic 2019 levels. Decreased vaccination coverage resulted in additional chronic HBV infections that were 36,342–395,594 in the WPR and 9,793–502,047 in the AFR; excess HBV-related deaths were 7,150–80,302 in the WPR and 1,177–67,727 in the AFR. These findings support the urgent need to sustain immunization services, implement catch-up vaccinations, and mitigate disruptions in hepatitis B vaccinations in future birth cohorts.

Chronic hepatitis B virus (HBV) infection is the leading cause of liver cancer and a major public health problem in the World Health Organization (WHO)–designated Western Pacific Region (WPR) and African Region (AFR). In 2019, of the estimated 296 million persons living with chronic HBV infection worldwide, ≈116 million (39%) resided in the WPR and ≈82 million (28%) resided in the AFR (*1*). Of the estimated 1.5 million new HBV infections that occurred globally, 140,000 (9%) new infections occurred in the WPR and 990,000 (66%) new infections occurred in the AFR (*1*).

In 2016, all WHO member states endorsed the global target for elimination of viral hepatitis as a public health threat by 2030; specific aims included reducing the prevalence of hepatitis B surface antigen (HBsAg), a marker of chronic HBV infection, to ≤0.1% among children 5 years of age and achieving ≥90% coverage with a hepatitis B vaccine birth dose (HepB-BD) and 3 additional infant doses (HepB3) (*2*). Interim targets to achieve viral hepatitis elimination by 2020 included HBsAg prevalence of ≤1% among children and coverage levels of ≥50% for HepB-BD and ≥90% for HepB3 among infants (*2*).

In both the WPR and AFR, all countries provide 3 doses of HBV vaccine; however, only 35 (95%) of 37 countries in the WPR and 13 (28%) of 47 countries in the AFR provide universal HepB-BD to all newborns. In addition, 2 countries in the WPR (Japan, New Zealand) and 1 country in the AFR (Mauritius) provide HepB-BD selectively to babies born to mothers who are HBsAg-positive. The WPR has made substantial progress in controlling HBV infection through successful HBV immunization programs for children. As of 2020, a total of 21 (57%) of 37 countries and areas in the WPR achieved HBsAg prevalence in ≤1% of children according to serosurvey evidence (*3*). The WPR

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target of ≥95% vaccination coverage was achieved by 19 (51%) WPR countries or areas for HepB-BD and 20 (54%) countries for HepB3, and the global target of ≥90% coverage was achieved by 23 (62%) countries for HepB-BD and 34 (92%) countries for HepB3 (*4*–*6*). However, progress toward hepatitis B control has been much slower in the AFR, where only 14 (30%) of the 47 countries have HepB-BD in their immunization schedule. Of those 14, only 5 (11%) countries reached the regional and global 2020 target of ≥50% HepB-BD coverage (*5*), and 19 (40%) of 47 countries achieved ≥90% HepB3 coverage (*6*). Nationally representative serosurvey data are lacking among children in most countries in Africa. However, modeled estimates reported that 25 (53%) countries achieved the regional target of ≤2% HBsAg prevalence and 13 (28%) countries achieved the global target of ≤1% HBsAg prevalence among children by 2020 (*7*).

The COVID-19 pandemic has strained public health capacity and disrupted the delivery and uptake of childhood vaccines, thereby threatening the control and elimination of major vaccine-preventable diseases. Of 61 countries worldwide that responded to a June 2020 immunization pulse poll, 45 (74%) countries reported a drop in vaccination demand, and the AFR reported the highest proportion of countries (89%) with decreased demand; in addition, 52 (85%) of responding countries reported a drop in coverage in May 2020 compared with January–February 2020 (*8*). Furthermore, vaccine shipments and supplies were affected early during the COVID-19 pandemic because of disruption in air transportation and closure of airports (*9*). As a result of COVID-19–related disruption of immunization services, ≈80 million children <1 year of age worldwide were at risk for vaccine-preventable diseases (*10*). In the WPR, preliminary data reported for the first quarter of 2020 showed a 10%–50% decrease in the number of children who completed 3 doses of HBV vaccine, and the average reduction in coverage was ≈20% (*11*). In the AFR, preliminary coverage data showed a drop in HepB3 coverage in 37 (79%) countries, and 10 countries reported a decrease in coverage >10% during the first half of 2020 compared with the same period in 2019 (*12*).

The COVID-19 pandemic and its negative effect on immunization and other essential health services poses a threat to progress toward decreasing the burden of hepatitis B among children and achieving HBV elimination by 2030. We estimated the additional numbers of chronic HBV infections and HBV-related deaths in the WPR and AFR, the regions most affected by HBV, that resulted from decreased HBV vaccination coverage during 2020 because of the COVID-19 pandemic.

Materials and Methods

Data Sources

We used a published mathematical model (*13*) to estimate the effects of decreased hepatitis B vaccination on HBV-related illness and death among children born in 2020. The model is a static model that estimates the number of HBV infections and deaths from mother-to-child transmission during the perinatal period (<1 year of age) and horizontal transmission during early (1–5 years of age) and late (>5 years of age) childhood. The model included the number of surviving infants, vaccination coverage with HepB-BD and complete HepB3 series, prevalence of HBsAg and HBV e antigen among women of reproductive age, and hepatitis B core antigen antibody prevalence among children 5 years of age and adults 30 years of age. The frequency of HBV seromarkers was compiled from published systematic reviews, population-based HIV impact assessments that included hepatitis B seroprevalence in AFR countries, and HBV profiles for WPR countries, which included nationwide and large-scale subnational serosurveys for the region. When data were not available from these sources, published estimates were used (Appendix Table 1, https://wwwnc.cdc.gov/EID/article/28/13/21-2300-App1.pdf). The efficacy of complete hepatitis B vaccination (HepB-BD and HepB3) was estimated to be 95% (*14*). For countries that did not provide HepB-BD but provided HepB3 vaccines as part of combination vaccines during childhood, we considered infants who received HepB3 vaccines to be unprotected against vertical transmission. However, because of the receipt of the 3 primary vaccines, we considered these infants to be protected against horizontal transmission with 95% vaccine efficacy (*14*).

We obtained population and death rate data from World Population Prospects, 2019 revision, published by the United Nations Population Division (*15*). We compiled HBV vaccination coverage data from the 2019 WHO/UNICEF estimates of national immunization coverage (WUENIC) (*16*). WUENIC estimates were based on official or administrative survey coverage data and included contextual information, such as status of vaccine stock and changes in vaccination schedule. When WUENIC estimates were unavailable, we used official or administrative vaccination coverage reported in the WHO-UNICEF Joint Reporting Form. Administrative vaccination coverage data are derived from the country's

immunization registry system and may be inaccurate because of underestimates or overestimates; thus, national authorities can provide their official vaccination coverage estimates, which are based on administrative data, surveys, and reports. If WUENIC estimates were unavailable for HepB3, we used official estimates, and, if those were unavailable, we used administrative coverage estimates. If WUENIC estimates were unavailable for HepB-BD, we used data sources in this order of preference: official coverage estimates of birth doses administered within 24 h after birth; administrative coverage of birth doses given within 24 h after birth; official coverage of total birth doses, which included birth doses provided <24 h or >24 h after birth; and administrative coverage of total birth doses. When the reported coverage was >100%, the coverage was capped at 100%. For countries that had not introduced HepB-BD or countries that provided selective HepB-BD vaccines, coverage was not reported to WHO and we could not compute the effects of changes in HepB-BD coverage in those countries.

Data Analysis

We estimated the total number of expected chronic HBV infections and deaths during the lifetime of children born in 2020 by first assuming HepB-BD and HepB3 coverage levels were identical to those in 2019, before the COVID-19 pandemic. We included deaths from HBV-related liver cirrhosis, hepatocellular carcinoma, and fulminant hepatitis in the analysis. A 20% reduction in vaccination coverage was reported in WPR countries in the first quarter of 2020 compared with 2019 (*11*), and a >10% decline in vaccination coverage was observed in the AFR during the first 6 months of 2020 compared with 2019 (*12*). Therefore, we estimated the number of chronic HBV infections and deaths in children born in 2020 when HepB-BD or HepB3 was decreased by 10% and 20% in 2020 compared with 2019.

For the AFR, we analyzed the number of chronic HBV infections and related deaths according to HepB-BD introduction status in countries from 3 operational geographic areas: Central Africa (10 countries), East/southern Africa (20 countries), and West Africa (17 countries). We calculated numbers of excess chronic HBV infections and related deaths on the basis of the estimated 10% or 20% decline in HepB-BD and HepB3 coverage in 2020 compared with 2019.

Results

We used the model to estimate the number of chronic HBV infections and HBV-related deaths during the lifetime of children born in 2020 who received different HBV vaccination coverage (Table). If 2019 hepatitis B vaccination coverages were maintained in 2020, the model estimated 332,179 chronic HBV infections in the WPR and 1,564,688 chronic HBV infections in the AFR during the lifetime of children born in 2020. If either HepB-BD or HepB3 coverage dropped by 10% or 20% in 2020 compared with 2019, the total estimated numbers of chronic HBV infection in these

Table. Estimated numbers of chronic hepatitis B virus infections and related deaths after decreased hepatitis B vaccine birth dose and third dose vaccination coverage caused by COVID-19 in World Health Organization Western Pacific and African Regions, 2020*

Variables	Baseline, 2019	Hepatitis B birth dose		Hepatitis B third-dose†	
		Decrease, 10%	Decrease, 20%	Decrease, 10%	Decrease, 20%
Western Pacific Region					
Hepatitis B birth dose coverage	84%	76%	67%	NA	NA
Hepatitis B third-dose coverage	94%	NA	NA	85%	75%
Chronic infections	332,179	368,521	404,863	529,976	727,773
HBV-related deaths					
Hepatocellular carcinoma	29,779	33,392	37,004	49,394	69,009
Liver cirrhosis	31,002	34,538	38,075	50,589	70,175
Fulminant hepatitis	1,442	1,442	1,442	2,390	3,339
Total	62,222	69,372	76,521	102,373	142,524
African Region					
Hepatitis B birth dose coverage	17%	15%	14%	NA	NA
Hepatitis B third-dose coverage	73%	NA	NA	66%	58%
Chronic infections	1,564,688	1,574,481	1,584,273	1,815,712	2,066,735
HBV-related deaths					
Hepatocellular carcinoma	81,267	81,805	82,342	94,405	107,543
Liver cirrhosis	112,011	112,651	113,290	130,895	149,779
Fulminant hepatitis	7,891	7,891	7,891	9,733	11,575
Total	201,170	202,347	203,524	235,033	268,897

*We assumed that in the absence of the COVID-19 pandemic, 2019 hepatitis B vaccination coverage levels would have been maintained in 2020; hepatitis B vaccination coverages for 2020 were estimated from 2019 baseline coverage levels, and baseline coverage levels were from World Health Organization/UNICEF estimates of national immunization coverage or derived from official or administrative estimates from specific countries. HBV, hepatitis B virus; NA, not applicable.

†Hepatitis B third-dose coverage was a combination of a hepatitis B birth dose and 2 additional doses of hepatitis B vaccine in 14 countries in the Western Pacific Region. Other countries provided up to 3 additional hepatitis B doses in a pentavalent vaccine.

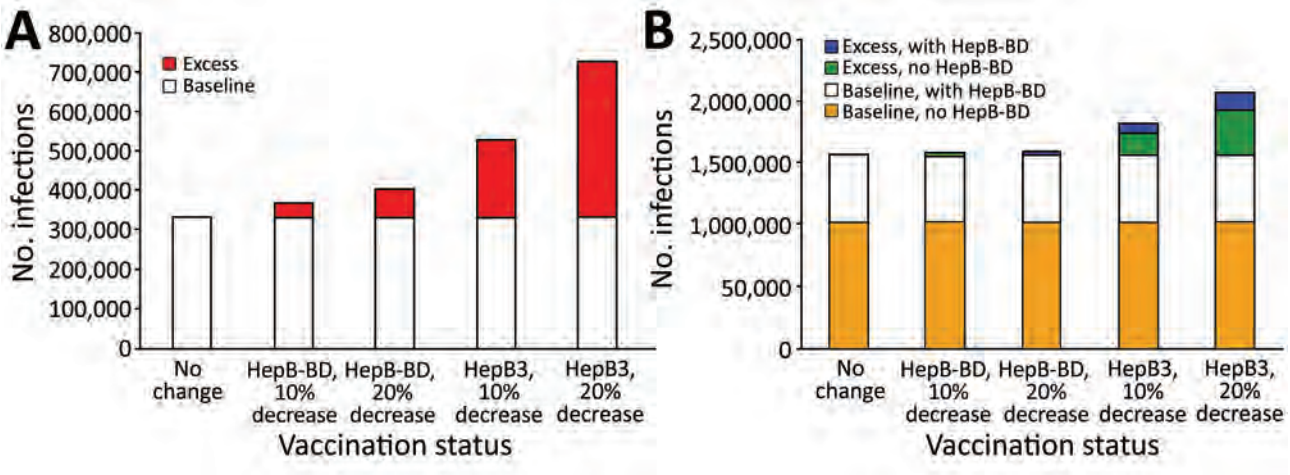

Figure 1. Numbers of additional chronic hepatitis B cases after decreased coverage for hepatitis B vaccine caused by COVID-19 in World Health Organization (WHO) Western Pacific Region (WPR) and African Region (AFR), 2020. We used a mathematical model to estimate the effect of decreased hepatitis B vaccination coverage on hepatitis B virus (HBV) infections among children born in 2020 compared with 2019. A) Total number of chronic HBV infections determined from 2019 data (baseline) and estimates of excess chronic HBV infections from the model after 10% or 20% decrease in HepB-BD or HepB3 vaccination coverage in the World Health Organization WHO Western Pacific Region. All countries and areas in the WPR have introduced HepB-BD, including 2 countries that provide HepB-BD only to infants born to hepatitis B surface antigen–positive mothers. B) Total number of chronic HBV infections (baseline) and estimates of excess chronic HBV infections after 10% or 20% decrease in HepB-BD or HepB3 vaccination coverage in the WHO AFR. Comparisons were made between countries with and without HepB-BD. Fourteen countries in the AFR have introduced HepB-BD, including 1 country that provides HepB BD-only to infants born to hepatitis B surface antigen–positive mothers. HepB-BD coverage data were only available for countries that provided universal birth doses. HepB-BD, birth dose; HepB3, third-dose hepatitis B.

children would be 368,521–727,773 in the WPR and 1,574,481–2,066,735 in the AFR (Table). The number of additional chronic HBV infections ranged from 36,342 (11%) to 395,594 (119%) in the WPR (Figure 1, panel A) and 9,793 (1%) to 502,047(32%) in the AFR (Figure 1, panel B). In AFR countries that introduced HepB-BD, a 10% decrease in HepB3 coverage from baseline resulted in 70,225 (13%) additional chronic HBV infections, whereas a 10% decrease in HepB-BD coverage resulted in an estimated 9,792 (2%) excess chronic HBV infections (Figure 1, panel B). In AFR countries that did not provide HepB-BD, a 10% decrease in HepB3 coverage caused 180,798 (18%) excess chronic HBV infections.

If 2019 levels of HBV vaccination coverage were maintained in 2020, the model estimated that HBV infections produced 62,222 HBV-related deaths in the WPR and ≈201,170 HBV-related deaths in the AFR (Table). If either HepB-BD or HepB3 decreased by 10% or 20% in 2020, the total number of HBV-related deaths would be 69,372–142,524 in the WPR and 202,347–268,897 in the AFR (Table) during the lifetime of children born in 2020. The increases in HBV-related deaths were from 7,150 (11%) to 80,302 (129%) in the WPR (Figure 2, panel A) and 1,177 (1%) to 67,727 (34%) in the AFR (Figure, panel B) compared with baseline values. In AFR countries that provided HepB-BD, a 10% decrease in HepB3 coverage resulted in 9,499 (14%) additional deaths, whereas a 10% decrease in HepB-BD coverage caused 1,177 (2%) excess deaths (Figure 2, panel B). In AFR countries that did not provide HepB-BD, a 10% decrease in HepB3 coverage produced 24,365 (18%) excess HBV-related deaths.

We estimated total lifetime numbers of chronic HBV infections and deaths among children born in 2020 by country for each region (Appendix Tables 2, 3). If 2019 hepatitis B vaccination coverage levels were maintained in the WPR in 2020, the highest estimated numbers of chronic HBV infections would have occurred in China (123,186), the Philippines (122,717), Vietnam (40,359), and Papua New Guinea (20, 888) and accounted for 307,150 (92%) of all 332,179 expected chronic infections in this region (Appendix Table 2). A 10% decrease in HepB3 coverage produced a 155% increase in chronic HBV infections in Brunei Darussalam, 131% increase in Fiji, and 131% increase in China. A 20% decrease in HepB3 coverage produced a 310% increase in chronic HBV infections in Brunei Darussalam, 265% increase in Fiji, and 256% increase in China. A 10% decrease in HepB-BD coverage resulted in an 80% increase in chronic HBV infections in Tonga, 32% increase in Mongolia, and 27% increase in Fiji; a 20% decrease in HepB-BD coverage

caused a159% increase in infections in Tonga, 64% increase in Mongolia, and 54% increase in Fiji (Appendix Table 2).

If 2019 HBV vaccination coverage levels were maintained in the AFR in 2020, countries in West Africa accounted for the highest number of chronic HBV infections (675,017), followed by East/southern Africa (463,185) and Central Africa (426,486) (Appendix Table 3). A 10% decrease in HepB3 coverage produced a 25% increase in chronic infections in countries in East/southern Africa, 14% increase in West Africa, and 9% increase in Central Africa. We estimated that the highest number of expected chronic HBV infections were in Nigeria (384,442), the Democratic Republic of the Congo (227,219), and Ethiopia (150,025) (Appendix Table 3). A 10% decrease in HepB3 coverage produced a 100% increase in chronic HBV infections in Rwanda, 93% increase in Cabo Verde, 75% increase in Sao Tome and Principe, and 63% increase in Algeria. A 20% decrease in HepB3 coverage caused a 199% increase in chronic HBV infections in Rwanda, 186% increase in Cabo Verde, 149% increase in Sao Tome and Principe, and 125% increase in Algeria. Among AFR countries that provided HepB-BD vaccination, a 10% decrease in HepB-BD coverage resulted in a 21% increase in excess chronic HBV infections in Cabo Verde, an 18% increase in Sao Tome and Principe, 11% increase in Senegal, and 10% increase in Botswana. A 20% decrease in HepB-BD coverage produced a 43% increase in excess chronic HBV infections in Cabo Verde, 36% increase in Sao Tome and Principe, 21% increase in Senegal, and 36% increase in Botswana (Appendix Table 3). Estimated increases in HBV-related deaths after decreased HepB3 or HepB-BD coverage showed patterns similar to those of chronic HBV infections in countries from the WPR and AFR (Appendix Tables 2, 3).

Discussion

The COVID-19 pandemic has led to substantial disruptions in routine immunization services and subsequent reductions in vaccination coverage in the WPR and AFR. Using a mathematical model (*13*), we estimated that a 20% decrease in HepB3 vaccination coverage because of COVID-19 would produce >500,000 excess chronic HBV infections and >67,000 additional HBV-related deaths in the AFR and >395,000 excess chronic infections and >80,000 additional HBV-related deaths in the WPR during the lifetimes of children born in 2020. A 10% decrease in HepB3 vaccinations also would produce substantial increases in chronic HBV infections and HBV-related deaths in both

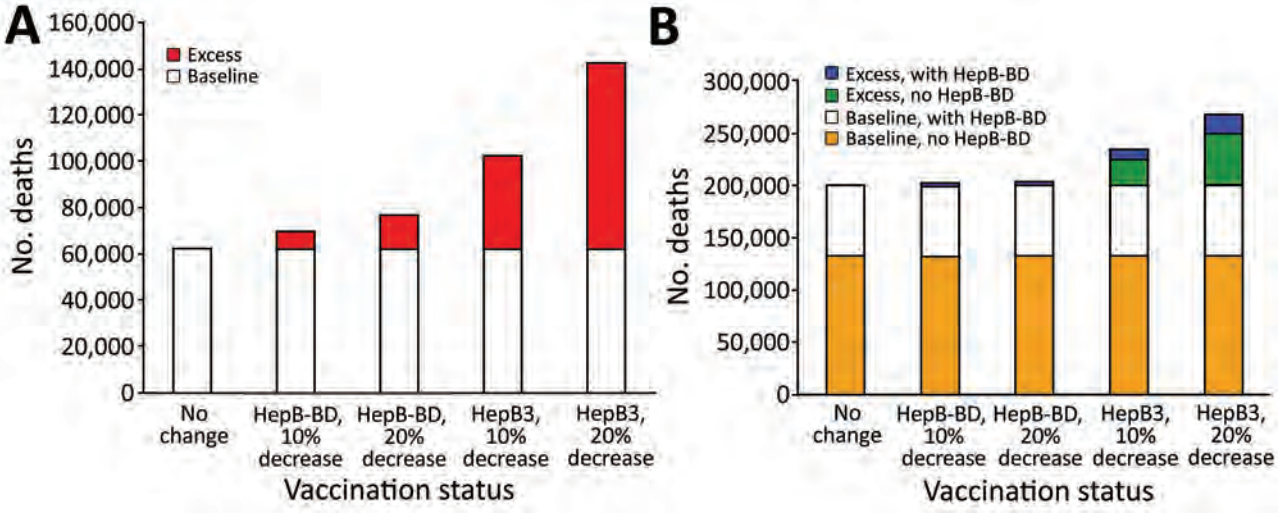

Figure 2. Numbers of additional hepatitis B virus (HBV)–related deaths after decreased coverage for hepatitis B vaccine caused by COVID-19 in World Health Organization (WHO) Western Pacific Region (WPR) and African Region (AFR), 2020. We used a mathematical model to estimate the effect of decreased hepatitis B vaccination coverage on HBV-related deaths among children born in 2020 compared with 2019. A) Total number of HBV-related deaths determined from 2019 data (baseline) and estimates of excess deaths after 10% or 20% decrease in birth dose (HepB-BD) or third-dose hepatitis B (HepB3) vaccination coverage in the WHO WPR. All countries and areas in the WPR have introduced HepB-BD, including 2 countries that provide HepB-BD only to infants born to hepatitis B surface antigen–positive mothers. B) Total number of HBV-related deaths (baseline) and estimates of excess deaths after 10% or 20% decrease in HepB-BD or HepB3 vaccination coverage in the WHO AFR. Comparisons were made between countries with and without HepB-BD. Fourteen countries in the AFR have introduced HepB-BD, including 1 country that provides HepB BD-only to infants born to hepatitis B surface antigen–positive mothers. HepB-BD coverage data were only available for countries providing universal birth doses. HepB-BD, birth dose; HepB3, third-dose hepatitis B.

the AFR and WPR. A 10% decrease in HepB-BD vaccination coverage in the WPR would produce an estimated 11% increase in chronic HBV infections or HBV-related deaths compared with a 1% increase in chronic infections or HBV-related deaths in the AFR. This difference is likely because the AFR had a low baseline HepB-BD coverage of only 15% compared with 84% HepB-BD coverage in the WPR in 2019 (*17*). However, the increase in chronic HBV infections after a 10% decrease in HepB3 coverage was 1.4 times lower in AFR countries that introduced HepB-BD vaccinations compared with countries without HepB-BD, which indicates the value of HepB-BD vaccination in lowering HBV infection rates. As recently reported, wider introduction of HepB-BD in the AFR will enhance progress toward HBV elimination and prevent further infections and deaths (*18*).

The effects of COVID-19–related disruptions to immunization services may not be limited to children born in 2020. After the initial COVID-19 wave during January–February 2020, both the WPR and AFR experienced subsequent waves during July–December 2020 (*19*). Because of emerging new SARS-CoV-2 variants, spikes in COVID-19 cases are expected to continue (*9*). A pulse survey on continuity of essential health services was conducted in 2021 and, among countries responding to the survey, 24% of countries in the WPR and 48% in the AFR reported ongoing disruptions in immunization services (*20*).

Childhood immunization is recognized as a core health service that should continue during the COVID-19 pandemic in conjunction with COVID-19 prevention and control measures for caregivers and health workers (*21*). Administering the HepB-BD vaccine within 24 hours of birth prevents 70%–95% of perinatal transmission from HBV-infected mothers (*22*). In the WPR, >90% of births are hospital-based, and neonates are more likely to receive HepB-BD vaccination when born in hospitals (*23*). However, the pulse survey indicated that 20% of WPR countries had disruptions in facility-based births, and 43% of countries reported disruptions in antenatal but not postnatal care (*20*). Therefore, hospitals in the WPR should include HepB-BD vaccinations in their COVID-19 prevention and control planning and protocols to ensure newborns continue to receive HepB-BD within 24 hours after birth during the COVID-19 pandemic. Disruptions in facility-based births were reported in 31% of AFR countries; 43% reported disruptions in antenatal care, and 32% reported disruptions in postnatal care (*20*). In AFR countries that provide HepB-BD, vaccination services should be maintained and disruptions in reproductive and maternal care should be addressed. In addition, more AFR countries need to consider introducing HepB-BD in routine newborn immunizations to minimize the number of new chronic HBV infections and related deaths (*18*).

When routine immunization services are adversely affected and doses are missed, a catch-up vaccination strategy is essential to complete at least 3 doses of the HBV vaccine. If HepB-BD is missed within the first 24 hours after birth, infants should be given the first dose of HBV vaccine promptly upon first contact with the health system, although effectiveness in preventing mother-to-child transmission might be reduced (*24*). WHO has developed guidance for national immunization programs to assist in establishing or refining catch-up vaccination strategies and designing catch-up vaccination schedules (*25*). HBV catch-up vaccinations can be provided through fixed, outreach, mobile, or routine school-based immunization services (*25*). Periodic campaign-style intensification of routine immunization should be considered for catchup vaccinations or sustainment of routine immunization (*21*,*26*). Communication and community engagement strategies that regularly educate communities on the availability of immunization services, need to vaccinate even if late, and COVID-19 safety measures at vaccination sites are critical for reestablishing vaccine demand and uptake (*21*,*25*). Where immunization services have been restored, countries will need to plan for potential future COVID-19 spikes and recurrent disruptions of timely vaccination schedules (*21*).

The first limitation of our study is that estimates of decreased vaccination coverage in each region were based on preliminary data at an early stage of the COVID-19 pandemic. As countries adapt immunization practices and complete data become available, our estimations may not reflect actual effects of COVID-19 on HBV vaccination coverage. However, our findings show that immunization is critical for continued progress toward the elimination of HBV. Second, coverage data from 2019 was used to estimate the excess death and chronic HBV infection in 2020. In some countries, coverage might have fluctuated before 2019, and an average coverage for the past several years could be used as an alternative baseline estimate. Third, we considered the decrease in birth dose and third dose coverage to be independent. In some countries, particularly in the WPR, HepB-BD was considered the first dose of the HBV vaccine series, and a decrease in HepB-BD would also affect third dose coverage. In other countries,

particularly in the AFR, a pentavalent vaccine for the 3 additional doses was available and HepB-BD was not counted in the coverage of the third dose. Therefore, an analysis of different vaccine combinations may yield different results. Last, HBV seroprevalence data were not available from all countries, and we used data from countries with similar epidemiology when available.

The predicted consequences of COVID-19–related reduction in HBV vaccination indicate an urgent need to maintain immunization services, implement catch-up vaccinations, and mitigate disruptions in vaccination services for future births, especially in countries with a high prevalence of hepatitis B. The effects of COVID-19-related disruptions to immunization services are likely not limited to children born during 2020. It will be crucial for hospitals to include HepB-BD in their prevention and control protocols during the COVID-19 pandemic to ensure infants receive HepB-BD within 24 hours of birth. A catch-up vaccination strategy for completion of at least 3 HBV vaccine doses will be essential for children who missed their vaccinations. Countries must reduce the continued strain of COVID-19 on routine immunization services and effects on coverage that might threaten progress toward achieving hepatitis B elimination by 2030.

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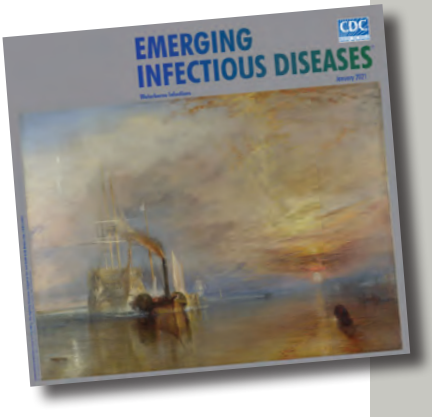
etymologia revisited

Petri Dish

[pe'tre 'dish]



The Petri dish is named after the German inventor and bacteriologist Julius Richard Petri (1852–1921). In 1887, as an assistant to fellow German physician and pioneering microbiologist Robert Koch (1843–1910), Petri published a paper titled "A minor modification of the plating technique of Koch." This seemingly modest improvement (a slightly larger glass lid), Petri explained, reduced contamination from airborne germs in comparison with Koch's bell jar.

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Past as Prologue—Use of Rubella Vaccination Program Lessons to Inform COVID-19 Vaccination

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The rapid rollout of vaccines against COVID-19 as a key mitigation strategy to end the global pandemic might be informed by lessons learned from rubella vaccine implementation in response to the global rubella epidemic of 1963–1965. That rubella epidemic led to the development of a rubella vaccine that has been introduced in all but 21 countries worldwide and has led to elimination of rubella in 93 countries. Although widespread introduction and use of rubella vaccines was slower than that for COVID-19 vaccines, the process can provide valuable insights for the continued battle against COVID-19. Experiences from the rubella disease control program highlight the critical and evolving elements of a vaccination program, including clearly delineated goals and strategies, regular data-driven revisions to the program based on disease and vaccine safety surveillance, and evaluations to identify the vaccine most capable of achieving disease control targets.

As COVID-19 spreads throughout the world, we recall a similar experience of a swiftly spreading respiratory disease over half a century earlier. In 1963, a rubella virus epidemic spread from Europe to the United States, causing great alarm among public health officials. The New York Times reported on February 8, 1964: "GERMAN MEASLES AT EPIDEMIC RATE; City and State Affected—2,302 Cases Reported Here Since Dec. 1; Virus Is Termed Mild; But Women Are Warned of Danger During First 3 Months of Pregnancy" (*1*).

Although rubella is generally a mild disease, rubella infection during early pregnancy can be devastating. Fetal infection can result in miscarriage, stillbirth, or infants born with life-threatening or disabling congenital malformations, known as congenital rubella syndrome (CRS). A pregnant woman infected with rubella in early pregnancy has up to a 90% chance of giving birth to an infant with CRS and that infant having ≥1 malformations, such as congenital heart defect, cataracts, and hearing impairment. CRS is the most substantial public health threat of rubella infection and is associated with an infant mortality rate of 20%–40% and lifelong sequelae for many of those infants that survive (*2*).

The outbreak of rubella in 1963 necessitated expeditious development of a vaccine to protect pregnant women and their infants and to stem societal disruption from the subsequent epidemic. Later, licensure and widespread availability of vaccines prevented future epidemics of rubella in the United States and other countries. As of October 2021, a total of 173 (89%) of 194 countries have introduced rubella vaccine, and 93 (48%) have been declared free of endemic rubella transmission (*3*).

Rubella and SARS-CoV-2 viruses have several similarities (Table 1). Both viruses are enveloped, positive-stranded RNA viruses (*2*,*4*) that are transmissible through respiratory droplets. Both viruses can result in asymptomatic infections, fostering silent disease transmission (*2*,*5*). On average, in countries with no available rubella vaccine, 1 rubella-infected person can infect 6–12 other susceptible persons (*6*), an infection rate similar to that of the SARS-CoV-2 Delta and Omicron variants (*7*,*8*). Both viruses are associated with serious disease complications. For rubella, the most serious complication is CRS (*2*); COVID-19 complications include respiratory failure, multisystem inflammatory syndromes, post–COVID conditions, and preterm delivery or stillbirth (*9*,*10*). Both viral infections can result in death. Like deaths attributed to rubella infection before vaccine introduction, most COVID-19–related deaths occur in specific high-risk populations. SARS-CoV-2 infections cause higher mortality among the elderly and those with specific underlying conditions than among younger, generally healthy adults. Because

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Table 1. Comparison of rubella and SARS-CoV-2 viruses*

Comparator	Rubella	SARS-CoV-2
Type of virus	Enveloped, positive-stranded RNA virus	Enveloped, positive-stranded RNA virus
Virus classification	Rubivirus in Matonaviridae family	Coronavirus in Coronaviridae family
Reservoir	Humans only	Mainly birds and mammals
Subtypes	1 serotype	Numerous variants with continual evolution
Transmission	Mainly respiratory droplet	Mainly respiratory droplet
Incubation period range, d	12–23	1–14
Reproductive number	6–12	6–10
Nature of clinical manifestations	Asymptomatic through mild prodromal symptoms to miscarriage and stillbirth	Asymptomatic to severe illness
Infections that are asymptomatic, %	20–50	31–40
Serious complications	Congenital rubella syndrome	Respiratory failure, multisystem inflammatory syndromes, post–COVID-19 conditions, stillbirths and preterm births
Major risk factors for serious complications	Infection early in pregnancy increases likelihood of CRS	Age, certain underlying medical conditions
Vaccine efficacy against infection, %	97	90
Waning immunity after vaccination	Seropositivity rates ranged 92%–100% 1–21 y after 1 dose	Possible; vaccine efficacy/effectiveness rates decreased on average 21 percentage points 1–6 mo after final vaccine dose of primary series, although mechanism not fully elucidated and multiple limitations exist

*CRS, congenital rubella syndrome.

of the commonalities of SARS-CoV-2 and rubella, the rubella disease control program might serve as a useful comparator in formulating COVID-19 vaccination strategy and implementation.

We believe that the US rubella disease control program, which incorporated strategic planning, goal communication, program initiation, and program revisions driven by data, provides key insights for developing vaccines to combat the COVID-19 pandemic. Here, we highlight key components of the rubella disease control and elimination program, including vaccination strategies and vaccine selection methods, and describe how these experiences might inform current COVID-19 vaccination programs.

Vaccination Strategy

The primary goal of a vaccination program is to reduce disease burden by achieving high population immunity levels through strategies aimed at both optimal immunization coverage and high vaccine effectiveness. The success of vaccination strategies depends greatly on practical aspects of implementation. An individual protection, or selective, approach targets specific groups that are defined by such factors as risk or age. The aim of this approach is to protect vulnerable groups against disease and severe outcomes (hospitalization, complications, death). Although the individual protection approach can prevent severe outcomes, some high-risk persons can be missed. In instances when the entire population is at risk of infection, there is ongoing transmission risk to vulnerable persons. Thus, a universal approach might be a better strategy in such circumstances since this approach indirectly impacts vulnerable subgroups by increasing population-level immunity and potentially interrupting or even eliminating virus transmission. A universal approach requires vaccines with high efficacy against infection across a wide range of vaccine recipients and viral subtypes.

The primary goal of national rubella vaccination programs is to prevent rubella infection in pregnant women and thereby prevent the severe outcome of CRS. When rubella emerged as a nationwide threat, 2 vaccination strategies were implemented to achieve this goal: an individual protection approach that prioritized vaccinating high-risk populations (adolescent females and women of childbearing age) to prevent CRS; and a universal approach that aimed to decrease and interrupt transmission at the population level by vaccinating the age group with the highest proportion of susceptible persons: primarily, young children and those potentially at highest risk (e.g., reproductive-age women).

In 1970, the United Kingdom adopted the individual protection approach, primarily vaccinating nonpregnant women of childbearing age. This decision was informed by concerns at that time regarding unknown duration of vaccine-induced immunity in children, as well as the fact that measles vaccination coverage in the United Kingdom was low and rubella vaccine would have been given at the same time as the measles vaccine (*11*). Surveillance data showed that this approach decreased the incidence of CRS cases and termination of pregnancies

associated with rubella (*12*). However, because the approach only focused on individual protection, viral transmission continued in the population at large. Unvaccinated women in the United Kingdom continued to be infected, and children continued to be born with CRS, albeit at a lower rate (*11*). Studies demonstrated that unprotected persons still posed a risk. For example, in 1 study, pregnant women with previous pregnancies had a higher risk of rubella infection than did women in their first pregnancies, suggesting that women with previous pregnancies may have been at risk of acquired rubella infection from their own children with rubella (*13*). Whereas control of rubella through individual protection was proving to be inadequate, immunization program advancements had occurred, and measles vaccination coverage had increased, which prompted UK policymakers to pivot to the universal approach: vaccinating all young children to protect the larger population.

In contrast to the initial UK approach, the United States launched its rubella vaccination program in 1969, using the universal approach. Children ≥1 year of age up to puberty were vaccinated against rubella with the aim of eliminating rubella virus transmission and infection. From 1969 through 1977, an estimated 80 million doses of rubella virus vaccine were distributed in the United States (*14*). As in the United Kingdom, the rubella vaccination program was systematically monitored through disease surveillance, seroprevalence studies, and vaccination coverage assessments (*15*). Those data illustrated that susceptibility remained high among women of childbearing age and that they were still being exposed. To decrease the rubella immunity gaps resulting from the universal approach, which was focused on pediatric vaccination, the United States expanded its rubella vaccination strategy in 1978 to include vaccination of older groups. After this policy shift and through the late 1980s, cases of rubella infection and CRS in the United States declined further (*16*). We provide a comparison of the individual protection and universal strategies (Table 2).

By determining disease burden and monitoring vaccination impact, disease control experts used rubella and CRS surveillance data to iteratively inform rubella disease control strategy and used vaccination coverage data to determine the progress of vaccination programs. Additional activities (e.g., monitoring vaccine safety through pregnancy registries, adverse events surveillance) provided data to ensure vaccine safety and gain public confidence. Those data sources were critical in determining the progress of specific programs. In the United States, surveillance data documented an end to rubella outbreaks by autochthonous transmission, and elimination was verified in 2004. In the United Kingdom, rubella surveillance and vaccination program data prompted a change in program strategy to a universal protection approach, which led to elimination, verified in 2016. The United States and the United Kingdom still continue to experience imported rubella cases from countries with high levels of ongoing transmission, usually from countries with low immunization coverage or those that have not introduced rubella vaccine (*16*). As such, both countries would still benefit from global elimination.

Globally, the World Health Organization (WHO) initially recommended an individual protection approach to rubella disease control, which evolved to a universal strategy. The first WHO recommendation in 2000 focused on ensuring that women of childbearing age were protected, without preference for a specific strategy (*17*). By 2011, WHO recommended both the individual protection and the universal strategies for countries, with a preference for the universal approach (*18*). In 2020, the WHO position shifted to recommending only the universal approach (*2*).

Although global strategies have shifted over time in response to new data, inequities in global rubella program implementation have been evident in both introduction and elimination activities. Introduction was initially only in high-income countries, but by 2020, rubella vaccine had been introduced in 48% of low-income countries. Of 21 countries that had not introduced rubella vaccine by the end of 2020, a total

Table 2. Comparison of the 2 strategies used for rubella control and elimination activities*

Comparator	Individual protection strategy	Universal strategy
Strategic target	High-risk individuals	Susceptible population
Populations	Women of child-bearing age	Infants and campaigns targeting susceptible individuals
Initial goals	Reduce cases of CRS	Elimination of rubella and CRS
Strategy used when	Low infant vaccination coverage; concerns for safety	High infant vaccination coverage (>80%)
Monitoring systems	Surveillance for CRS; rubella vaccination coverage; special surveys/studies	Surveillance for rubella and CRS; rubella vaccination coverage; special surveys and studies
Examples	Initial United Kingdom strategy; initial global (WHO) strategy	Initial United States strategy; current global (WHO) strategy

*CRS, congenital rubella syndrome; WHO, World Health Organization.

of 14 were low-income countries (*19*). Of the 93 countries that have eliminated rubella disease, only 3 were identified as low-income countries.

Vaccine Selection

The 1964–1965 rubella epidemic resulted in an estimated 12.5 million rubella cases in the United States, infecting 6% of the US population. Complications included >2,000 cases of encephalitis, 11,350 cases of miscarriage, and 20,000 cases of CRS. Of the CRS cases, >8,000 children were diagnosed with deafness, 3,580 were diagnosed as blind, and 1,800 children had developmental delays. The total estimated economic impact was $1.5 billion (*20*).

The epidemic catalyzed rubella vaccine development, which incorporated new laboratory techniques that, in turn, allowed the quick isolation of the rubella virus. During 1969 and 1970, a total of 4 rubella vaccines were licensed, 3 in the United States (HPV77-DE, HPV-77-DK, Cendehill) and 1 in Europe (RA27/3) (*21*). Each vaccine was administered as a single dose that provoked a durable, protective immune response when given to a person ≥9 months of age.

The 4 rubella vaccines were studied continuously for both effectiveness and safety. Immunogenicity of each rubella vaccine was studied from multiple perspectives. HPV77-DE was implemented widely in the United States and found to be immunogenic in 95% of vaccinees and protected 65%–94% of recipients during outbreaks. In contrast, RA27/3 achieved seroconversion in 95%–100% of vaccine recipients (*22*,*23*); in numerous outbreaks, protection from RA27/3 was ≥95% (*6*). Antibody levels in 8 comparative studies demonstrated that RA27/3 generated 2- to 4-fold higher antibody levels than either the Cendehill or HPV-77 vaccine (*22*). Furthermore, compared with the Cendehill vaccine, the RA27/3 vaccine produced higher antibody levels 6–8 weeks after vaccination (*22*). Later studies demonstrated that such antibody response to RA27/3 persisted many years after receipt of the vaccine (*22*). Challenge studies have shown that when vaccinated persons were exposed to wild rubella virus, only 3%–10% of the RA27/3 vaccine recipients experienced reinfection (i.e., had breakthrough infections) compared with 40%–100% of the HPV-77 or Cendehill vaccine recipients (*22*).

Research also evaluated and compared the safety of these vaccines. The RA27/3 vaccine provoked lower rates of adverse reactions among adults than did HPV-77-DK or HPV-77-DE, both of which were associated with significant acute joint reactions (*22*). The safety of vaccination during pregnancy, especially in regard to vaccine-associated CRS, was a chief concern for disease control experts and limited vaccination strategies initially employed in the United States (*24*). However, evidence slowly accumulated, including from mass vaccination campaigns in the Americas, that provided strong evidence that rubella vaccine did not cause CRS (*25*).

The higher effectiveness of the RA 27/3 vaccine, coupled with lower rates of adverse reactions, led to the vaccine's widespread adoption as the preferred rubella vaccine in the United States, resulting in its licensure in 1979 and the withdrawal of HPV-77 and Cendehill vaccines (*23*). Additional surveillance and comparative research studies strengthened the RA 27/3 vaccine's status as being especially effective in eliciting a strong immune response, decreasing risk of rubella virus transmission, and achieving these results with a very favorable safety profile (*21*). These findings resulted in this vaccine being accepted and used in almost all countries. A systematic literature review in 2019 showed that both single-dose and 2-dose regimens of rubella vaccine are highly immunogenic for a long period of time (*26*).

Lessons Learned from Rubella Vaccination in the COVID-19 Context

Today, rubella transmission has been eliminated in many countries throughout the world as a result of data-driven strategies and an effective, highly immunogenic, and safe vaccine that was developed and approved over time through rigorous scientific research and surveillance. The success of rubella control and elimination as we have described might inform policymakers as they make decisions regarding the COVID-19 vaccine program.

As was the case for the rubella pandemic, the COVID-19 pandemic has resulted in the rapid development and deployment of multiple vaccines. Unlike rubella virus, which had infected persons prior to its pandemic spread, SARS-CoV-2 emerged as a new virus to which the entire global population was susceptible. Although the rubella vaccine has yet to be introduced in 21 countries, COVID-19 vaccines have been introduced in every country (*27*). Vaccination inequities do, however, exist for COVID-19 vaccine introduction and use. High-income countries have achieved higher coverage than middle- and low-income countries. Limited vaccine supply, insufficient immunization program capacity, and socioeconomic issues have contributed to this disparity in regard to global vaccination (*28*).

When the highly constrained supply of the first COVID-19 vaccines became available in late 2020,

COVID-19 vaccination followed an individual protection approach, focusing on protecting the highest-risk populations and then expanding eligibility as vaccine supplies grew. Much like the United Kingdom's initial individual protection approach to rubella vaccination that resulted in a substantial decline in CRS cases, this selective approach resulted in sharp declines in COVID-19 hospitalizations and deaths among the vaccinated but left the unvaccinated at risk of infection and serious disease (*29*,*30*). Now that more COVID-19 vaccines have been approved and the vaccine supply expanded, vaccination has been broadened to a larger pool of eligible persons. This increased supply, coupled with new and ever-growing knowledge of each vaccine's advantages and disadvantages, has further informed COVID-19 vaccination program goals and efforts. In addition, surveillance measures have helped to identify priority populations for COVID-19 vaccination and monitor progress toward risk mitigation and population recovery. Vaccine safety surveillance systems and clinical studies have provided vital information to identify vaccine-associated adverse events.

As the COVID-19 vaccine supply increases and the pandemic evolves, comparative studies with objective criteria are needed to identify the vaccine(s) that meet the immediate goals of the global COVID-19 vaccination strategy, which is to minimize deaths, severe disease, and overall disease burden; curtail the health system impact; fully resume socio-economic activities; and reduce the risk of new variants (*31*). Currently available COVID-19 vaccines must be closely examined to distinguish which are most efficient in providing high seroconversion rates, long-term immunity against infection, serious illness, hospitalization, and death, and low rates of adverse events. The challenge of finding an optimal COVID-19 vaccine is compounded given that, unlike the rubella virus, which has only 1 serotype and no variants, SARS-CoV-2 variants continue to emerge (*4*). Ongoing COVID-19 vaccine effectiveness protocols and studies provide critical data that help researchers better understand troublesome trends, such as waning of vaccine-induced immunity or variant immune evasion (*32*–*34*), which further inform vaccine development and vaccination program goals. Innovative studies that examine varying vaccine schedules and combinations are underway, which will help to identify not only the most ideal vaccines but possibly also the best combination of vaccines (*33*).

Beyond vaccination strategies and vaccine choices, governments and public health authorities must consider other factors to help meet COVID-19 control goals. In terms of program implementation, key elements include cost considerations, expiration timeframes, cold chain requirements, and storage capacity. From a community perspective, factors affecting vaccination include preferences regarding administration and delivery, access to health services, and trust in healthcare providers and government information. Epidemiologically informed policy and control goals, when clearly and effectively communicated by trusted and empathetic sources, can create a unified vision for how nations can collectively bring an end to the COVID-19 pandemic, while proactively countering disinformation.

Disease control goals and vaccination strategy go hand in hand. Adopting a universal approach, as clinical trial data and licensure permit, would ensure that the world population can benefit from COVID-19 vaccination. Such an approach would require policymakers to address structural barriers to ensure access, equity, and confidence in vaccination. Thus, the success of achieving the goal of disease control depends on fully implementing the accompanying consensus strategy.

Conclusions

The success of the rubella disease control program provides valuable insights for the continuing battle against COVID-19. Key elements to a successful program include clearly delineated goals and strategies, regular data-driven revisions to the program based on surveillance, safety, and epidemiologic data, and evaluations to identify the most appropriate vaccine(s) to achieve disease control targets. Comparative vaccine studies are necessary to help identify the most appropriate vaccine to achieve programmatic goals, especially given the increase in both assortment and supply of COVID-19 vaccines. Whereas data guide strategic decision-making in determining a global response to the COVID-19 pandemic, such other factors as vaccine confidence and equity play important roles in defining and clearly communicating the programmatic goals. Those goals, at present, include protecting individuals from severe disease, hospitalization, and death as well as reducing health system strain and limiting emergence of new variants.

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Leveraging Lessons Learned from Yellow Fever and Polio Immunization Campaigns during COVID-19 Pandemic, Ghana, 2021

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Ghana is a yellow fever–endemic country and experienced a vaccine-derived polio outbreak in July 2019. A reactive polio vaccination campaign was conducted in September 2019 and preventive yellow fever campaign in November 2020. On March 12, 2020, Ghana confirmed its first COVID-19 cases. During February–August 2021, Ghana received 1,515,450 COVID-19 vaccines through the COVID-19 Vaccines Global Access initiative and other donor agencies. We describe how systems and infrastructure used for polio and yellow fever vaccine deployment and the lessons learned in those campaigns were used to deploy COVID-19 vaccines. During March–August 2021, a total of 1,424,008 vaccine doses were administered in Ghana. By using existing vaccination and health systems, officials in Ghana were able to deploy COVID-19 vaccines within a few months with <5% vaccine wastage and minimal additional resources despite the short shelf-life of vaccines received. These strategies were essential in saving lives in a resource-limited country.

Before and during the COVID-19 pandemic, Ghana experienced successes with vaccination campaigns for yellow fever and polio that influenced its deployment of COVID-19 vaccines (*1*,*2*). Ghana had successfully eliminated all 3 serotypes of wild polioviruses by 2008. In 2019, however, Ghana confirmed a case of circulating vaccine-derived poliovirus type 2 (cVDPV-2). As part of the response strategy, a reactive monovalent oral polio vaccine 2 (mOPV2) campaign targeting children <5 years of age was conducted in a phased approach across the country beginning in September 2019 (*1*).

Ghana is also among 34 yellow fever–endemic countries in Africa and experienced an outbreak of yellow fever in June 2014. As part of the efforts to prevent and control yellow fever, even during the COVID-19 pandemic, Ghana conducted a yellow fever preventive mass vaccination campaign in November 2020 among 81 districts in 14 (88%) of the 16 regions in the country. The campaign targeted ≈5.6 million persons 10–60 years of age and achieved administrative coverage of 94% in the targeted districts (*2*).

On January 30, 2020, the World Health Organization (WHO) declared COVID-19 a public health emergency of international concern, and on March 11, 2020, WHO declared COVID-19 a pandemic (*3*,*4*). In March 2020, Ghana confirmed its first 2 cases of COVID-19 (*5*). During February–August 2021, Ghana received 1,515,450 COVID-19 vaccines through the COVID-19 Vaccines Global Access initiative and other donors, such as the African Union, the Indian government, and United Arab Emirates (*6*). By March 14, 2020, when the first cases of COVID-19 were being identified, the country had achieved administrative coverage of 97% nationally for the mOPV2.

The COVID-19 response in Ghana has been coordinated by the Inter-Ministerial Coordination Committee (IMCC), which consists of cabinet members, key national government ministers and representatives from the President's Office of Ghana, and key officers from health and other social service agencies. The IMCC is chaired by the president of Ghana. The IMCC identified COVID-19 vaccination as one of the key strategies for effectively responding to the COVID-19 pandemic and charged Ghana's National Immunization Technical Advisory Group (NITAG)

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to develop a national COVID-19 vaccine deployment plan for Ghana.

Using proven microplanning and macroplanning strategies, national and subnational trainings were held to train supervisors, monitors, vaccinators, data collectors, and volunteers, and vaccines and other logistics were distributed to the 14 participating districts (*7*). In addition, supervisors were deployed to their respective field assignments. Phase 1 of the immunization campaign began within 7 days of vaccine receipt. We describe how the Expanded Program on Immunization (EPI) structures used for polio and yellow fever vaccine deployment and lessons learned from these previous campaigns were leveraged to quickly deploy COVID-19 vaccines in Ghana during March 1–August 23, 2021, regardless of the short shelf-life of vaccines received (1–3 months).

Methods

Setting

Ghana is a country in West Africa that shares borders with Togo, Cote d'Ivoire, and Burkina Faso. As of 2021, Ghana had a population of ≈30.08 million and an annual growth rate of 2.1% (*8*). The country provides free vaccination services. However, equity gaps remain a challenge among children >18 years of age of different socioeconomic backgrounds.

Ghana has 4 functional areas of the health system: administration and financing, healthcare service delivery, training, and regulatory. These functions are organized and implemented at the national, regional, and district levels, and some of these functions operate below the district level (i.e., subdistricts and health facilities). The Ghana Health Service (GHS), on behalf of the Ministry of Health (MoH), is the supervising agency for delivering primary and secondary healthcare services in the country, including immunization.

Developing the COVID-19 National Vaccine Deployment Plan

A technical working group made up of implementing partners including the WHO, US Centers for Disease Control and Prevention (CDC), and departments and divisions under the MoH/GHS was constituted under the directive of the Minister of Health. The NITAG led plan development. The team was tasked to develop national guidelines that would serve as a road map for the deployment of COVID-19 vaccines in Ghana. The plan was developed under the guidance of the WHO Strategic Advisory Group of Experts on Immunization. The final decision on prioritization in Ghana was under the recommendation of the NITAG.

Data from the WHO COVID-19 weekly epidemiologic updates, polio and yellow fever surge officers' reports, the District Health Information Management System, and the Surveillance Outbreak Response Management and Analysis System for COVID-19 Response were used to develop the Ghana COVID-19 Vaccine Deployment Plan. The plan described district prioritization on the basis of COVID-19 cases and deaths during March 2020–January 2021 (i.e., before vaccine deployment), enumerated priority groups (e.g., healthcare workers, persons ≥60 years of age, and persons with selected comorbidities, such as hypertension, diabetes, chronic lung disease, cancer, heart conditions, kidney disease, and other immunocompromising conditions) within districts, and a detailed near real-time assessment of districts' readiness to receive, store, and distribute vaccines. The plan called for vaccines to be administered by using the population segmentation approach.

Vaccination teams collected real-time data using the Open Data Kit (https://getodk.org) on tablets and mobile phones; data were synchronized to a central database accessible at all levels of the health system. Contact details and geographic coordinates were also captured. Text message reminders were sent to those who were due for their second dose. If those persons did not respond, community health nurses and surveillance officers used information captured during the first vaccine administration to trace the person. Persons with comorbidities were identified through reviews of medical histories.

At the national and regional levels, a visual dashboard was used to monitor vaccination activities to provide near real-time updates to field officers. Cold chain management systems during the yellow fever and polio campaigns were also assessed to determine their current condition in terms of functionality and storage capacity and ascertain whether expansion was necessary to ensure equity across regions. The assessment of the cold chain management systems during the polio and yellow fever campaigns gave a snapshot of the cold chain capacity in Ghana before COVID-19 vaccine deployment.

During the polio and yellow fever campaign, field monitors were deployed across regional, district, and subdistrict levels to provide real-time feedback using the Open Data Kit tool on tablets and phones for immediate action. Lot quality assurance sampling surveys were conducted to ensure adequate coverage in hard-to-reach areas. Residents of the Ghana College of Physician and Surgeons conducted the surveys, and training was done by the Ghana Health Service and WHO.

Developing of plans for social mobilization, training, cold chain management, vaccine deployment, coverage tracking, and postimmunization safety

monitoring relied on systems and personnel who had participated in the earlier polio and yellow fever vaccination campaigns. Before the yellow fever vaccination campaign, logistics support was needed for personal protective equipment and yellow fever vaccination cards. Within a period of 2 weeks, CDC Foundation raised enough funds to procure 87,841 (250-L) bottles of hand sanitizer worth US $224,371 and 5.6 million yellow fever vaccination cards worth US $130,000 to enable the yellow fever preventive mass vaccination campaign to proceed as planned.

In the area of regulatory preparedness and safety monitoring, the Ghana Health Service worked closely with Ghana Food and Drugs Authority (FDA) to assess the safety and efficacy of the yellow fever and polio vaccines before deployment. Because of the lack of capacity and resources to conduct clinical trials, Ghana FDA reviewed and validated reports from other stringent regulatory authorities. Other test parameters conducted by Ghana FDA included pH and UV tests. In addition, EPI and Ghana FDA collaborated to monitor adverse events after immunization, including causality assessment.

Lessons from these previous reactive campaigns were used to guide the proposed deployment strategies for COVID-19 vaccines. We calculated vaccine wastage rate by subtracting the total doses used from the total doses supplied, divided by the total dose supplied expressed as a percentage (*9*). We analyzed coverage and field supervision data for phase 1 of COVID-19 vaccine deployment by using Epi Info 7 (https://www.cdc.gov/epiinfo/index.html) and Power BI (https://powerbi.microsoft.com).

Ethics Statement

This activity was part of the national pandemic preparedness response by the Ghana MoH and GHS and was not deemed human subjects research. As such, ethical clearance was not required (Act 851 Public Health Act, 2012, Ministry of Health, Ghana). Primary data generated were stored electronically on national servers and password protected. Only reports with no personal identifying information were shared with other stakeholders such as WHO, UNICEF, and CDC.

Results

COVID-19 National Vaccine Deployment Plan

The National Vaccine Deployment Plan (NVDP) in Ghana has 10 main components: planning and coordination; regulatory preparedness and safety monitoring; vaccination strategies; deployment systems and modalities; immunization monitoring system; operational research and surveillance; communication and information; supply chain processes; waste management; and monitoring and evaluation. The development of the components of the NVDP was based on lessons learned during the yellow fever and polio immunization campaigns (Table 1). On the basis of lessons learned from the resource mobilization for the yellow fever campaign, Ghana was able to mobilize both human and logistical resources from institutions and implementing partners such as WHO, USAID, CDC, and World Bank for COVID-19 vaccine deployment.

Findings from the assessment of the cold chain structures used for the yellow fever and polio vaccination campaigns were used to develop proposals to government and other donor agencies for funding support. As a result, 94 ultra-low freezers sponsored by the government of Ghana, the government of Japan, World Bank, and UNICEF were installed across the country.

In terms of communication and information, media scanning was used to understand the drivers of vaccine hesitancy and acceptance among various subpopulations. Historical approaches, such as using mass media, celebrity ambassadors, and communication centers to promote vaccine uptake and address hesitancy, were used for COVID-19 vaccine deployment. The president of Ghana and some members of his leadership team were vaccinated live on national television to promote vaccination. For hard-to-reach areas, community leaders and opinion leaders were used to lead communication efforts addressing vaccine hesitancy. Using lot quality assurance sampling surveys to ensure adequate coverage in hard-to-reach areas helped affirm the need to extend the campaign in those communities by an extra 3–7 days.

Vaccine Deployment

As of August 23, 2021, a total of 1,424,008 doses o f vaccines (1,282,097 AstraZeneca [https://www.astrazeneca.com], 15,813 Sputnik V [https://www.sputnikvaccine.com], and 126,178 Janssen/Johnson & Johnson [https://www.jnj.com]) had been administered in Ghana, with <5% vaccine wastage and minimal additional resources despite the short shelf-life of vaccines received (K. Amponsah-Achiano, GHS, unpub. data, 2021 Aug 23). At the end of phase 1, a total of 461,800 persons were fully vaccinated and ≈865,422 persons had received ≥1 dose. Deployment was based on population and geographic segmentation across the country. Most vaccinations occurred in the Greater Accra and Ashanti regions, the 2 epicenters of the COVID-19 epidemic in Ghana.

The initial phase of deployment during March 1–August 23, 2021, used a population segmentation

Table 1. Lessons learned during yellow fever and polio immunization campaign that informed the COVID-19 National Vaccine Deployment Plan, Ghana, September 4, 2019–November 18, 2020*

NVDP component	Lessons learned during yellow fever and polio immunization campaigns
Planning and coordination	Activate or establish an Incident Management System for coordinating the vaccination response
Regulatory preparedness and safety monitoring	Liaise early with the Ghana (or any country) FDA to ensure the evaluation and approval of vaccines before deployment and the monitoring of adverse events following immunization
Vaccination strategies	Develop detailed and accurate microplans inclusive of strategies for hard-to-reach areas.
Deployment systems and modalities	Identify resources early for surge deployment of human resources and logistics for vaccination activities and campaigns; deploy Field Epidemiology and Laboratory Training Program alumni and residents as surge staff
Immunization monitoring system	Establish sites and deploy field officers for safety monitoring and reporting
Operational research and surveillance	Conduct surveys to assess the knowledge, attitudes, practices, and behaviors of the target population toward vaccine acceptance at predefined time points
Communication and information	Use media scanning to understand the drivers of vaccine hesitancy and acceptance among various subpopulations. Use mass media, celebrities as ambassadors, and communication centers to increase vaccine demand and reduce hesitancy. For hard-to-reach areas, community leaders and opinion leaders were used to lead communications to address vaccine hesitancy
Supply chain processes	Improve cold chain capacity (a system to maintain a desired temperature for viability of vaccines in the supply chain) before there is an outbreak or epidemic; adopt and use a standardized process for vaccine accountability and retrieval
Waste management	Use incinerators to destroy waste generated by vaccination under supervision.
Monitoring and evaluation	Deploy field monitors at regional, district, and subdistrict level to provide real-time feedback, using the Open Data Kit for immediate action. Ensure that every vial is accounted for daily. After every campaign, a monitoring team consisting of Ghana FDA, Environmental Protection Agency, WHO, and UNICEF officials should oversee the incineration of empty vials by region and certify that all vials have been accounted for. The Vaccine Accountability Monitoring officers should undergo formal training to ensure accuracy

*FDA, Food and Drug Authority; NVDP, National Vaccine Deployment Plan; WHO, World Health Organization.

approach that covered healthcare workers, frontline security personnel, persons with known comorbidities, teachers >50 years of age, persons ≥60 years of age, and frontline members of the executive, legislature, and judiciary sections of the government (Table 2; Figure). Of the 1,424,008 doses administered, ≥865,422 persons received their first dose, and 432,488 received their second dose. Overall, 558,666 persons were fully vaccinated (i.e., received 1 dose of Janssen/Johnson & Johnson vaccine or 2 doses of AstraZeneca or Sputnik V vaccine). About 52% of vaccine recipients were men (742,004) and 48% women (682,004).

Discussion

We describe how Ghana leveraged existing vaccination programs and structures and lessons learned from previous vaccination campaigns to ensure effective and efficient deployment of COVID-19 vaccines. The Ghana Technical Working Group for COVID-19 vaccine deployment ensured a comprehensive approach to COVID-19 deployment in Ghana.

The population segmentation used in administering the vaccines ensured that the most at-risk groups were covered to reduce severity of the disease. This approach has also been used in India (*10*). An incident management system for COVID-19 vaccine deployment established within the National Public Health Emergency Operations Center served as a platform for resource mobilization and reduced duplication among stakeholders and partners (*11*–*13*).

Regarding regulatory preparedness and safety monitoring, one of the lessons learned from the yellow fever and polio campaigns was the need to liaise early with the Ghana FDA to ensure the evaluation and approval of vaccines before deployment. All vaccines need

Table 2. Performance of phase 1 COVID-19 vaccine deployment, Ghana, March 1–August 23, 2021

Phase	Start date	No. regions	No. districts	Target segmentation	No. doses administered
Phase 1A	2021 Mar 1	3	43	Most at-risk groups in 43 hotspot districts	535,408
Phase 1B	2021 Mar 24	13	217	All healthcare workers	316,639
Phase 1C	2021 May 19	3	43	All persons vaccinated in Phase 1A during March 1–9, 2021 (12 weeks after first dose)	380,829
Phase 1D	2021 Jun 20	16	260	2021 census enumerators (1st dose) and 2nd dose vaccinations in selected districts	65,034
Phase 1E	2021 Aug 13	3	11	General population in selected areas	126,178
Total					1,424,088

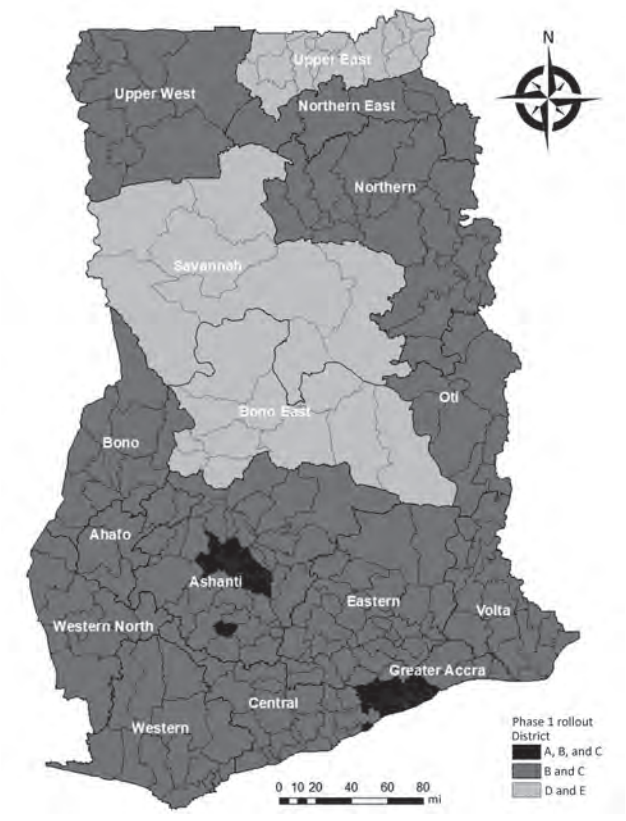

Figure. Distribution of phase 1 COVID-19 vaccination campaign deployment by district, Ghana, March 1–August 23, 2021. Based on population and geographic segmentation, phase 1A targeted the most at-risk groups in 43 hotspot districts; phase 1B targeted all healthcare workers; phase 1C targeted all persons vaccinated in phase 1A during within March 1–9, 2021 (12 weeks after first dose); phase 1D targeted 2021 census enumerators (first dose) and second-dose vaccinations in selected districts; and phase 1E targeted the general population in same districts. Phase 1E vaccination was with the Janssen/Johnson & Johnson vaccine (https://www.jnj.com).

Ghana FDA approval before they can be administered in the country. The close collaboration between Ghana FDA and EPI helped ensure a plan for monitoring adverse events after immunization to avoid duplicating efforts and harness data sharing for decision-making.

During the yellow fever and polio vaccination campaigns, rural communities in hard-to-reach areas representing ≈10% of the target population were not vaccinated because the communities were geographically remote relative to other campaign areas and could not be covered within the days allocated. To address this problem, the vaccination periods during the COVID-19 campaign were extended for a week in those locations. Separate campaigns were organized for communities that were cut off because of flooding and required special arrangements, such as use of canoes. All these considerations were factored into the COVID-19 vaccine deployment microplans. Capitalizing on existing microplanning strategies helped reduce the time for vaccine deployment for COVID-19 by ≈50% and ensured equity in vaccine distribution to rural, urban, and hard-to-reach communities within earmarked regions and districts.

One of the strategies that led to efficient deployment systems and modalities was early planning and identifying resources for surge deployment of human resources and logistics for vaccination activities and campaigns. This approach involved engaging institutions such as the Field Epidemiology and Laboratory Training Program to deploy alumni and residents as surge staff (*14*). Deploying surge officers during the yellow fever and polio vaccination campaigns in Ghana and Nigeria improved vaccination by increasing the number of routine immunization outreach sessions and expanding vaccine coverage, conducting active case searches and social mobilization, and strengthening partnerships with key stakeholders (*15*). This same strategy was used for the COVID-19 vaccination campaigns. Implementing partners also deployed field officers to support the monitoring activities.

Cold chain management is known to be an essential component of vaccine deployment, as has been reported in countries such as Tunisia (*16*,*17*). The cold chain in Ghana was revamped with support from Gavi, the Vaccine Alliance. The use of lot quality assurance sampling surveys in ensuring adequate coverage in hard-to-reach areas was demonstrated during previous vaccination campaigns in Ghana (*18*,*19*). The strategy of using celebrities, media houses, and social media influencers for social mobilization has also proven to be an effective approach for social mobilization in Ghana and other countries such as Hong Kong, France, and the United Kingdom (*20*–*22*).

Other lessons were also learned from the COVID-19 vaccine deployment in Ghana. We identified the need to further expand cold chain capacity to enable the storage of larger quantities of vaccines, because the country's previous capacity for vaccine storage was limited. In addition, ultra-cold chain capacity needed to be decentralized because capacity was only at the central and regional level and some selected facilities. This decentralization would require additional resources to transport vaccines to other parts of the country while maintaining the cold chain. With respect to leadership, we learned that successful vaccine deployment thrives on commitment by the country's leadership, which was evident at all levels of the health system. However, a limitation of our study is that the lessons learned from the yellow fever and polio campaign were drawn from 81 districts and might not be representative of the entire country.

Using existing systems to deploy COVID-19 vaccines saved time and resources. Ghana was able to deploy its COVID-19 vaccines within a short time (3 weeks–2 months after receipt of vaccines), which was essential because of the short shelf-life (1–3 months) of the vaccines. Unlike many countries that were not able to use all received vaccines before expiration, Ghana had <5% vaccine wastage. The country is currently planning for subsequent phases of vaccine deployment and providing technical assistance to other neighboring countries, such as Cote d'Ivoire, on strategies for effectively deploying COVID-19 vaccines.

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Effectiveness of Whole-Virus COVID-19 Vaccine among Healthcare Personnel, Lima, Peru

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In February 2021, Peru launched a COVID-19 vaccination campaign among healthcare personnel using an inactivated whole-virus vaccine. The manufacturer recommended 2 vaccine doses 21 days apart. We evaluated vaccine effectiveness among an existing multiyear influenza vaccine cohort at 2 hospitals in Lima. We analyzed data on 290 participants followed during February–May 2021. Participants completed a baseline questionnaire and provided weekly self-collected nasal swab samples; samples were tested by real-time reverse transcription PCR. Median participant follow-up was 2 (range 1–11) weeks. We performed multivariable logistic regression and adjusted for preselected characteristics. During the study, 25 (9%) participants tested SARS-CoV-2–positive. We estimated adjusted vaccine effectiveness at 95% (95% CI 70%–99%) among fully vaccinated participants and 100% (95% CI 88%–100%) among partially vaccinated participants. These data can inform the use and acceptance of inactivated whole-virus vaccine and support vaccination efforts in the region.

Peru is a middle-income country disproportionately affected by COVID-19 and struggling to protect its essential workforce (*1*–*4*). Despite early lockdowns, curfews, and other public health and social measures implemented to reduce disease spread (*5*), by May 22, 2021, Peru had 180,764 reported COVID-19–associated deaths and continued to accrue cases (*6*,*7*). As in many other middle-income countries, healthcare services in Peru were overwhelmed with patients, had limited personal protective equipment, and had delayed and limited COVID-19 vaccination, leading to unrest and strikes among healthcare personnel (*8*). On February 9, 2021, Peru initiated COVID-19 vaccination with the Beijing Institute of Biologic Products Coronavirus Vaccine (BBIBP-CorV; Sinopharm, https://www.sinopharm.com), an inactivated whole-virus vaccine. Healthcare personnel were a priority group for vaccination. During the study period (February 9–May 4, 2021), BBIBP-CorV vaccine was the only COVID-19 vaccine available for healthcare personnel in Peru (*9*,*10*). The manufacturer recommended 2 vaccine doses 21 days apart.

Evidence on BBIBP-CorV vaccine effectiveness could reduce hesitancy about the vaccine and support vaccination efforts. We used an existing multiyear influenza vaccine cohort of healthcare workers at 2 hospitals in Lima (*11*) to evaluate BBIBP-CorV vaccine effectiveness at preventing symptomatic and asymptomatic SARS-CoV-2 infections.

Methods

Study Design and Population

We designed a prospective cohort study that we conducted at 2 tertiary hospitals in Lima, Peru, during February 9–May 4, 2021. We invited healthcare workers 18–65 years of age from both hospitals to participate in the cohort. For study inclusion, participants had to work full-time (≥30 hours per week) at the facility; have routine, direct, hands-on or face-to-face contact with patients (within 1 m) as part of a typical work shift; and have worked at the facility for ≥1 year before enrollment.

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Data Collection

Participants provided written informed consent and completed a baseline questionnaire about their demographic characteristics and role in the hospital. Questions included information on self-reported exposure to COVID-19 patients, work in the intensive care unit (ICU), or work in the emergency department (ED). Participants provided serum samples at baseline and at the end of the study period. Each participant was followed for up to 16 weeks after enrollment. Participants responded to a weekly survey that included questions about COVID-19 exposure and receipt of BBIBP-CorV vaccine as documented by the hospitals. Participants also provided a weekly self-collected anterior nasal swab sample, which was tested for SARS-CoV-2 by real-time reverse transcription PCR (rRT-PCR) at the US Naval Medical Research Unit 6 (NAMRU-6) in Lima, following testing protocols from the US Centers for Disease Control and Prevention (CDC) (*12*). rRT-PCR testing was performed in pools of 5 samples; if pools tested positive, all 5 individual samples were tested separately. Serum samples were shipped to CDC (Atlanta, Georgia, USA) for pan-Ig serologic testing (B. Freeman et al., unpub. data, https://doi.org/10.1101/2020.04.24.057323).

We considered participants fully vaccinated starting 14 days after receipt of their second dose and partially vaccinated starting 14 days after receipt of the first dose and participants not meeting these criteria as unvaccinated. This study was reviewed and approved by the NAMRU-6 institutional review board.

Statistical Analysis

We compiled healthcare personnel demographics, occupational information, baseline serology, COVID-19 vaccine receipt, and laboratory detection of SARS-CoV-2. We applied χ^2 or Wilcoxon tests, as appropriate, to assess differences in demographics, occupational information, and baseline serology, stratified by SARS-CoV-2 detection and COVID-19 vaccine receipt.

We estimated vaccine effectiveness by using a multivariable logistic regression model adjusted for preselected characteristics, including age, sex, exposure to COVID-19 patients, work in ICU or ED, body mass index (BMI), and time of follow-up in days. We defined vaccine effectiveness as [1 – adjusted odds ratio] × 100% and calculated 95% CIs. For these analyses, we excluded persons who were seropositive at baseline and those with a positive COVID-19 test before February 9, 2021. The partial vaccination model only included participants who received 1 dose of the vaccine during the study period. Partially vaccinated participants were excluded from the full vaccination analysis. We calculated COVID-19 vaccine effectiveness under both full and partial vaccination scenarios. The outcome of interest in the model was SARS-CoV-2 detection; if SARS-CoV-2 was detected in a participant before first vaccination date or before the 2-week period after first vaccination, we considered the participant unvaccinated for the analysis. We conducted all analyses in R version 4.1.0 (R Foundation for Statistical Computing, https://www.r-project.org).

Results

Study Sample Characteristics, SARS-CoV-2 Infections, and COVID-19 Vaccine Receipt

The participant cohort comprised 290 healthcare workers followed during February 9–May 4, 2021; a total of 270 (93.1%) participants reported receiving ≥1 COVID-19 vaccine dose, 80% (216/270) of whom reported being fully vaccinated before the end of the follow-up period. The median follow-up period was 2 (range 1–11) weeks after the 2-week postvaccination period. Median age of participants was 45 (interquartile range [IQR] 38–52) years. Among all participants, 74% (215/290) were female, and 90% (260/290) reported being of mixed race. Only 3% (8/290) of participants reported a chronic medical condition, including asthma, diabetes, high blood pressure, chronic heart disease, autoimmune condition, HIV/AIDS, or other medical conditions requiring clinical care for ≥6 months. Among participants, 49% (143/290) were classified as overweight (BMI 25 to <30) and 22% (64/290) as obese (BMI ≥30). Over one third (106/290) of participants had a reactive result for SARS-CoV-2 pan-Ig antibodies on baseline serum samples, and SARS-CoV-2 was detected by rRT-PCR among 25 (9%) participants during follow-up. Participants who were seronegative at baseline were more likely to subsequently test positive for SARS-CoV-2 through rRT-PCR than participants who were seropositive at baseline ($p<0.001$) (Table 1).

COVID-19 Vaccine Effectiveness

After excluding participants who were seropositive at baseline and those with a positive COVID-19 test before February 9, 2021, and adjusting for age, sex, exposure to COVID-19 patients, work in the ICU, work in the ED, BMI, and time of follow-up in days, we estimated overall BBIBP-CorV vaccine effectiveness against symptomatic or asymptomatic SARS-CoV-2 infection as 97% (95% CI 88%–99%) for those who received ≥1 dose of the vaccine. Effectiveness was 100%

Table 1. Characteristics, vaccine receipt, and SARS-CoV-2 laboratory detection among 290 participants in a study on effectiveness of whole-virus COVID-19 vaccine among healthcare personnel, Lima, Peru, February 9–May 4, 2021*

		SARS-CoV-2 testing†			Vaccination status‡				
Characteristics	All workers	Positive	Negative	p value	Unvaccinated	Partially vaccinated	p value	Fully vaccinated	p value
Total no. (%)	290 (100)	25 (9)	265 (91)	NA	20 (7)	54 (19)	NA	216 (74)	NA
Median age, y (IQR)	45 (38–52)	48 (41–54)	45 (38–51)	0.82	39 (37–49)	47 (39–52)	0.14	45 (39–52)	0.12
Age range, y									
18–39	85 (29)	6 (24)	79 (30)	NA	10 (50)	14 (26)	NA	61 (28)	NA
40–49	110 (38)	10 (40)	100 (38)	NA	5 (25)	22 (41)	NA	83 (38)	NA
50–65	95 (33)	9 (36)	86 (32)	NA	5 (25)	18 (33)	NA	72 (33)	NA
Sex									
M	75 (26)	6 (24)	69 (26)	1.0	1 (5)	25 (46)	<0.01	49 (23)	0.12
F	215 (74)	10 (76)	196 (74)	NA	19 (95)	29 (54)	NA	167 (77)	NA
Race/ethnicity									
Mixed race	260 (90)	21 (84)	239 (90)	0.45	19 (95)	45 (83)	0.48	196 (91)	0.89
Indigenous	19 (7)	2 (8)	17 (6)	NA	1 (5)	3 (6)	NA	15 (7)	NA
Black	8 (3)	1 (4)	7 (3)	NA	0	5 (9)	NA	3 (1)	NA
White	3 (1)	1 (4)	2 (1)	NA	0	1 (2)	NA	2 (1)	NA
Education									
High school only	37 (13)	2 (8)	35 (13)	0.75	0	13 (24)	0.02	24 (11)	0.10
Associate or bachelor's degree	233 (80)	21 (84)	212 (80)	NA	20 (100)	38 (70)	NA	175 (81)	NA
Postgraduate education	20 (7)	2 (8)	18 (7)	NA	0	3 (6)	NA	17 (8)	NA
Comorbidities									
Any medical condition§	8 (3)	2 (8)	6 (2)	0.52	1 (5)	2 (4)	0.74	5 (2)	0.64
BMI¶									
Normal	83 (29)	9 (36)	74 (28)	0.61	9 (45)	17 (31)	0.47	57 (26)	0.20
Overweight	143 (49)	12 (48)	131 (49)	NA	7 (35)	27 (50)	NA	109 (50)	NA
Obese	64 (22)	4 (16)	60 (23)	NA	4 (20)	10 (19)	NA	50 (23)	NA
Smoking daily/some	11 (4)	1 (4)	10 (4)	1.0	1 (5)	3 (6)	1.0	7 (3)	1.0
Job type									
Physician	11 (4)	1 (4)	10 (4)	0.62	0	0	<0.01	11 (5)	0.08
Nurse	63 (22)	2 (8)	61 (23)	NA	1 (5)	10 (19)	NA	52 (24)	NA
Midwife or dentist	12 (4)	1 (4)	11 (4)	NA	0	0	NA	12 (5)	NA
Technician, assistant	135 (47)	14 (56)	121 (46)	NA	15 (75)	17 (31)	NA	103 (48)	NA
Pharmacist, social worker, nutritionist	2 (1)	0	2 (1)	NA	1 (5)	0	NA	1 (0)	NA
Physical therapist	4 (1)	0	4 (2)	NA	0	2 (4)	NA	2 (1)	NA
Administrator, security, maintenance, transporter	49 (17)	7 (28)	42 (15)	NA	1 (5)	20 (37)	NA	28 (12)	NA
Other	14 (5)	0	14 (5)	NA	2 (10)	5 (9)	NA	7 (3)	NA
Exposed to COVID-19 patients in healthcare setting	249 (86)	18 (72)	231 (87)	0.59	17 (85)	45 (83)	1.0	187 (87)	1.0
ICU	27 (9)	4 (16)	23 (9)	0.40	0	8 (15)	0.16	19 (9)	0.34
ED	101 (35)	11 (44)	90 (34)	0.43	9 (45)	20 (37)	0.72	72 (33)	0.42
Median hours worked at site/week (IQR)	36 (36–36)	36 (36–40)	36 (36–36)	0.93	36 (36–39)	36 (36–48)	0.23	36 (36–36)	0.40
Median hours patient-provider face-to-face/week (IQR)	30 (24–36)	30 (20–30)	30 (25–36)	0.04	33 (30–37)	30 (25–36)	0.31	30 (24–36)	0.11
Reactive SARS-CoV-2 serology at baseline	106 (37)	0	106 (40)	<0.01	5 (25)	15 (28)	1.0	86 (40)	0.28

*Values represent no. (%) unless otherwise indicated. p values were calculated by using χ^2 test for categorical and Wilcoxon signed rank test for continuous variables. BMI, body mass index; ED, emergency department; ICU, intensive care unit.
†At least once by weekly testing during follow-up period.
‡Vaccination of healthcare workers started in Lima on February 9, 2021, and was assessed by interview on a weekly basis. Partially vaccinated refers to persons who received 1 dose of whole-virus COVID-19 vaccine during the study period; fully vaccinated refers to persons who received 2 doses of whole-virus COVID-19 vaccine during the study period. Partially and fully vaccinated groups were separately compared against unvaccinated persons.
§Asthma, diabetes, high blood pressure, chronic heart disease, autoimmune condition, HIV/AIDS, another medical condition requiring clinical care ≥6 mo.
¶Normal (18.5 to <25); overweight (25 to <30); obese (≥30).

(95% CI 88%–100%) for partially vaccinated participants and 95% (95% CI 70%–99%) for fully vaccinated participants (Table 2).

Discussion

Among vaccinated participants in this cohort, we estimate BBIBP-CorV vaccine was ≥90% effective in preventing SARS-CoV-2 infection in the weeks immediately after vaccination. Furthermore, our findings indicate that, during February–May 2021, 1 of 10 study participants in 2 tertiary hospitals in Lima were infected with laboratory-confirmed SARS-CoV-2.

Healthcare personnel are at increased risk for SARS-CoV-2 infection (*13*). Our findings show continued detection of SARS-CoV-2 infection during the study period. In Peru, estimates reported >600 physicians and nurses had died of COVID-19 by June 2021 (*1*). Protecting the healthcare workforce is a global priority to ensure healthcare delivery to the population. The World Health Organization (WHO) Strategic Advisory Group of Experts on Immunization roadmap for prioritizing use of COVID-19 vaccines in the context of limited supplies includes healthcare personnel as one of the highest priority groups for vaccination (*14*). The government of Peru initiated COVID-19 vaccination on February 9, 2021, and healthcare personnel were the initial targeted group to receive the vaccine (*15*).

Our study indicates the BBIBP-CorV vaccine is effective against SARS-CoV-2 infection in the period immediately after vaccination. Our findings are compatible with those reported by WHO, in which BBIBP-CorV vaccine efficacy was estimated at 78.9% (95% CI 65.8%–87%) against COVID-19 disease in an unpublished clinical trial, with a follow-up time of 2 months (*16*). Furthermore, our findings are consistent with interim estimates published by WHO, in which vaccine effectiveness against rRT-PCR–confirmed cases among adults ≥18 years of age in Bahrain was 90% (95% CI 88%–91%) (*17*).

In our study, we suspect that B.1.1.1 (Alpha) was the dominant circulating SARS-CoV-2 variant in early 2021 because it was detected in 43% (n = 23) of the samples that were sequenced. However, SARS-CoV-2 variant P.1 (Gamma) was identified in Peru in January 2021 (*18*); in addition, P.1 was identified in one of the 19 samples collected during January–February 2021 (data not shown). P.1 emerged in Brazil in mid-November 2020 and rapidly spread in the state of Amazonas in early 2021, causing several hospitalizations and deaths (*19*,*20*). WHO included P.1 as a variant of concern in January 2021 because of its increased transmissibility and virulence (*21*). Data collection over time are needed to assess vaccine effectiveness under real-life circumstances as new variants emerge and circulate.

Because of high COVID-19 illness and death rates, BBIBP-CorV vaccine was rolled out in Peru and numerous other countries despite the lack of robust effectiveness data (*22*). Long-term effectiveness data are still needed, but the results from our study support continued use of BBIBP-CorV, at least in the absence of available vaccines with proven long-term effectiveness. Data from this study can be used to support vaccination in the region because offering vaccine effectiveness data can improve vaccine uptake (*23*). Unlike some other COVID-19 vaccines, BBIBP-CorV does not require complicated cold chain logistics, such as ultralow freezer conditions, and can be used within the existing cold chain infrastructure of other national immunization programs (*24*).

Among our study's strengths is that we were able to rapidly implement a prospective cohort study by leveraging an ongoing prospective cohort established to evaluate influenza vaccine effectiveness among healthcare personnel with weekly nasal swab sampling and testing for SARS-CoV-2, regardless of symptoms. The frequency and breadth of sampling among our cohort enabled greater detection of infection than passive surveillance systems. Participation rate in this COVID-19 study was high (85%) and remained high throughout the 16-week follow-up period; >96% of participants submitted swab specimens in ≥13 of the 16 weeks of follow-up. SARS-CoV-2 infection was confirmed through rRT-PCR in NAMRU-6's high proficiency

Table 2. COVID-19 vaccine effectiveness by number of doses received in a study on effectiveness of whole-virus COVID-19 vaccine among healthcare personnel, Lima, Peru, February 9–May 4, 2021*

	COVID-19 cases		Non–COVID-19 cases		Vaccine effectiveness, % (95% CI)‡	
Vaccination status†	Vaccinated	Unvaccinated	Vaccinated	Unvaccinated	Unadjusted	Adjusted
Received ≥1 vaccine dose	10	9	138	6	95 (84–99)	97 (88–99)
Fully vaccinated	5	9	36	6	91 (63–98)	95 (70–99)
Partially vaccinated	5	9	25	6	87 (45–97)	100 (88–100)

*Totals exclude persons with reactive SARS-CoV-2 serology (n = 106) and persons with positive COVID-19 test before February 9, 2021 (n = 17).
†Persons who tested positive before vaccination date or before the 2-week period after vaccination were considered unvaccinated for the model. We defined full vaccination as the period starting 14 d after receipt of the second dose and partial vaccination as the period starting 14 d after receipt of the first dose. Participants not meeting these criteria were considered unvaccinated. The partial vaccination model only included persons who received 1 dose of the vaccine during the study period.
‡Adjusted for age, sex, exposure to COVID-19 patients, work in the intensive care unit, work in the emergency department, body-mass index, and time of follow-up in days.

laboratory, following CDC's SARS-CoV-2 diagnostic protocol, and did not rely on point of care testing with less sensitive assays.

The first limitation of our study is that the high vaccine effectiveness we observed might be related to the short follow-up period after vaccination, 1–11 (median 2) weeks after the 2-week postvaccination period; a longer follow-up period is necessary to fully evaluate the long-term effectiveness of the vaccine among this study population. Second, we did not estimate sample size for this study to measure vaccine effectiveness so that maximum sample could be achieved; the resulting sample size was insufficient to stratify vaccine effectiveness estimates by variant or by symptomatic versus asymptomatic infection. Third, because of the limited availability of laboratory staff and high volume of weekly respiratory specimens, we implemented a pooling strategy for SARS-CoV-2 testing, which might have decreased sensitivity to detect participants with low viral shedding. Finally, our study could not distinguish nasal carriage of the virus from lower respiratory tract SARS-CoV-2 infection.

In summary, 1 in 10 healthcare personnel in our study in Peru tested positive for SARS-CoV-2 during February–May 2021. Vaccination of healthcare personnel with BBIBP-CorV vaccine was effective at reducing SARS-CoV-2 infections in the weeks immediately after vaccination. Our data support Peru's ongoing COVID-19 vaccination efforts for reducing SARS-CoV-2 infections, especially among this critical workforce of healthcare professionals.

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The study protocol was approved by the NAMRU-6 institutional review board in compliance with all applicable federal regulations governing the protection of human subjects.

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Leveraging HIV Program and Civil Society to Accelerate COVID-19 Vaccine Uptake, Zambia

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To accelerate COVID-19 vaccination delivery, Zambia integrated COVID-19 vaccination into HIV treatment centers and used World AIDS Day 2021 to launch a national vaccination campaign. This campaign was associated with significantly increased vaccinations, demonstrating that HIV programs can be leveraged to increase COVID-19 vaccine uptake.

COVID-19 vaccine scale-up in Africa, the continent with the lowest vaccine coverage, is a current regional and global priority. As of May 1, 2022, only 17% of persons in Africa had been fully vaccinated (*1*). Initial vaccination campaigns in Africa were hampered by lower-than-forecasted vaccine donations (*2*). However, through efforts from multiple stakeholders, the vaccine supply to countries in Africa increased in the latter half of 2021. However, with increasing vaccine availability, new challenges became apparent, including the difficulty for under-resourced health systems with relatively low healthcare worker–to–population ratios to implement COVID-19 vaccination services, as well as difficulties reaching populations unaccustomed to adult immunization programs and vaccine misperceptions and misinformation. Facing these challenges, in August 2021, the government of Zambia worked with stakeholders to leverage its national HIV program (which has been supported by >$5 billion in funding in the previous 20 years) to enhance its COVID-19 vaccine campaign.

Zambia integrated COVID-19 vaccination into its existing HIV treatment centers with the goal of offering patients and family members vaccination services, thereby rapidly expanding static vaccination site numbers in the country. Successful strategies for engaging HIV treatment centers included using existing human resources by adequately preparing HIV healthcare workers to offer vaccination and encouraging them to get vaccinated themselves, developing targeted promotional materials for persons living with HIV who are at increased risk for severe illness (*3*), and rapidly adapting and implementing similar models across the country. After this preparatory work, Zambia used the annual World AIDS Day event to launch its December Campaign to help reach African Union targets (*4*), focusing on engaging civil society leaders to endorse vaccination and using a mixed service delivery model that added community-delivered vaccination based on successful community HIV programs to existing static service delivery (Table). Some strategies were adapted from Zambia's robust childhood vaccination program (*5*).

To evaluate whether the December Campaign accelerated COVID-19 vaccination in Zambia, we conducted time-series analyses by using publicly available data (Appendix, https://wwwnc.cdc.gov/EID/article/28/13/22-0743-App1.pdf) (*1*). All participants entered in the Our World in Data (https://ourworldindata.org/ dataset by February 21, 2022, for Zambia and 55 African Union member states were eligible for the analysis. We conducted 3 statistical analyses. First, in a single-group interrupted time-series analysis in Zambia only, we compared the number of persons reaching full vaccination status per day before the December 1, 2021, campaign start versus after the campaign start. Second, in a multigroup interrupted time-series analysis, we assessed whether Zambia's acceleration in COVID-19 vaccination coverage (i.e., acceleration in the percentage of total population reaching full vaccination status per day) after the December Campaign intervention was statistically superior to 2 control groups: 2 neighboring countries with similar pre-intervention vaccination coverage trajectories and similar vaccine availability, and the average for all 55 Africa Union member states. Third, we implemented

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2 sensitivity analyses for each of the above 2 analytic approaches by varying the approach to managing missing data (i.e., most recent value carried forward approach vs. interpolation approach) and comparing varied time periods for the analysis to determine the duration of December Campaign effect.

During December 2021, a total of 585,677 persons in Zambia were reached for vaccination, compared with approximately 1,071,682 million during April–November 2021. Daily COVID-19 vaccinations increased from 3,713/day before December 2021 to 17,783/day after December 1, 2021 (p<0.001) (Figure, panel A; Appendix Table 3).

Compared with the average for 2 neighboring countries with similar vaccination trends before December and vaccine availability, Zambia accelerated its population COVID-19 vaccine coverage rate by an additional 2.73%/month (p<0.001) (Figure, panel B; Appendix Table 4). Compared with Africa as a whole, Zambia vaccine coverage accelerated by 1.87%/month (p<0.001) (Figure, panel C; Appendix Table 5). This accelerated vaccination in Zambia was robust to the sensitivity analysis for which we used an interpolation approach to missing data instead of the approach carrying forward the most recent available data point (Appendix Tables 3, 6). In addition, the average post-December daily vaccination rate dropped only slightly, and the average post-December percentage gain per day in a fully vaccinated population remained relatively stable, indicating a sustained effect for nearly 3 months after the December Campaign launch. If current trends were sustained,

Table. Lessons learned from leveraging HIV programs to support COVID-19 vaccination, Zambia*

Pillar	Lessons
Planning and coordination	• Leverage existing in-country systems/programs/resources for COVID-19 vaccination. • Engage national, provincial, and district health bodies from the outset. • Develop district-level microplans based on standard tools that are approved at provincial and national levels. • Use joint planning by Ministry of Health, funding organizations, and provincial representatives. • Establish centralized M&E tools for national tracking of progress. • Begin with a small pilot in a few sites and rapidly iterate to improve quality, using a continuous quality-improvement approach. • Scale-up successful practices rapidly to quickly enhance effect. • Develop targets that can be implemented and achieved by lower levels (i.e., district health offices, service delivery teams).
Service delivery	• Adequately capacitate HCWs in HIV, MCH, and other clinics to deliver COVID-19 vaccines. • Invest in community mobilization and service delivery to overcome limits of a static service delivery approach and reach the greatest number of eligible persons, which means offering vaccines at public places (e.g., markets, malls, churches), chiefdoms, workplaces, congregate settings, and others. • Use existing community health services for HIV as vaccination points. • Anticipate additional human resource needs, and ensure adequate financial resources to support them.
Demand generation	• Ensure adequate HCW training in HIV and other clinics to answer patients' and eligible family members' questions about COVID-19 vaccines. • Encourage HCWs themselves to get vaccinated against COVID-19 by creating a safe space for unvaccinated HCWs to have their questions answered. • Engage public and private media nationally to address myths and misconceptions about COVID-19 vaccines. • Develop promotional materials that emphasize the value of COVID-19 vaccination for persons living with HIV because of the elevated risk for severe illness among members of this group. • Engage civil society (community, traditional, religious, and business leaders) to champion COVID-19 vaccination. Listen to and address their concerns about COVID-19 vaccines. • Use routine patient reminder call for upcoming visits to share information about vaccine availability in HIV clinics.
M&E	• Harmonize COVID-19 vaccine data collection in HIV and other clinics with the national COVID-19 vaccine M&E system. • Conduct frequent data analysis to inform site-level performance assessments and guide targeted quality improvement. • Generate feedback loops, particularly for poorly performing districts.
Logistics	• Push adequate vaccine supplies to each district based on their estimated target populations with the microplan. • Take inventory of health facility capacity to adequately store COVID-19 vaccines, and use existing infrastructure where possible. • Ensure that HIV clinic vaccine supply is incorporated into the wider health facility request.
Safety	• Provide AEFI training to HCWs. • Strengthen AEFI reporting system within HIV clinics.

*AEFI, adverse event following immunization; HCW, healthcare worker; MCH, maternal and child health; M&E, monitoring and evaluation.

Zambia could reach its targeted 70% eligible population coverage in November 2023, ahead of other countries in Africa (August 2024) (Appendix Table 7).

For Africa to reach the 2022 Africa Union targets and adequately protect the continent from subsequent COVID-19 waves, substantially accelerated COVID-19 vaccination delivery is needed (*4*). Moreover, rapidly reaching high vaccination coverage in Africa can help reduce the risk for emergence of new variants that can rapidly spread globally (*6*,*7*). These data suggest that strong government leadership can leverage a robust HIV program, civil society, and integrated HIV donor support from the US President's Emergency Plan for AIDS Relief and others to rapidly increase COVID-19 vaccine uptake. Zambia`s example could hasten similar adaptations in other Africa countries.

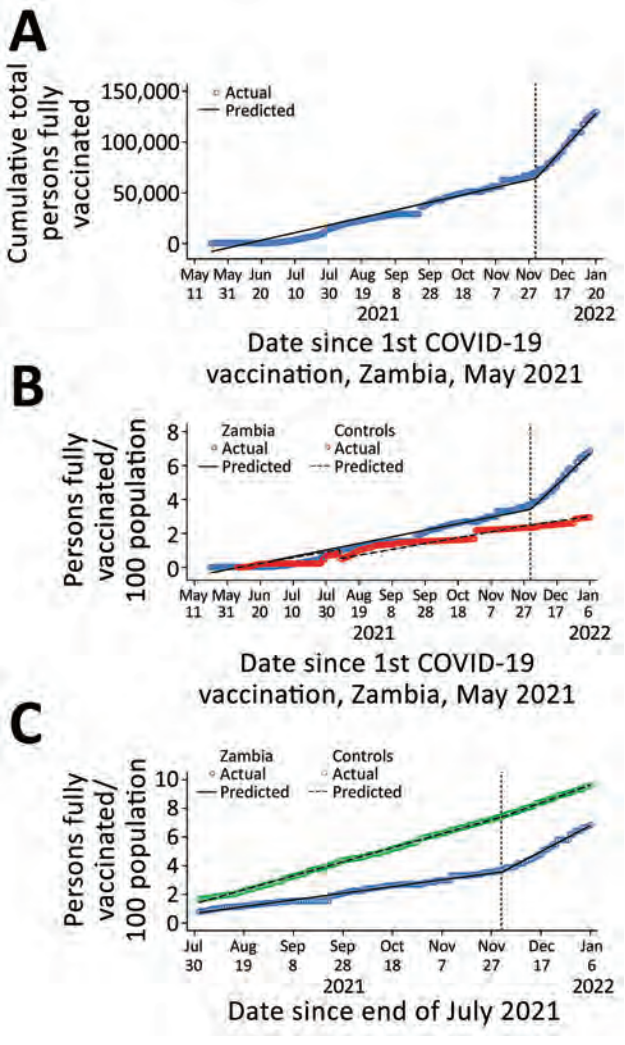

Figure. Time series of COVID-19 vaccination in Zambia, April 2021 to February 2022. A) Before and after the December Campaign. B) Compared with 2 neighboring countries with similar pre-intervention vaccination coverage trajectories and similar vaccine availability. C) Compared with the average for all 55 Africa Union member states. Prais-Winsten and Cochrane-Orcutt regression, lag(1). Vertical dashed line indicates start of Joint HIV Awareness and COVID-19 Vaccination Drive, December 1, 2021.

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Adopting World Health Organization Multimodal Infection Prevention and Control Strategies to Respond to COVID-19, Kenya

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The World Health Organization advocates a multimodal approach to improving infection prevention and control (IPC) measures, which Kenya adopted in response to the COVID-19 pandemic. The Kenya Ministry of Health formed a national IPC committee for policy and technical leadership, coordination, communication, and training. During March–November 2020, a total of 69,892 of 121,500 (57.5%) healthcare workers were trained on IPC. Facility readiness assessments were conducted in 777 health facilities using a standard tool assessing 16 domains. A mean score was calculated for each domain across all facilities. Only 3 domains met the minimum threshold of 80%. The Ministry of Health maintained a national list of all laboratory-confirmed SARS-CoV-2 infections. By December 2020, a total of 3,039 healthcare workers were confirmed to be SARS-CoV-2–positive, an infection rate (56/100,000 workers) 12 times higher than in the general population. Facility assessments and healthcare workers' infection data provided information to guide IPC improvements.

COVID-19, caused by SARS-CoV-2, emerged in China in December 2019 and quickly spread globally (*1*,*2*). Within a year, >79.2 million persons were infected and >1.7 million persons had died (*3*). In Kenya, the first case was confirmed in March 2020; by December 2020, a total of 96,458 cases and 1,670 deaths had occurred (*4*).

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In response to the pandemic the World Health Organization (WHO) released infection prevention and control (IPC) guidelines in March 2020 for preventing SARS-CoV-2 transmission during healthcare (*5*). WHO recommended that each health facility have a dedicated trained team or IPC focal person to implement basic IPC measures for protection of patients and healthcare workers (*6*).

In 2017, WHO recommended an evidence-based multimodal IPC strategy to address leadership, resources, and training gaps for more effective IPC programs (*7*,*8*). This strategy uses a combination of approaches to achieve the desired behavior change and quality improvement (*6*). The strategy has 5 elements: 1) system change to enable IPC practices; 2) training and education; 3) monitoring and feedback; 4) reminders and communications; and 5) culture of safety.

In response to COVID-19, the Kenya Ministry of Health (MOH) put in place a national COVID-19 task force with several technical committees, one of which was IPC. The MOH tasked the IPC committee with developing strategies to prevent and control the spread of COVID-19 in health facilities and among the public. To respond quickly, the committee decided to build on an existing IPC program within the MOH's Division of Patient and Healthcare Worker Safety. This division oversaw the development and dissemination of IPC-related guidelines, policies, and strategic plans; implementation of IPC training and surveillance activities; and formation of IPC committees (*9*). Kenya has 47 subnational governments (counties) with a structure mirroring the

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national level. The national IPC program supported the county programs for activity implementation. We describe how Kenya revised national and county IPC programs to adopt WHO's multimodal strategies to respond to the COVID-19 pandemic and the outcomes of these efforts in the first 9 months of the pandemic (March–December 2020).

Methods

Multimodal Interventions

1. Enabling Environment

The MOH established the IPC committee in March 2020 to provide leadership in IPC implementation across all levels of the healthcare system. The committee met weekly, coordinated work with other COVID-19 committees, and reported to the National Task Force. It advocated that the government and private sector commit resources to create an environment conducive to IPC interventions, including infrastructure improvements, equipment, supplies and staffing.

2. Education and Training

The IPC committee developed a COVID-19 training curriculum for healthcare workers from existing IPC training materials and led a national training-of-trainers (ToT) during March–April 2020. The national trainers trained county trainers who then cascaded the information to health facilities. The training consisted of a comprehensive 3-day practical workshop and an abbreviated 1-day training. Health facilities in areas with high infection risk were prioritized for the 3-day trainings. Training topics included introduction to IPC; standard and additional precautions; donning and doffing of personal protective equipment (PPE); waste management; overview of COVID-19, screening, and management; specimen collection, packaging, and transportation; and surveillance of COVID-19. To avoid group gatherings, the committee implemented biweekly IPC webinars on topics identified as facility gaps. The webinars incorporated subject matter experts, panel discussions, and county presentations to share experiences.

3. Guidelines, Reminders, and Communication

Localized Kenya COVID-19 guidelines, protocols, and information, education, and communication (IEC) materials were developed beginning in March 2020 based on WHO and US Centers for Disease Control and Prevention (CDC) guidelines with an emphasis on standard and respiratory precautions. The committee developed minimum requirements for IPC in COVID-19 quarantine and isolation centers and public health advisories to minimize community transmission.

4. Surveillance, Monitoring, and Feedback

The CDC Facility Readiness Assessment for COVID-19: IPC Considerations in Non-US Healthcare Settings checklist was adopted and modified to fit the Kenya context (*10*). The modified tool had 16 domains, each with a set of questions, possible responses (Yes/No/Not applicable), the assessor's guide, and a comments section. The questions were scored through healthcare worker interviews or observations at the facility. The domains were coordination, communication/reporting, written IPC/COVID-19 guidelines, hand hygiene supplies/facilities, general IPC supplies, critical IPC supplies, IPC training, screening and triage, COVID-19 patients' care, preparing for a surge, monitoring healthcare workers, environmental cleaning/disinfection, linen management, handling of COVID-19 cadavers, appropriate mask use, and appropriate glove use. Each domain had a maximum possible score of 100% (Table 1). The team calculated a mean score for each domain across all facilities and set a minimum threshold of 80%. County IPC coordinators were oriented to the tool by the national team and conducted assessments in 777 facilities across the country during July–September 2020. Based on facility-level findings, a work plan was made to address gaps. The work plans were specific: IPC gap identified, activities to address the gap, responsible person, and timeline to close the gap. A national public health emergency operations center (PHEOC) was activated to respond to COVID-19. Data for infected persons from the 43 government-approved SARS-CoV-2 testing laboratories across the country were sent to the PHEOC, which maintained a line list with basic demographic information.

5. Culture Change

To ensure the culture of safety was rapidly institutionalized, members of the IPC committee sought goodwill from government leaders. Committee members were asked to be agents of change by observing and demonstrating good IPC practices. Messages about COVID-19 were shared through electronic and print media. Healthcare facility administrators were asked to support implementation of IPC measures at the facility level and enhance a culture of safety.

Table 1. Infection prevention and control structures activated to respond to COVID-19 at various health system levels, Kenya, 2020*

Level	Structure	Membership and meeting frequency	Function
National	National COVID-19 Response coordination task force	Director general of health, department heads at MOH, WHO, CDC, and other key development partners. Met weekly during March–December 2020	Enhance coordination and leadership for COVID-19 prevention and control
	National COVID-19 IPC committee	Head of patient and healthcare worker unit and IPC team, WHO, CDC, Key IPC partners. Met weekly March–June 2020 then biweekly until December 2020	National coordination and guidance of the IPC interventions, policy and technical leadership on IPC issues
	National COVID-19 training and capacity building committee	MOH and key training partners. Met weekly March–June 2020 then biweekly until December 2020	National coordination of all COVID-19–related trainings and other education initiatives
	Resource mobilization committee	MOH and private sector players supporting PPE and IPC supplies. Met when needed	Mobilizing resources necessary for IPC measures (PPE, IPC supplies)
County	County COVID-19 Response team	County minister of health, county health director, departmental heads. Met weekly March–December 2020	Overall coordination of COVID-19 response at the county level
	County COVID-19 IPC committee	County IPC coordinator, departmental heads. Met monthly or as needed	Coordination of IPC activities in the county
Facility	Facility-level IPC committee	Multidisciplinary team. Met monthly or as needed	Implementation of COVID-19 IPC measures at facility level

*CDC, Centers for Disease Control and Prevention; IPC, infection prevention and control; MOH, Ministry of Health; PPE, personal protective equipment; WHO, World Health Organization.

Results

Outcomes of Implementing Multimodal Approaches

1. Enabling Environment

The national committee coordinated with county-level IPC committees to support the COVID-19 IPC response. Where no IPC committee existed, a new one was formed (Table 1). The private sector procured and fast-tracked local production of IPC supplies including PPE, hand hygiene supplies, and disinfectants. Through the Equity Group Foundation, 109 local manufacturers were trained to make PPE (*11*). The Kenya Medical Supplies Agency fast-tracked procurement of PPEs and other IPC supplies for distribution to facilities nationally. Separately, counties renovated and modified facility infrastructure to improve ventilation and create additional hand hygiene stations, triage stations, and patient waiting bays to avoid overcrowding and protect healthcare workers. In some facilities, tents were purchased to use as patient waiting bays and temporary holding and isolation areas to ensure adequate distance. The IPC committees at the facility, county, and national levels provided weekly updates on infection rates and emerging gaps to leadership, who in turn committed resources to address them.

2. Education and Training

During March–November 2020, a total of 69,892 (57.5%) of the estimated 121,500 healthcare workers in Kenya at the time were trained on IPC. Of these, 25,999 (37.2%) received the 3-day training, and 43,893 (62.8%) received the 1-day training. COVID-19 biosafety training was provided to 100 laboratory staff from 10 national molecular diagnostic laboratories and 2,058 staff members from county laboratories in preparation for SARS-CoV-2 testing. The teams conducted 10 IPC webinars, reaching an average of 200 participants per session.

3. Guidelines, Reminders, and Communication

During March–June 2020, the IPC committee developed or provided input in developing these COVID-19–related guidelines targeting healthcare workers: IPC considerations for healthcare settings, setting up quarantine and isolation centers, health and safety in the workplace, waste management, home-based care, safe handling of human remains, case management, and rational use of PPE. Posters, banners, and brochures with simplified information were developed in English and translated to local languages targeting the public. These materials consisted of information on understanding COVID-19, handwashing, cough etiquette, and home-based care. Public health advisories on proper use of masks and gloves were developed. Materials targeting healthcare workers were hosted on the MOH website and shared through training sessions (*12*). According to health facility assessments, only 52.6% of the facilities had all the documents by September 2020. Materials targeting the public were disseminated through print and electronic media.

4. Surveillance, Monitoring, and Feedback

According to the health facility assessment, only 3 domains met the minimum threshold mean score

of 80% across all facilities. The 3 domains included communication and reporting (80%), availability of hand hygiene supplies and facilities (81%), and appropriate mask use (89%) (Figure 1). The mean score across all domains was 61%; the lowest score was for handling of human remains (22%). The assessments yielded specific recommendations for remediation within each domain (Table 2). By late December 2020, PHEOC data indicated that 96,421 persons, including 3,039 healthcare workers, had laboratory-confirmed COVID-19 (Figure 2). Infections among healthcare workers accounted for 3.2% of all SARS-CoV-2 infections in Kenya. Compared with the general population (4.8/100,000 persons), the infection rate in healthcare workers (56/100,000 workers) was ≈12 times higher. Infections in healthcare workers mirrored the peaks in the general population during the June–August and October–December 2020 surge periods (Figure 2).

5. Culture Change

To ensure consistency in COVID-19 IPC practices, senior leadership in government complied with COVID-19 protocols. Top MOH officials provided daily COVID-19 updates on number of infections and fatalities and continually emphasized key prevention measures. Across electronic and print media,

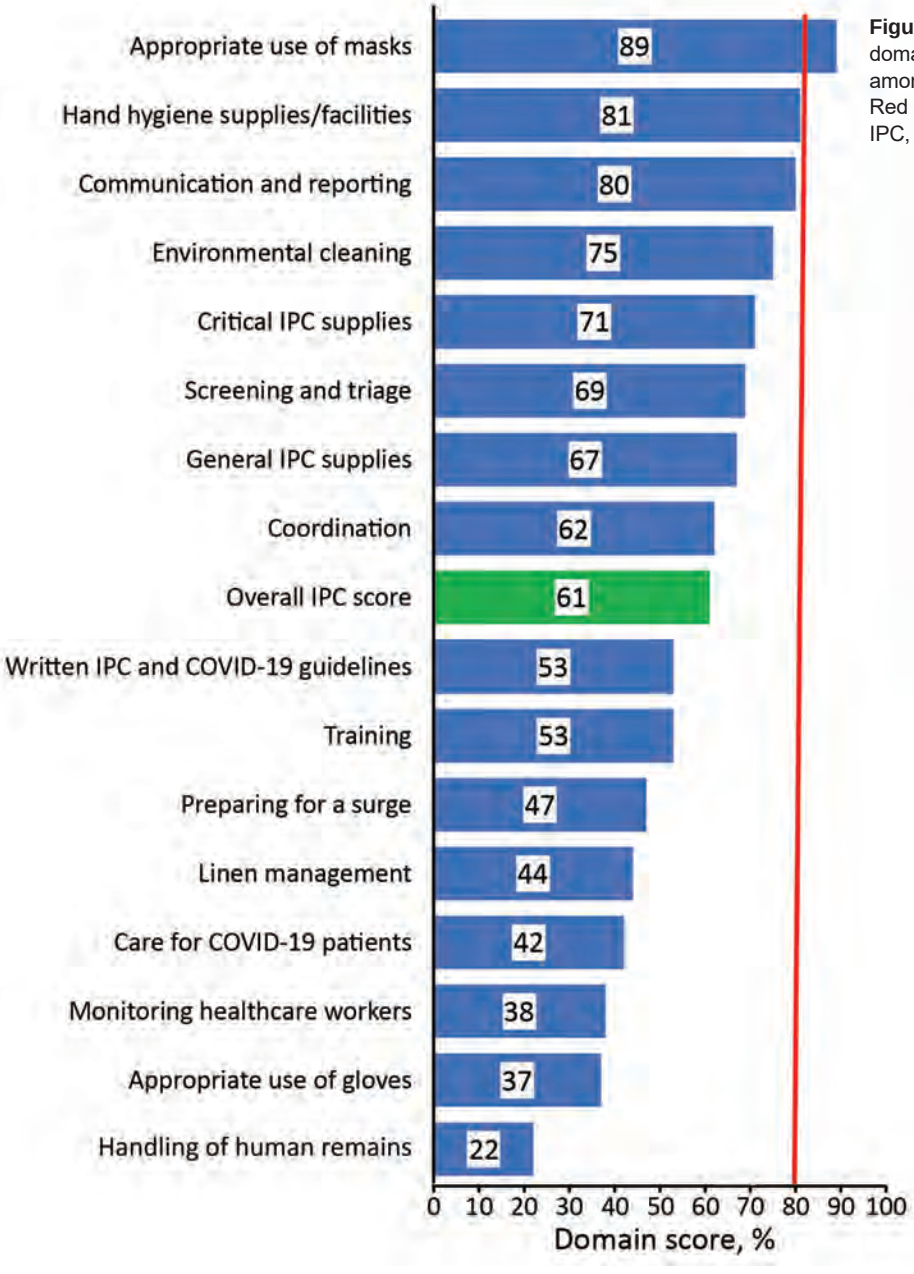

Figure 1. Assessment scores across various domains for IPC readiness assessment among 777 health facilities, Kenya, 2020. Red line indicates optimal score of 80%. IPC, infection prevention and control.

Table 2. Assessment scores and remediation activities recommended for each COVID-19–related domain assessed in 777 health facilities, Kenya, 2020*

Domain	Score, %	Recommended remedial actions
Appropriate use of face masks	89	Conduct PPE training, provide IEC materials, provide a variety of masks, conduct IPC audits
Hand hygiene	81	Conduct HH training, provide IEC materials, provide HH supplies (soap and alcohol-based hand rub) and renovate/install HH facilities
Communication and reporting	80	Provide IPC/COVID-19 guidelines, develop patient referral algorithms and referral contacts
Cleaning and disinfection	75	Provide disinfectants and other supplies, develop SOPs, and conduct routine audits
Critical supplies	71	Estimate supply needs, train on inventory management, appoint a supply-management lead
Screening and triage	69	Create clear signage, mark patient sitting areas, and provide PPE, screening tools, and data collection tools to the triage nurse
Supplies	67	Estimate supply needs, train on inventory management, appoint a supply-management lead
Coordination	62	Activate IPC committee or appoint IPC focal person, establish a COVID-19 response team
IPC and COVID-19 guidelines	53	Provide updated IPC/COVID-19 guideline and orient healthcare workers on the same
Training	53	Provide in-person and virtual training, webinars, and facility education sessions
Preparing for a surge	47	Define facility capacity, create temporary isolation centers (e.g. tents) and link with home-based care
Management of linen	44	Provide SOPs on linen management, provide supplies, separate isolation linen from others
Care COVID-19 patients	42	Improve patient flow, create donning/doffing areas, develop SOPs on case management/IPC and airborne precautions for aerosol-generating activities
Monitoring healthcare workers	38	Provide healthcare worker risk assessment tools, screening, and monitoring of exposed workers
Appropriate use of gloves	37	Improve training, IEC materials, availability of gloves and HH supplies
Handling of human remains	22	SOPs for body management, training of morticians and those handling bodies

*HH, hand hygiene; IEC, information, education and communication; IPC, infection prevention and control; PPE, personal protective equipment; SOP, standard operating procedure.

healthcare and political leaders were seen wearing masks, keeping physical distance, and practicing hand hygiene. Most meetings were held virtually, and training events were conducted in open-air environments for good ventilation. In health facilities, patients were required to wear a mask to receive service.

Discussion

Kenya's adoption of WHO multimodal strategies in response to the COVID-19 pandemic required a pragmatic approach and appropriate leadership in coordinating multiple stakeholders. Kenya enhanced the IPC structure across all levels of government and health facilities, which led to a standardized approach. This approach ensured that, in the face of COVID-19, healthcare workers felt protected, thus improving worker confidence and morale (*13*). The multimodal approach was shown to improve hand hygiene and other IPC practices in a cross-sectional survey of 17 hospitals in Greece (*14*). Similar sustainable improvements in hand hygiene were documented by Allegranzi et al. (*15*). Wang et al. (*16*) demonstrated that the COVID-19 pandemic highlighted the crucial role a structured IPC program plays in disease outbreak control. In 2020, WHO supported Ukraine to apply the multimodal approach in response to COVID-19 at the facility and national level, resulting in overall improvement of the IPC program (*17*).

Using standardized tools to assess health facilities enabled officials to identify gaps in IPC policy and guidelines implementation and create specific recommendations for remediation. Immediate targeted interventions were implemented at the facility level on the basis of the work plan. In addition, refresher trainings and national webinars were carried out on the basis of cross-cutting gaps. The WHO recommends use of IPC facility assessments to provide feedback and make IPC program improvements (*18*). It recommends implementing an assessment framework using a tool to assess 8 IPC core components that scores the IPC measures at the facility as inadequate, basic, intermediate, and advanced. Follow-up assessments should be conducted quarterly, semiannually, or annually. Although the baseline assessment mean score in Kenya of 61% was lower than the score of 86% documented in Germany, the difference could be accounted for by timing, setting, and tools used (*19*). Sachdeva et al. (*20*) showed varied compliance to IPC measures among 30 facilities in India. The assessment in Kenya demonstrated that the domains of hand hygiene and mask use scored the highest. This finding is likely because the 2 methods were being emphasized as the key COVID-19 prevention measures. Handling of human remains scored the lowest because no healthcare worker training had been held on that

subject. Although risk for SARS-CoV-2 transmission through a dead body is minimal, standard precautions should be practiced and education offered to allay fears (*21*–*24*). Other domains that scored low included appropriate use of gloves, monitoring of healthcare workers, and care for COVID-19 patients, which might reflect a knowledge gap because of low access to training, lack of supportive guidance documents, and a shortage of gloves at the time.

In 2020, healthcare workers made up 3.2% of all SARS-CoV-2 infections in Kenya, which was lower than the global percentage of 3.9% (May 2020) and the percentages in Nigeria (6%), Italy (10%), and Spain (15%) (*25*–*29*) but higher than that reported in Singapore (1.7%) (*30*). The infection rate among HCWs in Kenya was 12 times higher than the general population and higher than the 5.5 times higher rate documented in Ontario, Canada (K.L. Shwartz et al., unpub. data, https://www.medrxiv.org/content/10.1101/2020.06.12.20129619v2), an indication that healthcare workers remained at higher risk for infection. Despite the high number of healthcare workers trained in early 2020, the infection rate remained high. Almost two thirds of the trainings were held for 1 day, which was inadequate to cover some practical topics, such as donning and doffing of PPE. Use of PPE in this period was inadequate or improper because of global shortages. Infrastructure renovations to address overcrowding of patients, ventilation, and hand hygiene facilities might have been slow to resolve. Healthcare workers were overstretched and had prolonged exposure to many patients (some of whom were asymptomatic) during the surge periods in June–August and October–December 2020 (Figure 2). Such reasons have been documented in China (*31*). A follow-up case control study was conducted in Kenya to explore reasons for the high infection rate. Preliminary findings indicated that lack of PPE and lack of IPC trainings were risk factors for infection (M. Njeru, unpub. data). In the absence of COVID-19 vaccines in Kenya at the time, other measures to protect healthcare workers were implemented, such as training, provision of appropriate PPE, and active screening and prompt quarantine or isolation of exposed or infected workers.

This review had several limitations. Simultaneously implementing many of the new interventions and obtaining accurate and timely reports from all facilities and counties was difficult during the pandemic. No active surveillance occurred among healthcare workers; only persons with laboratory-confirmed SARS-CoV-2 were included in the national list. Persons who were asymptomatic and not tested were not considered. In addition, although many guidance documents were developed at the national level, only about half had reached the assessed facilities. Time pressures were intense, and many mitigation activities were happening concurrently. Dissemination of all documents in development was not well streamlined. These factors would have

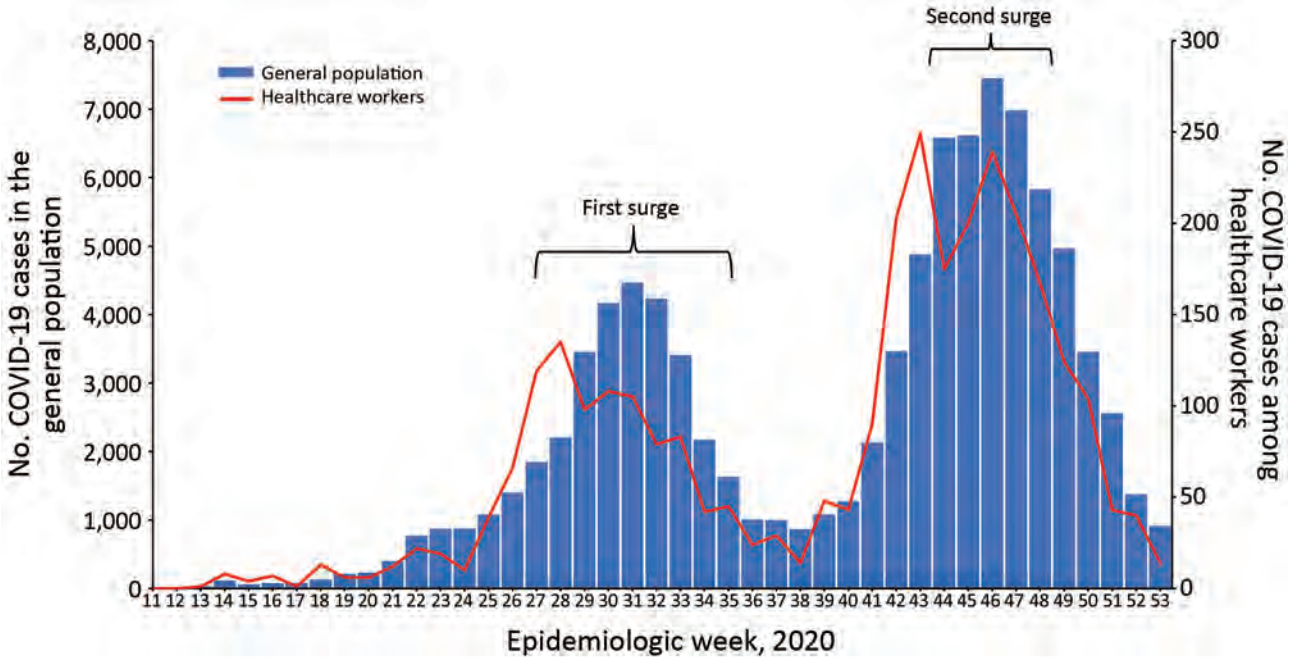

Figure 2. Epidemic curve for COVID-19 in general population and healthcare workers, Kenya, 2020.

delayed adoption of COVID-19 prevention measures at facilities. Despite these limitations, this article provides a broad picture of Kenya's COVID-19 IPC response. While the measures were in response to COVID-19, they likely reduced transmission of influenza and other respiratory viruses, as was shown in the United States, Australia, Chile, and South Africa, as well as a reduction in diarrheal disease as demonstrated in Kenya (*32*,*33*).

Although some challenges occurred, the IPC multimodal approach was a practical response to the pandemic in Kenya. Consideration can be made for adoption of this approach based on a country's context. Systems to monitor the effects of implementation and address emerging gaps should be put in place. This approach might reduce the effect of COVID-19 by protecting healthcare workers and patients in current and future pandemics.

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Infection Prevention and Control Initiatives to Prevent Healthcare-Associated Transmission of SARS-CoV-2, East Africa

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The coronavirus disease pandemic has highlighted the need to establish and maintain strong infection prevention and control (IPC) practices, not only to prevent healthcare-associated transmission of SARS-CoV-2 to healthcare workers and patients but also to prevent disruptions of essential healthcare services. In East Africa, where basic IPC capacity in healthcare facilities is limited, the US Centers for Disease Control and Prevention (CDC) supported rapid IPC capacity building in healthcare facilities in 4 target countries: Tanzania, Ethiopia, Kenya, and Uganda. CDC supported IPC capacity-building initiatives at the healthcare facility and national levels according to each country's specific needs, priorities, available resources, and existing IPC capacity and systems. In addition, CDC established a multicountry learning network to strengthen hospital level IPC, with an emphasis on peer-to-peer learning. We present an overview of the key strategies used to strengthen IPC in these countries and lessons learned from implementation.

Good infection prevention and control (IPC) practices are critical for preventing of healthcare-associated infections, maintaining essential healthcare services, and protecting patients and healthcare workers (HCWs) (*1*–*3*). Healthcare-associated infections can lead to poor clinical outcomes, more illnesses and deaths, longer hospital stays, and increased healthcare expenditures (*4*,*5*).

In addition to these negative effects of poor IPC practices on routine healthcare delivery, devastating consequences have also been highlighted during infectious disease outbreaks, in which healthcare facilities can serve as amplification points (*6*,*7*). As demonstrated by the COVID-19 pandemic and outbreaks of Ebola virus disease in West Africa and the Democratic Republic of the Congo, healthcare-associated transmission of infectious pathogens can lead to reductions in the healthcare workforce and a decrease in healthcare use because of safety concerns (*8*–*10*).

The COVID-19 pandemic showed gaps in IPC capacity globally and highlighted the need to build and reinforce national-, subnational-, and facility-level IPC programs aimed at protecting HCWs, patients, and visitors and preventing disruptions to essential healthcare services (*11*). Rapid capacity building becomes imperative during outbreaks such as COVID-19. However, building sustainable IPC systems and establishing good IPC practices at the healthcare facility level is a stepwise process

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that requires time and effort through multimodal approaches (*12*). Through platforms such as the United States President's Emergency Plan for AIDS Relief (PEPFAR) and Global Health Security Agenda (GHSA), past US Centers for Disease Control and Prevention (CDC) investments and relationships have supported many countries and healthcare facilities in navigating this process. These efforts aimed to ensure a trained and dedicated IPC workforce that had adequate resources and guidelines to successfully implement IPC programs (*13*).

In East Africa, where basic IPC capacity in healthcare facilities is limited, CDC leveraged existing platforms and built upon ongoing IPC efforts to provide technical assistance and funding support to 4 countries (Kenya, Uganda, Ethiopia, and Tanzania) to strengthen IPC and reduce healthcare-associated transmission of SARS-CoV-2. We present an overview of the strategies CDC used to support IPC capacity building in these 4 countries during the pandemic, as well as lessons learned from implementation.

CDC Contributions

In each country, CDC collaborated with the Ministry of Health and implementing partners to identify IPC gaps and priorities, and to develop tailored work plans to rapidly build capacity in priority areas, expand existing IPC initiatives, and strategically plan and implement COVID-19 prevention activities (Table). Different approaches and interventions for IPC strengthening were used across the 4 countries according to their specific needs, priorities, available resources, and existing IPC capacity and systems.

Commonly identified gaps across the 4 countries included limited IPC programs at the national, subnational, and healthcare facility levels; limited IPC knowledge and practices among HCWs; shortages of personal protective equipment (PPE); and inadequate infrastructure (e.g., sanitation and hygiene facilities, ventilation). Planned and implemented activities aligned with CDC's operational considerations to prevent COVID-19 transmission in non-US healthcare settings and World Health Organization core components. The core components provide evidence-based recommendations on strengthening IPC programs and practices at the national, subnational, and facility levels (*12*–*14*). To further enhance IPC capacity building across the region, CDC supported establishing a multicountry learning network to cultivate hospital-level IPC capacity building, with an emphasis on peer-to-peer learning.

Supporting National IPC Programs

To properly strengthen and sustain IPC across a healthcare system, national IPC governance structures are needed with the authority, expertise, and resources to oversee IPC programs, strategic plans, policies, and reporting mechanisms (*15*). On the basis of the strengths and gaps of each country, CDC supported capacity building at the national level by helping to establish and strengthen the national IPC unit, developing national IPC strategic plans, policies, and COVID-19 specific IPC guidelines, and creating an IPC monitoring and evaluation framework.

Supporting National IPC Units

Personnel with dedicated IPC training, time, and resources are key to ensuring prioritization of IPC and sustained improvements. Before the COVID-19 pandemic, all 4 countries in East Africa had a designated IPC focal person at their respective Ministries of Health. Only Kenya and Tanzania had formal, well-established national IPC units with dedicated staff, budgets, and strategic action plans. To rapidly strengthen national capacity to address the COVID-19 pandemic and implement national IPC priorities, CDC provided resources for the Ministries of Health in Uganda and Ethiopia to hire staff for national IPC units.

Table. Key infection prevention and control initiatives supported by CDC in response to the COVID-19 pandemic by country, 2020–2021*

	National level			Healthcare facility level			
Country	Develop national IPC unit	Develop guideline, policy, strategic plan	Develop monitoring and evaluation framework	Establish and develop IPC focal persons and committees	Develop COVID-19–specific IPC guidance and interventions	HCW training and mentorships	Assess and monitor IPC practices
Kenya	Supported existing IPC unit	X	–	X	X	X	X
Uganda	X	X	X	X	X	X	X
Ethiopia	X	X	–	X	X	X	X
Tanzania	Supported existing IPC unit	X	X	X	X	X	X

*Information indicates activities supported by CDC during COVID-19 responses. This list is not comprehensive of IPC activities and resources available in each respective country. CDC, Centers for Disease Control and Prevention; IPC, infection prevention and control; X, CDC supported the respective activity in response to the COVID-19 pandemic; –, CDC did not support the respective activity as part of the response to the COVID-19 pandemic.

Development of Guidelines, Policies, and Strategic Plans

IPC guidelines establish standards for local adherence and guide healthcare facility leadership and HCWs in proper implementation of routine activities and strategic initiatives. National IPC policies and strategic plans are essential because they ensure alignment of national priorities and implementation efforts (*12*). National IPC guidelines were in place in each of the 4 countries before the pandemic. CDC investments and initiatives in Kenya before the pandemic were instrumental in the development of guidelines, national IPC strategic plans, and policies.

As part of IPC capacity building efforts in response to the COVID-19 pandemic, CDC supported development of the first national IPC strategic plan and policy documents for Ethiopia, which was linked to establishment of the national IPC unit. Similarly, technical assistance was provided to Tanzania in developing a 5-year plan for strengthening IPC. In Uganda, CDC is supporting the development of a national IPC strategic plan.

Regarding IPC guidelines, CDC supported development of national standard operating procedures for COVID-19 specific case management and IPC in Tanzania and is assisting with upcoming revisions of national guidelines for Uganda. Moreover, CDC supported Uganda in drafting national guidelines for managing COVID-19, which included content on HCW monitoring and management, screening and triage, rational use of PPE, waste management, and environmental cleaning and disinfection.

Monitoring and Evaluation

Monitoring IPC indicators at the national and healthcare facility level is essential to understanding whether IPC standards and priorities are being met, identifying gaps, and informing necessary improvements and interventions (*16*,*17*). CDC supported the national IPC unit in Tanzania in development of a national IPC monitoring and evaluation framework and protocol, including key IPC performance indicators for central reporting, which involved collaborating with national and international partners. Follow-up activities will include disseminating the monitoring and evaluation framework to healthcare facilities across Tanzania and orienting key HCWs to its contents and reporting methods. Likewise, in Uganda, CDC is supporting the development of an IPC monitoring and evaluation framework with key performance indicators to strengthen IPC program implementation, monitoring, and evaluation in the country.

Facility-Based IPC Initiatives

CDC collaborated with Ministries of Health and implementing partners and used the PEPFAR platform to rapidly build capacity in healthcare facilities across the 4 supported countries. Although initiatives aimed to construct and strengthen facility-level IPC programs, key areas of focus to prevent healthcare-associated SARS-CoV-2 transmission included establishing appropriate screening and triage of patients upon initial encounter at a healthcare facility to ensure early identification and isolation of patients with suspected COVID-19, limiting the entry of HCWs and visitors with suspected COVID-19, and identifying and isolating inpatients with suspected COVID-19. However, in Tanzania, in alignment with Ministry of Health priorities, efforts were focused on strengthening basic IPC and preventing all healthcare-associated infections. Efforts also included environmental controls to minimize crowding and ensure adequate ventilation in patient care and waiting areas.

Overall, Ethiopia has ≈4,500 public hospitals and health centers and 16,000 health posts; Tanzania has ≈9,800 healthcare facilities, including dispensaries (*18*); Kenya has ≈14,000 facilities (*19*); and Uganda has ≈7,900 facilities. In each country, healthcare facilities were targeted to receive technical assistance and implementation support: 16 in Ethiopia, 73 in Tanzania, 238 in Kenya, and >2,000 in Uganda received IPC mentorship. The rationale and methods for selecting facilities to support varied across countries. Facilities were prioritized on the basis of factors such as geographic location, patient volume, baseline capacity as determined by readiness assessments, existing relationships with implementing partners, or whether facilities were receiving ongoing CDC investments through existing platforms (e.g., PEPFAR). All countries ensured facilities targeted for support from CDC did not receive duplicative support from other nongovernmental organizations.

IPC Focal Persons and Committees

CDC efforts aimed to ensure that healthcare facilities had functional IPC focal persons and committees by building the capacity of each individual to lead and oversee IPC activities in their respective facilities. In Uganda, implementing partners supported capacity building for existing IPC focal persons and establishment of new IPC focal persons and committees at facilities across 59 of 145 districts in Uganda. The Ministry of Health in Tanzania, through collaborations between CDC and implementing partners, improved existing IPC committees

and focal persons in 73 healthcare facilities across 7 of the 31 regions in Tanzania by cascading a train-the-trainer strategy extending from national-level IPC experts to regional and district teams to facility-based IPC focal persons and committees. In Ethiopia, where CDC and implementing partners focused heavily on COVID-19–specific interventions, baseline assessments found that, in the 16 supported healthcare facilities, IPC focal persons were in place but IPC committees, if they existed, were often inoperative. Likewise, in Kenya, IPC facility readiness assessments revealed that many county-level IPC focal persons were not functional. To address these gaps, training and mentorship for IPC focal persons and committees was conducted. In Ethiopia, checklist tools were also created for focal persons and committee members to support proper performance of routine tasks.

Development and Implementation of COVID-19–Specific IPC Guidance and Processes

In the context of novel pathogens, developing targeted IPC guidance and protocols for implementation is crucial to communicating recommended IPC standards to frontline HCWs, guiding IPC practices, and ensuring safe delivery of essential healthcare services. Although guidance on COVID-19 prevention was made available in these countries, many healthcare facilities lacked standard operating procedures for implementation of COVID-19–specific IPC activities. In Ethiopia, CDC and implementing partners developed standard operating procedures and tools to guide facilities in conducting screening and triage for patients and visitors, HCW screening and monitoring, and identifying and cohorting inpatients. As of July 2021, all 16 supported healthcare facilities were conducting COVID-19 screenings for arriving patients and visitors. In addition, in the 9 facilities with inpatient services, patients with suspected COVID-19 were isolated. In Kenya, systems for screening, triage, and patient isolation were implemented in 238 healthcare facilities across 13 priority regions through quality improvement processes. To improve early recognition and isolation of inpatients and HCWs who had suspected COVID-19, Kenya prioritized establishing inpatient surveillance and HCW monitoring in a smaller cohort of facilities. As a result, a system for inpatient surveillance was started at 10 hospitals.

Implementing partners and CDC staff in Ethiopia spearheaded facility mapping to develop schematics of existing patient and visitor flow. Information gathered was used to reengineer the internal patient and visitor flow, incorporate screening stations for patients and visitors, separate screening stations for HCWs, and establish waiting and testing stations for persons with respiratory symptoms or infections. Similar activities were conducted in Kenya and Uganda.

Last, in Ethiopia, efforts also focused on reinforcing appropriate hand hygiene practices. These practices were addressed by increasing hand hygiene stations throughout facilities and using quality improvement measures to bolster compliance.

HCW Training and Mentorship

Training and mentorship were core methods used in educating HCWs and ensuring proper adherence to IPC guidance and recommended practices. In Kenya, implementing partners provided technical assistance to frontline HCWs and focused on effectively establishing standard, droplet, and airborne precautions. In addition to these COVID-19 prevention activities, training addressed rational use of PPE by using videos and demonstrations on donning and doffing. Furthermore, facility-level mentorship focused on establishing an appropriate triage process, ensuring adherence to recommended isolation practices, and instituting HCW and inpatient monitoring for COVID-19. Finally, biweekly IPC webinars were established to build IPC capacity at the facility level.

In Ethiopia, implementing partners trained HCWs on standard and transmission-based precautions, as well as COVID-19–specific IPC interventions. More than 200 HCWs received comprehensive IPC training for COVID-19 and >3,200 ancillary staff received job-specific IPC training for COVID-19. To promote good mentorship and supportive supervision practices, the regional health bureaus developed tools and checklists for mentors. Emphasis was placed on the need for performance indicators to guide improvement plans.

In Uganda, leveraging a mentorship approach developed to build IPC capacity during the 2018–2020 Ebola virus disease outbreak in the Democratic Republic of the Congo, CDC supported implementing partners in providing mentorship to >2,000 healthcare facilities across 59 districts. Mentorship focused on addressing COVID-19–specific IPC, including screening, triage, and isolation; standard and transmission-based precautions; risk assessment; and work plan development. CDC provided technical support for evaluating the IPC mentorship program; the evaluation results will strengthen the approach and inform next steps of the IPC mentorship program to sustain improvements and address lingering gaps.

In Tanzania, IPC focal persons trained by regional and district teams mentored and cascaded general IPC training to >700 frontline HCWs. Trainings were focused on screening and triage for all infectious diseases and general IPC topics, such as standard-based and transmission-based precautions, medical device disinfection and sterilization, waste management, prevention and surveillance of key healthcare-associated infections, and antimicrobial drug resistance. After those comprehensive trainings, facility-based IPC focal persons provided daily IPC mentorship to frontline HCWs during routine job-related activities.

Assessment and Monitoring of IPC Practices and Activities

IPC assessments to identify gaps and determine priorities are essential to guide IPC interventions and inform the development of tailored workplans. Equally necessary is the routine monitoring of IPC practices to ensure effectiveness and guide needed adjustments to IPC improvement strategies.

In Ethiopia, baseline and monthly IPC assessments determined the level of IPC readiness among CDC-supported healthcare facilities. The assessment tool was used to collect data on core elements aimed at preventing healthcare-associated SARS-CoV-2 transmission. Initial results, in December 2020, showed that most facilities lacked procedures, training, designated spaces, supplies, and equipment for patient screening and triage, HCW screening, and inpatient isolation and cohorting. Among 11 facilities, only 3 facilities had initiated patient screening and triage, and none had started screening HCWs for COVID-19. These findings informed the development of site-specific workplans, which were put in place by facility-based IPC focal persons in collaboration with implementing partners. HCWs received targeted COVID-19 training; close mentorship and support for IPC implementation; and the necessary supplies, equipment, and space reorganization for compliance with interventions for preventing SARS-CoV-2 transmission in the healthcare facilities. After 1 year, all facilities had patient screening and triage systems in use and were actively conducting COVID-19 screening for HCWs. Likewise, facilities with inpatient services had started inpatient isolation and cohorting procedures.

CDC supported the completion of comprehensive IPC assessments in targeted healthcare facilities in Tanzania by using the nationally approved Standards-Based Management and Recognition IPC assessment tool. IPC assessment results are fed back to the national level for review to guide IPC capacity building decisions and efforts at the national level.

In Uganda, CDC supported development of a facility-level IPC assessment tool that was used to monitor IPC improvements across facilities in which IPC mentorships were conducted. Data collected were analyzed to inform ongoing IPC programming.

A national healthcare facility assessment for COVID-19 IPC was conducted rapidly in all 47 counties in Kenya by using mobile applications, and results were used for rapid planning and resource mobilization. A triage monitoring checklist, developed by CDC, was used to audit and collect data on the screening and triage activities in the 238 supported healthcare facilities. With CDC and implementing partner support, healthcare facilities targeted in Kenya also focused efforts on monitoring and ensuring the appropriate use of PPE, with specific attention to mask use during healthcare delivery.

East Africa IPC Network

The East Africa Infection Prevention and Control Network establishes a regional IPC Community of Practice; supports training, capacity building, knowledge sharing and joint learning; and implements quality improvement projects. The main goal of this initiative is to reduce the incidence of COVID-19 and healthcare-associated infections by improving compliance with IPC standards at participating hospitals. The network comprises 22 hospitals across the 4 countries: Ethiopia (5 hospitals), Kenya (6 hospitals), Tanzania (5 hospitals), and Uganda (6 hospitals). The Ministry of Health of each country, the International Center for AIDS Care and Treatment Programs at Columbia University, and CDC worked together to select participating hospitals.

The East Africa Infection Prevention and Control Network learning activities include weekly case-based learning sessions, monthly webinars, and trainings on quality improvement methods and science. Activities focus on professional development for facility IPC focal persons who receive direct, in-person supportive supervision from local IPC mentors. This hands-on support enables an exchange of best practices; skills building; innovation; and rapid dissemination of tools, case studies, and implementation strategies. Moreover, a regional IPC advisor provides oversight and support to all 4 countries. Topics covered in learning sessions, webinars, one-on-one mentorship, and supplemental trainings are prioritized on the basis of results from IPC focal person

self-assessments and facility IPC assessments. The network also supports a moderated Telegram group (instant messaging communication platform) to share documents and resources, conduct polling, and connect IPC focal persons across the region with one another to improve communication.

Challenges to Improving IPC and Lessons Learned

Many challenges were encountered in working to improve IPC in these complex settings during the COVID-19 pandemic. First, countries had varying degrees of established national-, subnational-, and facility-level IPC programs, and existing surveillance and prevention activities needed strengthening. However, having an infrastructure of dedicated staff was still critical to quickly ramping up in the face of a large pandemic. Ensuring good coordination and communication between Ministries of Health, implementing partners, and frontline HCWs and facilities was critical. Continued support of these structures will be essential as the pandemic evolves and for emerging threats to healthcare delivery. Moreover, prioritizing IPC at the national level requires commitment from leadership and resource allocation to ensure sustainable capacity building over time.

The global shortage of PPE presented an additional challenge to healthcare facilities because most facilities did not have a reliable PPE supply chain or system to monitor PPE use and stock. There is a need to improve the international and national supply chains for PPE, implement systems for monitoring PPE use and stock, and ensure correct and rational use of PPE by HCWs.

Although lack of PPE was a major IPC gap, provision of PPE alone was not enough to improve IPC practices. Standardized IPC protocols were often lacking and, even when in place, adherence was limited. Frontline HCWs had limited IPC knowledge, which necessitated a heavy emphasis on training and mentorship. However, onsite support to healthcare facilities and HCWs was challenged by COVID-19 restrictions. Much of the communication took place through virtual platforms, but internet connections were not always reliable and interfered with the ability to provide remote technical assistance. As access to technology improves, so will opportunities for online education, virtual technical assistance, and even remote evaluations of IPC at healthcare facilities.

Surveillance for COVID-19 among HCWs and patients was challenging. Early in the pandemic, HCW monitoring for COVID-19 was not prioritized. Surveillance for new symptoms of COVID-19 among inpatients also proved difficult because few facilities had a system for routine identification of healthcare-associated infections. Therefore, new surveillance paradigms had to be created and implemented. For example, CDC, in collaboration with in-country partners and Ministries of Health, was able to quickly launch facility-based monitoring tools that are being used to track effect in facilities. Data to ascertain the relevance of these indicators are needed to inform future IPC capacity building strategies and implementation efforts.

Conclusions

In East Africa, the COVID-19 pandemic showed major gaps in healthcare facility IPC that needed to be addressed to preserve the safe delivery of essential healthcare services. Rapidly building IPC capacity emerged as a key priority to stemming the spread of COVID-19, and leveraging existing platforms (e.g., PEPFAR, GHSA) contributed to rapid implementation of IPC interventions. As a result of IPC improvement initiatives, IPC programs were established or strengthened at national and healthcare facility levels; IPC focal persons and committees were put in place and capacitated; IPC guidance, national strategic plans and policies, and monitoring and evaluation frameworks were developed; HCWs received IPC training and mentorship; IPC assessments of healthcare facilities were conducted; and, informed by results of IPC assessments, quality improvement interventions were put into place.

Although these interventions materialized in response to COVID-19, many were based on work started before the pandemic to support long-term, sustainable IPC improvement efforts at the healthcare facility and national level. To reduce routine healthcare-associated infections and avert future outbreaks, interventions implemented to achieve a rapid expansion of IPC and reduce the spread of SARS-CoV-2 in healthcare facilities should be sustained and expanded to reduce transmission of other endemic infectious diseases, including tuberculosis and influenza, and other respiratory and nonrespiratory pathogens. Countries, donors, and implementing partners should build upon programs developed for COVID-19 to improve healthcare safety beyond the pandemic. Although IPC funding might decrease as the pandemic subsides, continued prioritization of IPC by Ministries of Health and national IPC leaders within each country can result in continued progress and momentum with regard to IPC strengthening.

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Effects of COVID-19 Pandemic on Voluntary Medical Male Circumcision Services for HIV Prevention, Sub-Saharan Africa, 2020

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Beginning in March 2020, to reduce COVID-19 transmission, the US President's Emergency Plan for AIDS Relief supporting voluntary medical male circumcision (VMMC) services was delayed in 15 sub-Saharan African countries. We reviewed performance indicators to compare the number of VMMCs performed in 2020 with those performed in previous years. In all countries, the annual number of VMMCs performed decreased 32.5% (from 3,898,960 in 2019 to 2,631,951 in 2020). That reduction is largely attributed to national and local COVID-19 mitigation measures instituted by ministries of health. Overall, 66.7% of the VMMC global annual target was met in 2020, compared with 102.0% in 2019. Countries were not uniformly affected; South Africa achieved only 30.7% of its annual target in 2020, but Rwanda achieved 123.0%. Continued disruption to the VMMC program may lead to reduced circumcision coverage and potentially increased HIV-susceptible populations. Strategies for modifying VMMC services provide lessons for adapting healthcare systems during a global pandemic.

Voluntary medical male circumcision (VMMC, https://www.who.int/teams/global-hiv-hepatitis-and-stis-programmes/hiv/prevention/voluntary-medical-male-circumcision) has reduced HIV acquisition by ≈60% among men who engage in heterosexual sex and is an essential part of the Joint United Nations Program on HIV/AIDS strategy for ending AIDS by 2030 (*1*–*4*). In 2007, the World Health Organization and the Joint United Nations Program on HIV/AIDS recommended that countries in which prevalence of medical male circumcision was low and prevalence of HIV infection was high should be prioritized for VMMC (*5*). Countries originally prioritized were Botswana, Eswatini, Ethiopia, Kenya, Lesotho, Malawi, Mozambique, Namibia, Rwanda, South Africa, Tanzania, Uganda, Zambia, and Zimbabwe; South Sudan established a program in 2018 (*6*). Since the start of the program, the US President's Emergency Plan for AIDS Relief (PEPFAR) has supported most VMMCs performed in prioritized countries (*7*). Most VMMCs are performed through conventional surgical methods, but some countries use device-based methods (*8*). VMMC programs provide a unique opportunity for men to access reproductive and sexual health services, beyond primary care, by providing a package of services that includes voluntary HIV testing, linkage to HIV care and treatment, and other HIV prevention services (*5*,*9*).

During 2008–2020, a total of 26.8 million VMMCs were performed in prioritized countries and were estimated to have averted 340,000 new HIV infections in men. Future population-level benefits are projected

to be larger, including reductions of HIV infection up to 30%–40% in women (*10*,*11*). Timely VMMC among the priority age group, male clients 15–29 years of age, contribute to population-level HIV prevention benefits (*12*). However, depending on the length and severity of COVID-19, those population-level benefits could be affected (*13*).

Starting in March 2020, to minimize COVID-19 transmission risk, national governments instituted mitigation measures that led to the suspension or pausing of VMMC services. VMMC programs were vulnerable to the effects of mitigation measures, given that interventions such as suspending elective medical interventions and closing healthcare facilities directly affected services. Differences in demand for VMMC also resulted from changes in healthcare-seeking behavior; potential clients avoided healthcare settings because of the risk for nosocomial acquisition of disease. In addition, VMMC programs were affected by PEPFAR guidance released in April 2020, which recommended phasing out circumcisions among male clients 10–14 years of age (*14*). This change in guidance was prompted by an increase in reported adverse events among those 10–14 years of age and by modeling estimates demonstrating that the greatest reductions in HIV incidence were achieved by targeting men ≥15 years of age (*15*,*16*). The change in client age can potentially affect circumcision coverage given that, historically, the greatest proportion of VMMC male clients were 10–14 years of age.

Reports of the effects of the COVID-19 pandemic on public health services are limited, particularly in low-resource settings (*17*–*19*). To elucidate the effects of the COVID-19 pandemic on VMMC services, we compared VMMC services performed in 2020 with previous years among the 15 prioritized countries. Quantifying disruptions from the COVID-19 pandemic on a specific elective surgical procedure, VMMC, is valuable given that these procedures indicate pandemic-related disruptions to broader healthcare systems.

Collection of PEPFAR Monitoring, Evaluation and Reporting (MER) data is considered a public health program activity. The US Centers for Disease Control and Prevention Office of Human Research Protection Procedures determined that collection of MER data as nonresearch.

Methods

To quantify the effects of the COVID-19 pandemic on VMMC services in US government fiscal year 2020, we

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analyzed key performance indicators from the MER database (*20*). All PEPFAR-supported VMMC programs report indicators quarterly in accordance with the US government fiscal year (October 1 through September 30 of the following year). Primary indicators reported include the total number of male clients circumcised and achievement of annual targets at the national level. Disaggregated indicators reported include VMMC performance by client age group and follow-up visit attendance (defined as client return for a postprocedure visit within 14 days of circumcision). To provide more information about the effects of the updated policy to phase out VMMC among clients <15 years of age, annual and quarterly VMMC results were reported separately for clients <15 and ≥15 years of age. We compared reported indicators in 2020 with those from 2016–2019 among all prioritized countries. We compared quarterly performance for the total number of nonmilitary VMMC sites and the number of clients per site across 14 countries for 2020. Nonmilitary VMMC sites are typically located at civilian health facilities, and military sites generally offer services at military facilities and target service members, their families, and the surrounding communities. We excluded from the site-level analyses military-supported VMMC sites because they do not report disaggregated VMMC indicators at the site level, as well as South Sudan because its program offers VMMC only at military sites.

To supplement the quantitative results, we conducted an exploratory review of narrative reports for April–June 2020. Programs submit narrative reports every quarter as one of the MER reporting requirements. Narrative reports provide an opportunity for programs to describe specific site-level issues that may have affected VMMC performance. We reviewed narrative reports to identify the following references to the effects of COVID-19 on VMMC services: national and local COVID-19 mitigation measures, efforts to maintain demand in VMMCs, and reallocation of resources. First, we reviewed narratives to broadly identify emergent themes across countries, and then we conducted a more thorough review in which countries were categorized into 1 of 3 impact levels. We analyzed narrative reports by using Microsoft Excel (https://www.microsoft.com) and used Stata 16 software (https://www.stata.com) for all other analyses.

Results

VMMC Performance

The total number of VMMCs performed each year in the 15 prioritized countries decreased 32.5%, from 3,898,960 in 2019 to 2,631,951 in 2020 (Appendix Table 1, https://wwwnc.cdc.gov/EID/article/28/13/21-2455-App1.pdf). In most (11 of 15) countries, the total number of VMMCs performed was lower in 2020 than in 2019; mean percentage reduction was 49.4% (Appendix Table 2). The total number of annual VMMCs performed during 2016–2019 ranged by country from an average of >1,000 in South Sudan to >700,000 in Tanzania. Among 6 countries with larger programs (Kenya, Mozambique, South Africa, Tanzania, Uganda, and Zambia), performing on average of >250,000 VMMCs annually during 2016–2019, all countries except Zambia experienced a reduction of >100,000 VMMCs performed in 2020 compared with 2019. Among the larger programs, the largest reduction in performance was in South Africa; 513,631 VMMCs performed in 2019 decreased by 68.9% to 159,739 in 2020.

Achievement of Annual Targets

Among all 15 countries combined, 66.7% of the 3,948,875 annual target (median 200,000, interquartile range 30,074–399,387) was met in 2020, compared with 102.0% of the 3,822,403 annual target in 2019 (median 145,035, interquartile range 31,884–430,986) (Appendix Table 1). The mean percentage achievement of annual targets was 62.2% in 2020 compared with 98.1% in 2019. In 2020, most (12 of 15) countries did not meet their annual national target (Appendix Table 2). Among the 12 countries that did not meet their national target in 2020, seven countries had either surpassed or achieved 90.0% of their annual target in 2019. Countries that exceeded their national annual targets in 2019 (South Africa by 101.0% and Zimbabwe by 104.9%) achieved less than half (30.7% and 42.6%, respectively) of their annual target in 2020.

Quarterly Performance

The number of VMMCs performed during the first 2 quarters of fiscal year 2020 (October–December 2019 and January–March 2020) was 39.6% higher than the historic average during 2016–2019 (Appendix Table 1). During January–March 2020, just more than half (8 of 15) of countries increased the number of VMMCs performed compared with the same period in 2019; the average increase was 48.1% more VMMCs performed per country. However, during the early COVID-19 pandemic period, April–June 2020, the total number of VMMCs performed was 74.2% lower than it had been during the same period a year earlier. The number of VMMCs performed during April–June 2020 decreased in 13 countries, by 18.3% to 100.0%,

compared with the same period in 2019. In South Africa, no PEPFAR-supported VMMCs were performed during April–June 2020.

Historically, most VMMCs, an average of 57.8% of the annual VMMC total targets in 2016–2019, are performed during April–September (Figure 1; Appendix Table 1). However, during April–September 2020, only 35.0% of the annual total number of VMMCs were performed. Although the number of VMMCs performed increased for most countries (12 of 15) during July–September 2020 compared with the previous period, most countries (8 of 15) performed fewer than half the number of VMMCs than they had in the corresponding period in 2019.

Performance by Age Group

In 2020, a total of 26.7% of all VMMCs were performed for clients <15 years of age, representing a 56.2% decrease from the 41.1% performed for persons in this age group in 2019 (Appendix Table 1). After the PEPFAR policy to phase out VMMCs for clients <15 years of age was released in April 2020, eight countries did not report VMMCs among male clients 10–14 years of age during April–September 2020. The lowest number of VMMCs for male clients <15 years of age was reported during July–September 2020; 6.3% of all VMMCs were performed for male clients in this age group, compared with 40.3% in the same period in the previous year.

The annual total number of VMMCs performed for male clients ≥15 years of age was 1,879,201 in 2020 compared with 2,292,868 in 2019, representing a 18.0% decrease in the number of VMMCs performed in clients ≥15 years of age. During July–September 2020, most (94.3%) VMMCs were performed for clients ≥15 years of age, and the total volume of VMMCs conducted for persons in this age group was similar at 601,039, compared with 653,818 for the same period in 2019. However, clients ≥15 years of age contributed to the decline in achievement of PEPFAR annual targets, which decreased from 60.0% in 2019 to 47.6% in 2020.

Performance at the Site Level

Among the 14 countries reporting VMMCs at nonmilitary sites, the number of male clients circumcised at nonmilitary sites decreased 58.6%, from a mean of 1,857 clients/site during January–March 2020 to a mean of 768 clients/site during April–June (Figure 2). The number of nonmilitary sites performing VMMCs per country declined 39.3%, from a mean of 183 sites during January–March to a mean of 110 during April–June 2020. Although the total number of nonmilitary sites performing VMMCs increased 29.1% during 2020, from a mean of 110 during April–June to 142 during July–September, this increase remained 19.1% below the mean number of nonmilitary sites performing VMMCs during October 2019–March 2020.

Follow-up Visits

Among all 15 countries, the overall proportion of VMMC clients who had a postprocedure follow-up visit increased from 89.6% in 2019 to 91.1% in 2020. Eight countries reported a decreased rate of follow-up visits in 2020 compared with the previous year, and 7 countries reported either the same rate of follow-up or an increase, ranging from 2.2% to 19.1%. The rate of client follow-up stayed the same, at 93% during October 2019–June 2020, and decreased to 88% during July–September 2020.

VMMC Narrative Reports

Our review of the narratives indicated that service disruptions varied from minimal to major. Countries categorized as minimally affected reported only slight modifications to their program and minor reductions in performance. Moderately affected programs

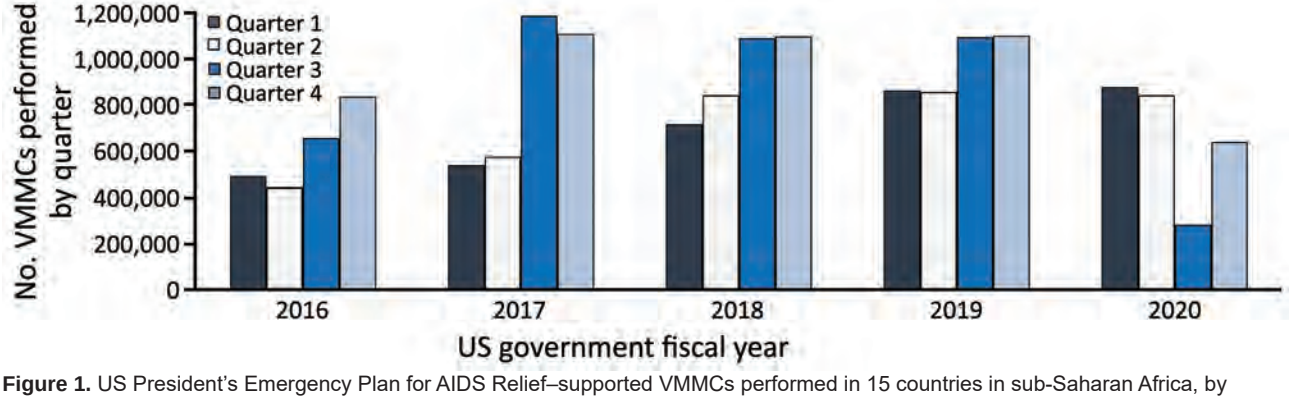

Figure 1. US President's Emergency Plan for AIDS Relief–supported VMMCs performed in 15 countries in sub-Saharan Africa, by quarter and fiscal year (October 1–September 20), 2016–2020. VMMC, voluntary medical male circumcision.

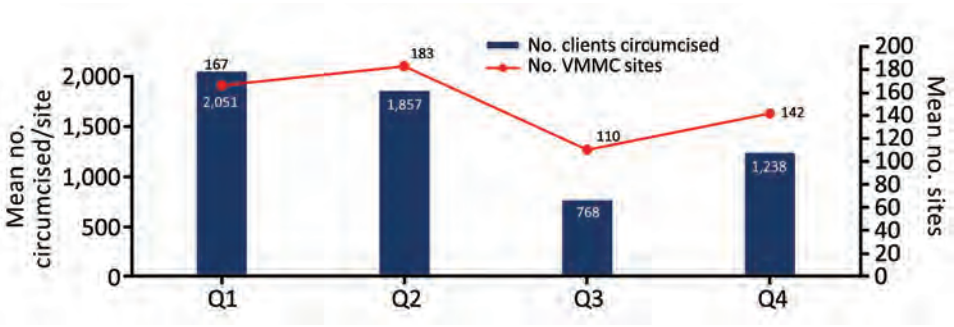

Figure 2. Mean number of male clients circumcised per US President's Emergency Plan for AIDS Relief (PEPFAR)–supported nonmilitary VMMC site and mean number of PEPFAR VMMC sites, 14 countries in eastern and southern Africa prioritized for VMMC, by quarter, PEPFAR fiscal year 2020. Scales for the y-axes differ substantially to underscore patterns but do not permit direct comparisons. Q, quarter; VMMC, voluntary medical male circumcision.

reported suspending services for at least 1–2 months, and majorly affected programs reported suspending services for >2 months. Zambia and South Sudan were identified as having minimally disrupted programs, and although there were service disruptions mentioned in the narrative reports, overall performance was only somewhat affected. In South Sudan, services continued with restrictions on the number of clients allowed in the waiting area. Moderately disrupted programs had service suspensions during April–June but eventually resumed offering VMMCs to clients who sought services through walk-in visits; however, outreach efforts to recruit clients stopped. Among all countries, the most commonly reported mitigation measures that reduced VMMC services were curfews, shelter-in-place orders, and physical distancing requirements.

VMMC narrative reports also described redirecting efforts to support and assist local service providers with COVID-19–related activities. Those efforts shifted the focus of programs, and many diverted staff to support COVID-19 response, particularly during the early part of the pandemic (*21*). Other VMMC staff were used to support essential HIV clinical services (e.g., treatment services). In addition, programs adapted demand creation strategies, which included logging clients interested in VMMC, booking clients for the next month, using COVID-19 contact tracers to also serve as VMMC mobilizers, and disseminating messages through community campaigns.

Countries that continued to offer VMMCs reported adjusting services to minimize risk for COVID-19 transmission. Adjustments included telescreening, space modifications to manage client flow, prior registration of clients, appointment-only visits, extended hours, and restricted numbers of clients allowed at a site per day. In some countries, to comply with restrictions in movements and curfews,VMMC sites were offered only at health facilities located in communities. Infection prevention measures included distributing personal protective equipment to staff, screening clients for COVID-19, and sanitizing spaces.

Discussion

VMMC is part of countries' HIV prevention portfolio and can contribute to HIV epidemic control (*22*,*23*). To maximize these public health benefits, country-specific VMMC program targets are established. However, because of the COVID-19 pandemic, most countries prioritized for VMMC did not reach these targets in 2020. A global target of 25 million VMMCs during 2016–2020 and 41.5 million by 2030 has been endorsed by countries prioritized for VMMC (*24*). Substantial progress has been made toward these targets, but those gains have been affected by the COVID-19 pandemic.

Overall, the VMMC program has grown substantially since 2016; mean annual increase in the number of VMMCs performed during 2016–2019 is 20.7%. VMMC performance before the COVID-19 pandemic (October 2019–March 2020) indicated successful scale-up of the program and that performance was on track to outperform the previous year. However, the number of VMMCs performed was substantially lower during April–September 2020 than during the previous year; decreases were especially pronounced during April–June 2020. These patterns are consistent with known COVID-19 mitigation measures, particularly in the early phase of the pandemic.

Reductions in the number of VMMCs performed during 2020 were similar to disruptions of other elective surgical procedures. In the United States, one study found that the overall rate of elective surgical procedures decreased 48.0% during the initial shutdown of elective procedures in March 2020 compared with the previous year (*25*). In Ethiopia, a study found that elective surgeries dropped by 32.0% at a

major hospital after the COVID-19 pandemic was declared (*26*). Compared with disruptions to other HIV prevention services (e.g., preexposure prophylaxis), VMMC services were more disrupted and time to service resumption was longer (*27*).

PEPFAR recommends that VMMC programs conduct COVID-19 readiness assessments to determine if sites can reopen. By the end of September 2020, all countries had resumed VMMC services. However, the rate of resumption was not uniform, most likely because of varying COVID-19 epidemiology and differences in response policies (*28*). Countries such as South Africa experienced severe effects, given that they reported some of the highest COVID-19 case counts on the continent, prompting ongoing national COVID-19 mitigation measures (*29*–*31*). Zimbabwe was also affected by high COVID-19 cases counts and subsequent national lockdowns (*32*).

One success for VMMC programs in 2020 was implementation of the new PEPFAR guidance to stop providing VMMCs for clients <15 years of age. This success is demonstrated by performance of 11.3% of VMMCs for clients 10–14 years of age during April–June 2020, compared with 41.0% during the same period in 2019. Implementation of the updated PEPFAR guidance released in April 2020 varied across countries; clients <15 years of age continued to be circumcised throughout 2020. This variability probably resulted from some countries continuing to perform device-based circumcisions for clients 13–14 years of age, given that a World Health Organization prequalified medical device has been approved for use in this age group. Although overall the number of VMMCs conducted for clients ≥15 years of age decreased in 2020 compared with 2019, the number of VMMCs conducted for clients in this age group was the highest during July–September, compared with the same period during 2016–2018. This increase probably directly resulted from programs adapting demand creation strategies to target older clients. Follow-up visits may have potentially increased in 2020 compared with 2019 because programs started conducting virtual follow-up visits when in-person visits were not safe or feasible.

Narrative reports from April–June 2020 suggest that governments enacted various types of COVID-19 mitigation measures given the different public health needs, priorities, and resources across countries. Although these measures presented new challenges to reaching HIV epidemic control targets, they also provided opportunities for improvements. Innovative approaches that enabled continuation of VMMC services included programs offering virtual follow-up visits, using web-based mobile apps for real time reporting, increasing flexibility for clients who prefer off-hour services, and adopting practices to avoid overcrowding.

Lessons learned from the COVID-19 pandemic can be used to inform other elective surgical and prevention services and to update VMMC policies and guidelines to help prepare for future global and national emergencies. Mechanisms for rapid availability and allocation of funding to safely resume services and carry over unused funds can be established. We recommend greater financial support for programmatic components, such as demand creation activities that can be safely implemented during the pandemic, including adaptating social and digital media platforms. These activities may be more costly than traditional in-person mobilization efforts. Those costs are a result of extended site hours, expanded numbers of VMMC sites, and increased transportation to sites to limit the number of clients in a vehicle. Support to maintain VMMC services during the COVID-19 pandemic is particularly valuable, given that modeled estimates have demonstrated that, in certain settings, the risk for death from HIV may be far greater than the risk for death from COVID-19 (*33*).

The pandemic will probably have long-term effects on VMMC program practices; country reports describe challenges with VMMC-eligible men expressing concerns about visiting public health facilities for fear of contracting COVID-19 or overburdening healthcare services (*34*). Factors that could continue to keep VMMC programs from resuming services to prepandemic levels include ongoing travel restrictions, varying global COVID-19 epidemiology, and low COVID-19 vaccination coverage.

Of the 4 limitations to our study, the first is the limitation to PEPFAR program data, which captured the timing of pausing and resuming VMMC services on a quarterly basis only. Thus, temporal trends between mitigation measures or national COVID-19 epidemiology and decisions to pause services could not be described at a weekly or monthly level. Second, COVID-19 mitigation measures were not uniformly implemented across or within all countries, and the extent to which these measures were executed was not included in this analysis. Third, the findings from this analysis are limited to PEPFAR-supported sites in 15 countries in eastern and southern Africa. Last, this analysis was ecologic, and the effect of the COVID-19 pandemic on VMMC in 2020 cannot be distinguished from other effects such as changes in client age eligibility.

To optimize the HIV prevention benefits of VMMC, steps can be taken to increase program

resilience to ensure that HIV prevention interventions are able to quickly adapt to public health emergencies, particularly to COVID-19 mitigation measures. These efforts are relevant given that the severity of the effect of COVID-19 in countries prioritized for VMMC remains unknown. If healthcare systems are not able to maintain HIV prevention programs while managing the response to the COVID-19 pandemic, they are likely to experience increasing HIV incidence.

The findings and conclusions in this report are those of the authors and do not necessarily represent the official position of the funding agencies.

About the Author

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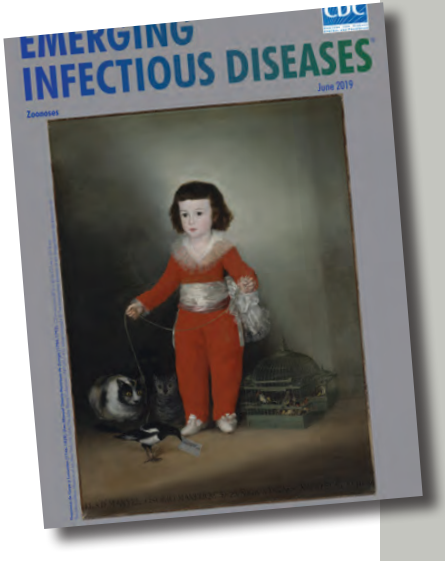

Neospora caninum

[ne-os′ pə-rə ca-nin′ um]

From the *neo-* (Latin, "new") + *spora* (Greek, "seed") and *canis* (Latin, "dog"), *Neospora caninum* is a sporozoan parasite that was first described in 1984. It is a major pathogen of cattle and dogs but can also infect horses, goats, sheep, and deer. Antibodies to *N. caninum* have been found in humans, predominantly in those with HIV infection, although the role of this parasite in causing or exacerbating illness is unclear.

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Sexual Violence Trends before and after Rollout of COVID-19 Mitigation Measures, Kenya

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COVID-19 mitigation measures such as curfews, lockdowns, and movement restrictions are effective in reducing the transmission of SARS-CoV-2; however, these measures can enable sexual violence. We used data from the Kenya Health Information System and different time-series approaches to model the unintended consequences of COVID-19 mitigation measures on sexual violence trends in Kenya. We found a model-dependent 73%–122% increase in reported sexual violence cases, mostly among persons 10–17 years of age, translating to 35,688 excess sexual violence cases above what would have been expected in the absence of COVID-19–related restrictions. In addition, during lockdown, the percentage of reported rape survivors receiving recommended HIV PEP decreased from 61% to 51% and STI treatment from 72% to 61%. Sexual violence mitigation measures might include establishing comprehensive national sexual violence surveillance systems, enhancing prevention efforts during school closures, and maintaining access to essential comprehensive services for all ages and sexes.

COVID-19 mitigation measures such as curfews, lockdowns, and travel restrictions reduce disease transmission, but these measures also disrupt economic activities and social networks, and hinder access to health and social services (*1*,*2*). Mass disruption of socioeconomic activities often has unintended consequences, including an increase in sexual violence and prolonged exposure to abusers, while concomitantly limiting survivors' access to and the availability of medical and social services (*2*–*5*).

A COVID-19 case was confirmed in Kenya on March 13, 2020. The government rolled out a series of measures to contain the spread of COVID-19 and mitigate its impacts on March 15, 2020. These measures included school closures, movement restrictions, curfews, rescheduling of clinical services, and reassignments of health workers to COVID-19 case management (Appendix Figure 1, https://wwwnc.cdc.gov/EID/article/28/13/22-0394-App1.pdf).

In May 2020, the United Nations Population Fund warned that an additional 31 million cases of sexual and gender-based violence would be seen globally during implementation of COVID-19 mitigation measures and called on governments to be alert to these dangers (*6*). In July 2020, one study found that patterns of sexual violence against children in Kenya had changed and that the average age of survivors declined from 16 to 12 years (H.D. Flowe et al., unpub. data, https://doi.org/10.31234/osf.io/eafwu). That study also found that 76% of offenses occurred during the day and coincided with normal school hours. Another study during the lockdown noted that 78% of perpetrators were known to the victim, either family members or neighbors (*7*). These studies were not designed to quantify national estimates of sexual violence, but they attest to the heightened exposure of women and girls to sexual violence.

To determine whether sexual violence increased in Kenya during the COVID-19 pandemic, we examined trends in reported sexual violence cases in Kenya during January 2015–June 2021. Because COVID-19 mitigation measures also disrupted clinical services, we assessed changes in overall quality of care for

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sexual violence survivors, including HIV postexposure prophylaxis (PEP) and sexually transmitted infection (STI) treatments.

Methods

Definitions and Data Sources

We obtained monthly sexual violence reports from the Kenya District Health Information System (DHIS2) database covering January 2015–June 2021. Those data cover patients who received clinical care in hospitals, health centers, and dispensaries registered by the Kenya Medical Practitioners and Dentists board. Those health facilities also offer other routine clinical services, such as malaria treatment. Aggregate facility-level sexual violence data are extracted from the Kenya Ministry of Health Sexual Gender-Based Violence (SGBV) register (MOH 365) and entered into DHIS2 monthly; patient-level data are not available in the DHIS2 database.

We used sexual violence case definitions as outlined in the National Guidelines on the Management of Sexual Violence in Kenya (*8*) and the SGBV register (*9*). Those documents outline acts of sexual violence list acts of sexual violence as rape, attempted rape, defilement, incest, sexual assault, gang rape, and forcible anal penetration (*8*). Rape covers forcible anal penetration in both sexes (*8*). In contrast, the legal definition of rape in Kenya is forcible vaginal penetration only.

We appraised the following data: overall sexual violence, a general category that includes attempted rape and other unspecified forms or types of sexual violence; rape, including forcible penetration of vagina or anus; rape-related HIV PEP; and rape-related STI treatment. We included PEP and STI treatment outcomes to assess whether the sexual violence survivors received minimum standard care according to the national guidelines (*8*) or if standards of care changed during the pandemic. Because we expected these 2 indicators to directly correlate, they also served as data quality checks for overall sexual violence and rape cases.

Of note, a registered facility can report a sexual violence survivor as a sexual violence or rape case and document whether the patient received HIV PEP or STI treatment. At the end of each month, the facility aggregates reports for and enters information into DHIS2 using inputs for the total number of rape consultations (rape), among which the facility notes the number of rape survivors who received PEP (rape-PEP), and the number who received STI treatment (rape-STI). Because dispensaries and health centers might collect information in paper or electronic form before data are entered into DHIS2, 1 sexual violence survivor might be reported to DHIS2 $\leq$3 times, as rape, rape-PEP, or rape-STI.

Of 47 counties in Kenya, we excluded 14 (30%) from our analysis because they had incomplete or missing data in DHIS2. The excluded counties account for ≈19.5% of the country's population (Figure 1).

Statistical Approaches and Assumptions

We hypothesized that monthly reported cases of sexual violence evolve with time, based on changing sociocultural, policy, and legal factors. We also hypothesized that seasonal variations in sexual violence occur and that case numbers would be higher in some months than others; thus, we hypothesized both long-term trends and seasonal patterns in reported sexual violence cases. To calculate the effect of COVID-19 lockdowns on sexual violence, we followed the traditional time-series approach and estimated the trends that would have been expected during the lockdown, had the lockdown not happened. We considered the difference between the reported cases and the estimated nonlockdown trend as effects of the lockdown.

We first conducted descriptive analyses and checked for seasonal patterns in sexual violence by separating monthly variations from long-term trends (Appendix Figure 2). We then conducted several statistical tests to select the most appropriate time-series models (Appendix). We used those selected models to estimate the effects of the lockdowns on sexual violence and quality of sexual violence survivor care.

We made several assumptions for our analyses to make our models realistic. First, we assumed no changes in data reporting occurred during the study period, including changes in reporting requirements, definitions of indicators, or data collection tools. We checked this assumption by examining data quality reports from the DHIS2 database and through discussions with public health program officers working on sexual violence in Kenya.

Second, we assumed that no factors or events that could affect sexual violence trends, but were unrelated to the pandemic, were occurring when the lockdown started. Such factors might include new legislation penalizing sexual violence or mass disruptive events, such as civil conflict. We checked this assumption through discussions with program staff, by using date falsification tests to change the lockdown start date to several months before and after March 2020, and by using Supremum Wald tests to look for unusual patterns in the data (*10*).

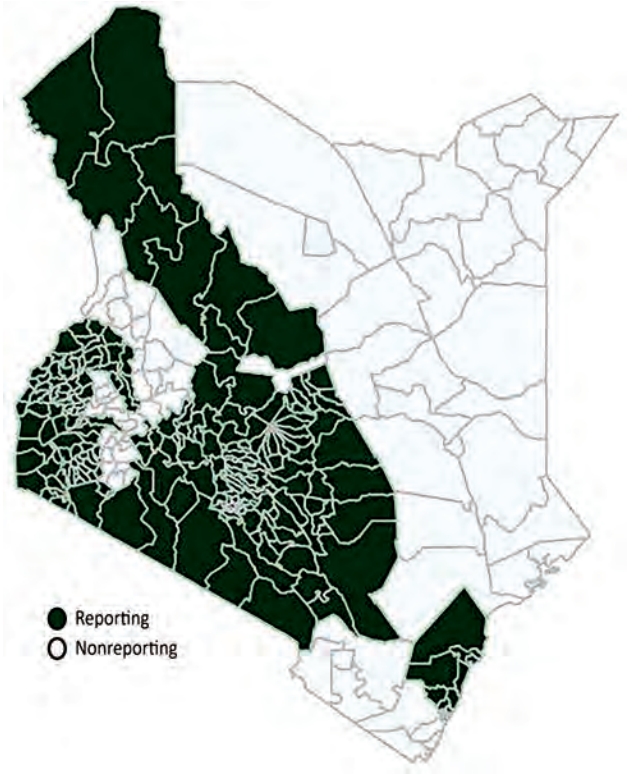

Figure 1. Counties reporting sexual violence cases before and after rollout of COVID-19 mitigation measures, Kenya, January 2015–June 2021. The shaded areas indicated counties that have complete sexual violence reports in the Kenya DHIS2 database, which were included in the analyses. The following counties did not report sexual violence data to the DHIS2: Baringo, Bomet, Elgeyo-Marakwet, Garissa, Isiolo, Kericho, Kwale, Lamu, Mandera, Marsabit, Nandi, Taita Taveta, Tana River, Wajir, and West Pokot. DHIS2, District Health Information System 2.

Third, we assumed that potential perpetrators at the population level were unaware of impending lockdowns and subsequently did not modify their behavior in anticipation of the lockdown. Any pre-lockdown anticipatory effects would have biased the nonlockdown estimates upward or downward depending on the direction of the effects (*11*). We tested this assumption by using date falsification and Supremum Wald tests and by examining raw sexual violence trend graphs (Figure 2; Appendix). Because time-series analyses require ≥50 observations for stable estimates of the underlying trend and to model for seasonality, we expanded our dataset to include 78 observation months (*12*,*13*).

Because different time-series approaches have inherent strengths and limitations, we compared estimates across different models to increase result confidence. For example, before and after analyses, we assumed no long-term trends were occurring. However, interrupted time-series require multiple observations; thus, we checked estimates of the seasonal autoregressive integrated moving average model (SARIMA) as our primary method and crosschecked the estimates by using 4 additional methods: seasonal Holt-Winters, Bayesian structured time-series (BSTS), ordinary least squares interrupted time-series analysis (ITSA), and negative binomial interrupted time-series regressions (NBREG) (Appendix).

Software and Ethics Approval

We conducted analyses in Python version 3.7 (Python Software Foundation, https://www.python.org) and Stata version 14 (StataCorp LLC, https://www.stata.com). We developed a web-based application, SGBV Rapid Trend Analysis Tool (https://sgbv-app.herokuapp.com), for researchers who wish to conduct similar analyses. The details of the statistical methods, tests, and interpretation of results are included as part of the tool. This study was reviewed in accordance with US Centers for Disease Control and Prevention human subjects review procedures and was determined to not meet the definition of research as defined in 45 CFR §46.102(l).

Results

We found that reported cases of sexual violence in Kenya doubled during the COVID-19 pandemic. The pre–COVID-19 (January 2015–March 15, 2020) monthly mean number of cases was 2,387 (95% CI 2,289–2,485) but rose to a monthly mean of 5,269 (95% CI 4,289–6,250) after COVID-19 lockdowns began on March 15, 2020 (Table; Figure 2). From the prelockdown to postlockdown periods, DHIS2 data inputs for rape increased from 1,037 to 1,801/month, rape-PEP increased from 628 to 910/month, and rape-STI increased from 745 to 1,115/month.

We noted a dip in the upward trajectory of reported sexual violence cases after COVID-19 restrictions were relaxed during November 2020–February 2021 (Table; Figure 2). However, a fresh upsurge in cases occurred after COVID-19 restrictions were reimposed in March 2021 (Figure 2; Appendix Figure 2).

We found that reported sexual violence cases decreased during a series of national healthcare worker strikes in 2017 (Figure 2). We also found seasonal variations in reported sexual violence cases, and that peaks typically occur during November–January, coinciding with the main school vacation in Kenya (Appendix Figure 2).

The base SARIMA model showed that, after COVID-19 mitigation measures were introduced in March 2020, reported sexual violence cases increased

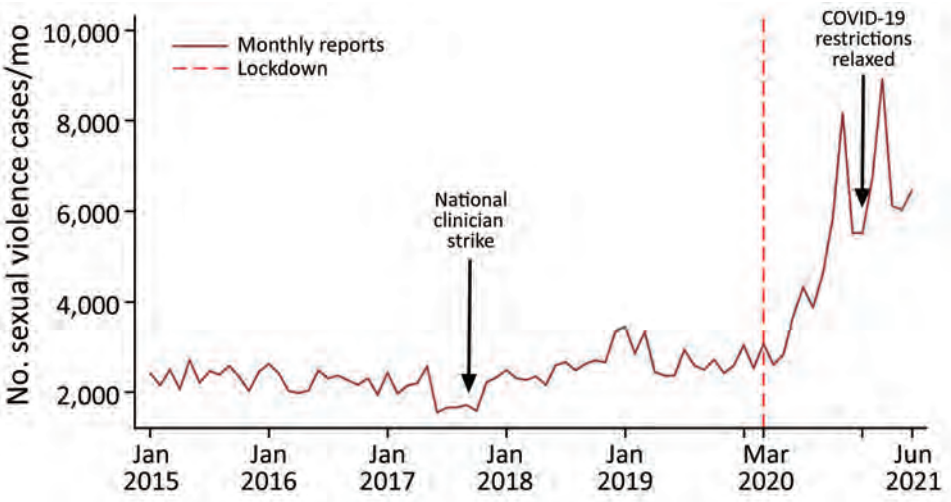

Figure 2.Overall unadjusted trends in sexual violence cases before and after rollout of COVID-19 mitigation measures, Kenya, January 2015–June 2021. The graph shows monthly number of reported sexual violence cases; vertical red dashed line represents the official start of the COVID-19 pandemic and associated lockdowns in Kenya.

by a monthly average of 73% (2,229). SARIMA model estimates were more conservative than estimates using the alternate models; ITSA showed a 95% increase, NBREG 122%, and BSTS 112% (Appendix Figure 3). Those results translate to a cumulative increase of 35,668 (95% CI 28,972–42,364) reported sexual violence cases compared with the modeled scenario without COVID-19 restrictions.

Overall, reported sexual violence cases increased for all age groups during lockdown, but the highest increase occurred among persons in the 10–17-year age group, which had an 117.2% increase. Other age groups also had increased rates: 20.7% among persons <10 years of age, 37.2% among those 18–49 years of age, and 16.3% among those ≥50 years of age (Figure 3; Appendix Figure 4).

We found a model-dependent 22%–76% increase in monthly reported rape cases (Appendix Table). The proportion of rape survivors receiving the minimum package of standard care recommended by national guidelines (*8*) declined. Of note, during the prelockdown period, only 61% of rape cases were reported to have received PEP, and only 72% received STI treatment. In the postlockdown period, the proportion of rape survivors receiving PEP declined from 61% to 51%, and those receiving STI treatments declined from 72% to 61%; however, the number of PEP and STI treatments administered increased overall (Table).

Discussion

During the lockdown period, we found a 73%–122% increase in reported sexual violence cases, confirming previous studies and media commentaries about an increase in sexual violence during the pandemic (*7*; H.D. Flowe et al.). Monthly reported cases increased as the lockdown progressed, and reports during December 2020 were 4 times higher than the pre–COVID-19 monthly average. Case reports moderately declined in January 2021, coinciding with relaxation of some COVID-19 mitigation measures, and surged again in March 2021 after mitigation measures were reintroduced (Figure 2; Appendix Figure 2).

During COVID-19 lockdown, reported sexual violence cases more than doubled among persons 10–17 years of age, but all age groups had increased rates (Appendix Figure 4). We hypothesize that the spike in cases among the adolescent group resulted from extended school closures, which led to increased contact time with potential abusers. Other studies using survivor-level data have shown a shift in abuse patterns to daylight hours and a decline in mean age of sexual violence survivors from 16 to 12 years of age (*7*; H.D. Flowe et al.). We were not able to assess this change with the available data.

For the period before the pandemic, our descriptive analyses found a strong seasonal pattern in sexual violence, and peaks coincided with school vacations (Appendix Figure 2). We did not find any literature

Table. Summary statistics of sexual violence trends before and after rollout of COVID-19 mitigation measures, Kenya*

Indicator	Prelockdown, mean (95% CI)	Postlockdown, mean (95% CI)	SARIMA parameters
Total sexual violence cases	2,387 (2,289–2,485)	5,269 (4,289–6,250)	(4,1,0) x (1,1,0,12)
Rape	1,037 (989–1,085)	1,801 (1,576–2,028)	(0,1,0) x (1,0,0,12)
Rape-PEP	628 (603–653)	910 (814–1,007)	(1,1,1)
Rape-STI treatment	745 (714–776)	1,115 (980–1,249)	(0,1,0)

*Trends were measured during January 2015–June 2020. PEP, postexposure prophylaxis for HIV; SARIMA, seasonal autoregressive integrated moving average; STI, sexually transmitted infection.

regarding seasonal variation in sexual violence reports in East Africa, but program managers should consider incorporating these variations in their sexual violence intervention plans.

We found a correlated increase in 2 national indicators of the quality of sexual violence care, rape-related PEP treatment and facility-reported cases associated with STI treatment. These indicators showed an absolute increase in treatments administered (Appendix Table), but the average proportion of reported survivors receiving the minimum standard-of-care declined from 61% to 51% for PEP and 72% to 61% for STI treatment. Further studies are needed to determine why only 61% of rape cases received PEP and only 72% received STI treatment before the lockdown and why the percentage of rape cases receiving PEP and STI treatment decreased further during lockdown.

Our results mirror previous studies that found an increase in cases of sexual violence during pandemics or in the aftermath of major disasters (*1*). Our results are higher than those found in a preanalysis and postanalysis conducted by the United Nations Population Fund, which compared data from Mali in April 2019 to data from April 2020 (*14*). That analysis found a 35% increase in gender-based violence in Mali; however, the number of reporting organizations decreased from 32 to 13 during the analysis period, so these data are likely underestimates (*14*).

Our results are also consistent with a study examining patterns of sexual violence against adults and children in Kenya during the lockdown (*7*). That study found that children were more likely than adults to be victimized, primarily resulting from school closures because violations occurred more frequently during the day, by someone known to the survivor, and in private rather than a public location (*7*).

We used 4 different time-series approaches, each with their own strengths and weakness, to assess the robustness of the findings (Appendix Figure 3). We conducted several falsification and statistical tests to assess whether other competing events might have affected the results. We also assessed seasonality and secular trends, thereby avoiding biases in preanalysis and postanalysis evaluations when comparing observations from corresponding months across different years.

Our investigation likely underestimated sexual violence cases during lockdown. First, sexual violence is often underreported because of stigma, fear of retribution, cultural normalization of sexual violence, mistrust of authorities, lack of knowledge about services, and weak legal systems (*5*,*7*,*15*). Second, DHIS2 data are restricted to registered facilities, are often incomplete, and do not capture medical care received elsewhere, such as in nonregistered facilities like clinics in slums or at home. Third, because DHIS2 does not receive data from stand-alone rape crisis centers and does not receive reports from 30% of the counties in Kenya (Figure 1), especially those in North-Eastern and central Rift Valley Provinces, the DHIS2 rape data might not fully represent the total population of rape survivors in Kenya. Fourth, movement restrictions could have hindered access to medicolegal care (facilities and police). Fifth, survivors could have avoided seeking help in health facilities during the early phases of the pandemic because of fear of getting infected with SARS-CoV-2. Therefore, survivors who went to healthcare facilities during the COVID-19 pandemic could have had more severe injuries, might represent a subset of the population that could navigate pandemic restrictions such as curfews, have been of higher socioeconomic status, or lived in proximity to health facilities. We have no

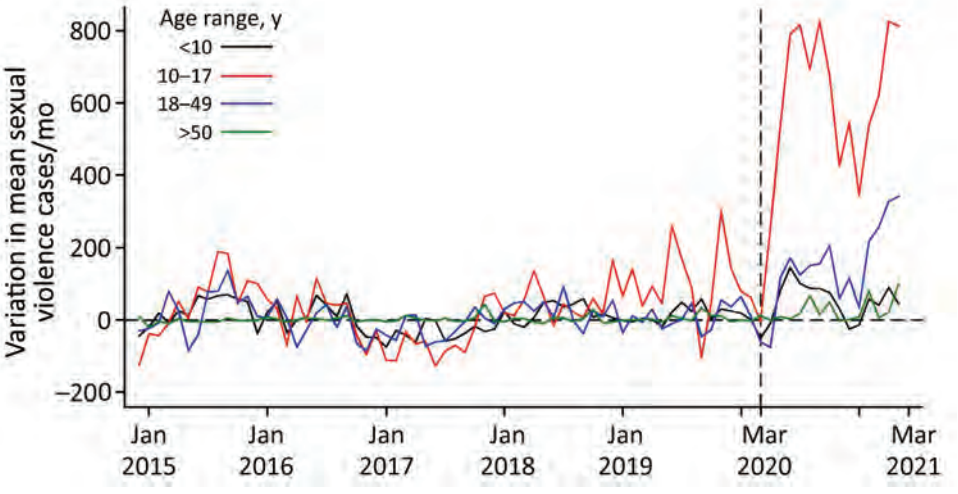

Figure 3. Mean sexual violence cases by age before and after rollout of COVID-19 mitigation measures, Kenya, January 2015–June 2021. Changes in age-disaggregated cases were calculated by using a Bayesian structural time series model. The horizontal dashed line represents the baseline; the vertical dashed line represents the official start of the COVID-19 pandemic and associated lockdowns in Kenya.

way of testing for this information in the data. Finally, case-patient sex was not reported to DHIS2, and we do not know how many facilities or standalone rape crisis centers provide sexual violence services to male survivors or if the sex distribution of rape cases changed during lockdown. Thus, we do not know if gaps in PEP and STI treatment were worse in male versus female sexual violence survivors.

Because we did not have patient-level data, we were unable to conduct detailed subanalyses, such as age-sex disaggregation, incident time of day or day of week, or perpetrators' ages or their relationships with the survivors. National-level aggregates smoothed out random variations in healthcare service access and reporting at healthcare facility–level, these aggregates do not capture geographic heterogeneity in sexual violence patterns that enable more targeted interventions. Additional analyses are therefore essential.

Conclusions

We used DHIS2 data to examine trends in reported sexual violence cases during the COVID-19 pandemic in Kenya. We found that reported sexual violence and rape cases nearly doubled during COVID-19 lockdown periods, particularly among persons 10–17 years of age. We found strong seasonal patterns in sexual violence reports before the COVID-19 pandemic, and reports spiked during school vacations.

We found that gaps in PEP and STI treatment administered to rape survivors existed in Kenya before COVID-19 lockdowns began. However, the percentage of rape survivors receiving PEP and STI treatment dropped further during the lockdown. Additional studies could investigate why gaps in PEP and STI treatment occurred.

Nonetheless, our findings likely underestimate sexual violence in Kenya during the COVID-19 pandemic. We suggest that sexual violence surveillance systems be strengthened and expanded to include all counties in Kenya. In addition, communities could identify safe spaces for children when schools are not in session and keep safe houses open and accessible for persons fleeing abusers during lockdowns. Further studies are needed to monitor the possible additional adverse effects of COVID-19 pandemic lockdowns, such as increases in teenage pregnancies and increased incidence of HIV and STIs in children and adolescence. Because the immediate and long-term deleterious effects of sexual violence on survivors and society are unclear, additional studies to generate better quality data and policies would be useful.

In conclusion, our findings can inform planning for future pandemics or other events that result in the mass disruption of socioeconomic activities, such as earthquakes and hurricanes (*1*). Lockdown plans and policies should include sexual violence prevention and mitigation strategies. Communities should maintain access to comprehensive sexual violence care according to national standards as an essential service for all ages and sexes during pandemic lockdowns, disasters, and national emergencies.

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The findings and conclusions in this paper are those of the authors and do not necessarily represent the official position of the US Centers for Disease Control and Prevention or the Kenya Ministry of Health.

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Clinical and Economic Impact of COVID-19 on Agricultural Workers, Guatemala[1]

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We evaluated clinical and socioeconomic burdens of respiratory disease in banana farm workers in Guatemala. We offered all eligible workers enrollment during June 15–December 30, 2020, and annually, then tracked them for influenza-like illnesses (ILI) through self-reporting to study nurses, sentinel surveillance at health posts, and absenteeism. Workers who had ILI submitted nasopharyngeal swab specimens for testing for influenza virus, respiratory syncytial virus, and SARS-CoV-2, then completed surveys at days 0, 7, and 28. Through October 10, 2021, a total of 1,833 workers reported 169 ILIs (12.0 cases/100 person-years), and 43 (25.4%) were laboratory-confirmed infections with SARS-CoV-2 (3.1 cases/100 person-years). Workers who had SARS-CoV-2–positive ILIs reported more frequent anosmia, dysgeusia, difficulty concentrating, and irritability and worse clinical and well-being severity scores than workers who had test result–negative ILIs. Workers who had positive results also had greater absenteeism and lost income. These results support prioritization of farm workers in Guatemala for COVID-19 vaccination.

Essential workers have been at greater risk for COVID-19 than for the general population, but little is known about the risk to persons working within the agricultural sector in low- to middle-income countries (LMICs) (*1*–*3*). Limited data from the United States have demonstrated a high burden of SARS-CoV-2 in this population (*1*); many agricultural workers continued working throughout the pandemic (*4*). In LMICs, agricultural workers play a critical role in food security and represent a major economic force. In Guatemala, these workers are 35% of the overall labor force, and agricultural products account for 45% of all exports and 11.3% of total gross domestic product (*5*). Guatemala is also a major trading partner of the United States, exporting US $2.1 billion in agricultural products annually, including nearly 50% of the banana supply of the United States (*6*). Therefore, agricultural workers in Guatemala and similar LMICs are arguably essential not only for local food security but also for the food security of international trading partners, such as the United States.

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In addition to increased risk for exposure to SARS-CoV-2, the virus that causes COVID-19, persons working in the agricultural sector might also be at increased risk for poor clinical outcomes from COVID-19 because of a high prevalence of comorbidities associated with environmental stress, such as chronic kidney disease of unknown origin (Mesoamerican nephropathy) (*7*–*9*). Economic outcomes, such as work absenteeism and decreased job performance while working (presenteeism), are also critical factors, as is the case with influenza (*10*–*14*). Because agricultural workers are often the primary income earners for their households, the consequences may extend to their households and communities. Despite the increased clinical and economic vulnerability of agricultural workers and their critical role in global food security, little is known about the socioeconomic consequences of COVID-19 and other respiratory illnesses among this essential workforce, and the subsequent effects on their households and communities.

The Agricultural Workers and Respiratory Illness Impact (AGRI) Study was designed as an influenza cohort and expanded to include other viral respiratory pathogens, including SARS-CoV-2. The study has 2 primary aims: to characterize the clinical and socioeconomic outcomes of acute respiratory viral infections among farm workers in Guatemala, and to measure the effectiveness of a workplace-based vaccination program in improving these outcomes. Here, we provide a comprehensive description of the AGRI cohort and a summary of clinical and economic outcomes from the first year of virologic surveillance.

Methods

Study Setting and Population

This 5-year study was conducted within a large banana farm in the coastal lowlands of southwestern Guatemala. Farm workers are exposed to high temperatures and humidity and are at risk for environment-associated chronic medical conditions, such as chronic kidney disease of unknown origin (*7*,*15*). Previous surveys (2015, 2017–2018) found a predominantly young, male, and economically vulnerable workforce. Farmworkers are typically the sole income earners for their households and report high rates of food insecurity, similar to other agribusiness workers in the region and migrant worker populations in the United States (*16*,*17*). The regional population experiences high levels of food insecurity, stunting, poverty, and communicable diseases and low access to healthcare (*18*,*19*).

As is typical in many agribusinesses, field workers and packaging workers receive baseline pay plus daily bonuses based on productivity recorded by the company. Managers and workers in administrative job categories are paid by day. Workers who become ill and receive excused absences from their managers receive two thirds of baseline pay for the duration of the excused absence, up to a maximum of US $15.60/day. Workers with laboratory-confirmed SARS-CoV-2 are mandated to quarantine at home with excused absences for up to 2 weeks.

All eligible workers within the 9 banana farm worksites were offered enrollment in the study during June 15–December 30, 2020, and annually thereafter. Inclusion criteria were age ≥18 years, plans to remain employed by the agribusiness for ≥1 year, access to a telephone, and agreement to enable use of company-based absenteeism and job performance records. For this analysis, participant follow-up was performed through October 10, 2021; all study procedures (testing and follow-up) performed after that date were considered missing, even if the associated influenza-like illness (ILI) case was previously identified.

After written informed consent was obtained, study nurses collected contact information and demographic, occupational, socioeconomic, and clinical data, including risk factors for severe COVID-19. Workers provided enrollment and annual blood specimens that were screened for markers of chronic kidney disease (e.g., estimated glomerular filtration rate [*20*]), SARS-CoV-2 nucleocapsid IgG (Elecsys Immunoassay; Roche, https://www.roche.com), and in some instances SARS-CoV-2 neutralizing antibodies (Beckham/Santiago Laboratories, University of Colorado, Aurora, CO, USA). Workers leaving employment had exit interviews and were removed from the study, but data collected during their employment were retained in the study database.

Surveillance for ILI

After enrollment, all workers began prospective active surveillance for ILI, initially defined as a self-reported fever/temperature ≥38°C and cough in the previous 10 days, to focus on detection of influenza (*21*). In January 2021, the ILI case definition was expanded to include fever, cough, or shortness of breath in the previous 10 days (COVID-19–like illness [*22*]), to increase sensitivity of COVID-19 case detection (*23*).

We used 3 strategies for detecting ILI. The first strategy was symptom screening through workers self-reporting symptoms to a study nurse during

weekly worksite visits, work supervisors routinely querying workers for cough and fever at daily team meetings, and telephone contact to a study nurse by workers experiencing symptoms at any time. The second was sentinel surveillance of all workers who had ILI and presented to worker health posts within the farm. The third was active monitoring and ILI screening phone calls to absent workers identified on the company absenteeism registry. During worksite visits, study nurses visited worksites at given times each week, and workers were able to self-report to the nurse at that time. Work supervisors (or nurses at health posts) could also notify the study team on behalf of workers after obtaining their permission. In February 2021, absenteeism calls were discontinued because those ILI case-patients were consistently identified through other surveillance approaches.

Syndromic Illness Characterization

Study nurses interviewed workers who had ILI and collected clinical, epidemiologic, and outcome data for the workers and general epidemiologic and socioeconomic outcome data for their households. Study nurses also collected nasopharyngeal swab specimens, which were placed in viral transport medium and tested within 24 hours for SARS-CoV-2 by using the Q COVID rapid antigen test (Q-NCOV-01G; Biosensor SD, https://www.sdbiosensor.com) (*24*). Aliquots were also tested for influenza A/B viruses and respiratory syncytial virus (RSV) by using the Cobas Liat Influenza A/B (and RSV) real-time reverse transcription PCR (RT-PCR) instrument (Roche) (*25*). Patients who had ILI and tested positive for SARS-CoV-2, influenza, or RSV are hereafter referred to as SARS-CoV-2–positive ILI, influenza-positive ILI, or RSV-positive ILI, respectively. The first 40 available ILI specimens collected through April 2021 and shipped to the University of Colorado were also tested for an additional 15 respiratory pathogens by using the multiplex BioFire FilmArray RP2.1 assay (*26*). Viral testing results were shared with participants when available (usually within 24 hours) and weekly with the Guatemala Ministry of Health.

Clinical and Socioeconomic Outcome Assessments

The study relied on a case–cohort study design to measure self-reported clinical and socioeconomic outcomes. All persons in the overall cohort with ILI were considered to be case-patients. Each week, a subcohort of 15 enrolled workers who did not have ILI in the preceding 28 days were selected at random (≈5% of the cohort/month) as controls. Study nurses administered follow-up surveys over the telephone to case-patients at 1 and 4 weeks after their ILI visit. Controls were notified that they had been selected (day 0) and received the same surveys 1 and 4 weeks later; controls did not undergo diagnostic testing, and a control who had ILI develop during the 4-week follow-up was considered to be a case-patient at the time of illness.

Clinical and well-being outcomes were collected by using the Influenza Intensity and Impact Questionnaire (FluiiQ) Inventory (*27*), which is a validated Spanish-language outcome measure designed for clinical and epidemiologic outpatient studies of influenza and RSV. The inventory consists of 13 items for symptom severity, a combined systemic score (7 items) and respiratory score (6 items). The well-being scores are impact on daily activities score (7 items), impact on emotions score (4 items), and impact on others score (5 items). Each combined score is averaged by the number of individual items such that all scores are 0–3; a higher score indicated greater severity or negative impact on well-being. The follow-up surveys also collected health-seeking behavior (e.g., hospitalization, medication use).

During follow-up surveys, economic outcomes were assessed by using questions adapted from the 2016 World Health Organization Manual for Estimating the Economic Burden of Seasonal Influenza (*28*) and supplemented with the World Bank National Survey of Living Conditions (*29*), which includes a Spanish translation (La Encuesta Nacional de Condiciones de Vida) used in Guatemala (*30*). The survey collected data on direct medical costs, direct nonmedical costs (i.e., transportation), and indirect costs related to loss of productivity (i.e., absenteeism) for the worker and the household. Results were compared with the basic food basket price in Guatemala, which reflects the minimum kilocalories intake (2,262 kilocalories) for a 4.77-member household for 1 month (US $386.30 in March 2021) (*31*). Although not included in this analysis, company-reported individual-level data were linked to workers, including absenteeism, productivity metrics (task-specific units of production, such as tons of bananas harvested per day), and wages.

Statistical Analysis

We calculated incidence density (number of cases per person-time of follow-up) of ILI and pathogen-specific ILI. We used descriptive statistics to calculate differences between clinical and socioeconomic outcomes between groups. For normally distributed continuous variables, we calculated means and SDs and used the Student *t*-test to determine major differences between groups. For non–normally distributed

continuous variables, we calculated medians and interquartile ranges and used the Wilcoxon rank-sum test to determine major differences between groups. For categorical variables, we used χ^2 and Fischer exact tests to determine major differences in distribution of categories between groups. For all analyses, $p<0.05$ was considered statistically significant.

Ethics

The study was approved by the Colorado Multiple Institutional Review Board (protocol #19-1836) and the Guatemala Ministry of Health National Ethics Committee (HRMC-560-2020). The local Southwest Trifinio Community Advisory Board for Research agreed to the study. Workers receive no compensation for study participation.

Results

During June 15, 2020–October 10, 2021, a total of 2,371 workers were screened for enrollment; 160 (6.7%) were ineligible, and 378 (17.1%) declined participation (Figure 1). Of the 1,833 enrolled participants (Table 1), 1,590 (86.7%) remained active in the study as of October 10, 2021, representing 1,402.9 person-years of surveillance. Workers who declined participation were slightly younger than participants (29.6 vs. 30.9 years; $p<0.01$) but had similar sex distribution and ethnicity.

Most workers were male (84.1%) and worked in the fields (69.0%). Self-reported chronic medical conditions were uncommon except for obesity (body mass index ≥30 kg/m^2, 11.3%) and kidney disease (3.2%); 12.8% of workers (n = 234) took medications, most of whom (n = 122, 52%) took vitamins, followed by pain relievers/anti-inflammatory drugs (14%), antimicrobial drugs (7%), diabetes-related medications (7%), and proton pump inhibitors (6%). Only 5.9% reported ever having received an influenza vaccination, including 17 (6.4%) of 267 workers who self-reported chronic diseases. Workers began to receive COVID-19 vaccination through the workplace in August 2021 (ChAdOx1, AstraZeneca, https://www.astrazeneca.com; and mRNA-1273, Moderna, https://www.modernatx.com). Of 1,334 workers enrolled during June–December 2020 who had samples available, 616 (46.2%) were reactive for SARS-CoV-2 nucleocapsid IgG.

Household size averaged 5.7 persons (3.3 adults, 2.3 children), and half the workers (n = 877; 48.2%) lived the urban municipality of Coatepeque; the study catchment area was ≈2,600 km^2 (Figure 2). Median self-reported monthly income for the individual worker was US $337.20 (interquartile range $311.30–$389.10) and for the household was US $363.20 (interquartile range $324.30–$505.80); 58.0% of workers reported being worried about the inability to purchase food in the preceding 12 months.

Asymptomatic Control Subjects

Of the 915 asymptomatic randomly selected controls (August 10, 2020–October 10, 2021), the study team was able to contact 696 (76.0%) by telephone. There were no significant differences in enrollment characteristics between those contacted and those not contacted. Of the 696 controls who were contacted initially, 623 (89.5%) were successfully contacted at 1 week and 588 (84.4%) at 4 weeks.

Absenteeism

During August 31, 2020–February 19, 2021, a total of 36 workers (51.4%) had ≥1 day of work absence. Study personnel contacted 504 (68.5%) after 3 attempts, and there were no differences between contacted and uncontacted workers other than number of children (2.7

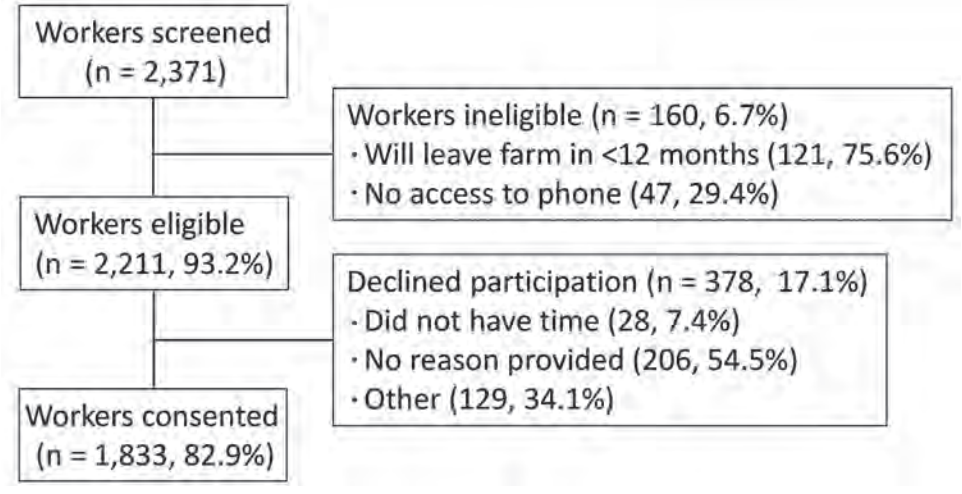

Figure 1. Flow diagram showing cohort of agricultural workers enrolled in the Agricultural Workers and Respiratory Illness Impact Study, southwestern Guatemala, June 2020–October 2021, and followed through October 10, 2021. Ineligible and nonconsenting workers were able to provide multiple reasons for not participating. Only workers who completed the day 0 (diagnosis) visit were called on day 7 and day 28. Follow-up visits scheduled for after October 10, 2021, were considered missing.

vs. 2.2; p<0.01). We compiled risk associations for absenteeism (Appendix Table 1, https://wwwnc.cdc.gov/EID/article/28/13/21-2303-App1.pdf).

Respiratory Illnesses

During June 15, 2020–October 10, 2021, the study identified 169 ILI episodes occurring among 145 persons; of those, 136 (93.8%) persons (for 157 ILI episodes) completed the 7-day follow-up survey and 129 (89.0%) persons (for 149 ILI episodes) completed the 28-day follow-up survey by completion of analysis (Appendix Table 2). The mean (±SD) number of days of fever at the time of testing was 3.3 (±2.0) days and of cough was 3.3 (±1.9) days; 97.5% of samples were collected <7 days after symptom onset. Of the 153 ILI episodes (among 132 unique persons) who had completed SARS-CoV-2 antigen testing by completion of analysis, 43 (28.1%) were positive for SARS-CoV-2. Of 151 ILI episodes (among 131 persons) who had complete influenza and RSV RT-PCR testing, 6 (3.7%) were RSV positive and 0 were influenza positive.

Incidence density for ILI was 12.0/100 person-years and for SARS-CoV-2–positive ILI was 3.1/100 person-years (Figure 3). The ILI and COVID-19

Table 1. Characteristics of 1,833 cohort participants in study of clinical and economic impact of COVID-19 in agricultural workers, Guatemala*

Characteristic	Value
Worker demographics	
Age, y, mean (SD)	30.9 (8.7)
Sex	
M	1,541 (84.1)
F	292 (15.9)
Latino ethnicity	801 (43.7)
Indigenous	113 (6.2)
Other	3 (0.2)
Do not know	916 (43.7)
Health worker	
Obesity, BMI >30 kg/m^2, n = 1,159 with data	131 (11.3)
Class 1, 30–<35	103
Class 2, 35–<40	24
Class 3, ≥40	4
Underlying conditions	
Kidney disease	58 (3.2)
Blood disorder, e.g., sickle cell disease	25 (1.4)
Cardiovascular disease, e.g., heart failure, CAD	29 (1.6)
Diabetes	27 (1.5)
Liver disease	19 (1.0)
Asthma	10 (0.6)
Pulmonary disease, e.g., COPD	10 (0.6)
Neurologic disease, e.g., stroke	10 (0.6)
Taking medications	234 (12.8)
Received influenza vaccine	108 (5.9)
Work conditions	
Type of work	
Administration	60 (3.3)
Field worker	1,264 (69.0)
Field manager	77 (4.2)
Packer/plant worker	413 (22.5)
Plant manager	19 (1.0)
Duration of employment, y	
<2	1,115 (60.9)
3–4	242 (13.2)
≥5	475 (25.9)
Monthly income, US$, median (IQR)	337.2 (311.3–389.1)
Household conditions	
No. adults in house, median (IQR)	3 (2–4)
No. children in house, median (IQR)	2 (1–3)
Concern about food insecurity in last year	1,063 (58.0)
Household monthly income, US$, median (IQR)	363.2 (324.3–505.8)
US$ spent in the past 7 days, median (IQR)	
Meat, fish, and seafood	25.9 (13.0–38.9)
Milk, eggs, and dairy products	15.6 (9.7–25.9)
Greens, vegetables, and fruit	13.0 (6.8–19.5)
Alcoholic drinks and tobacco	0 (0–0)

*Values are no. (%) except as indicated. BMI, body mass index; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; IQR, interquartile range; US $, US dollars.

Figure 2. Study region (area 2,600 km^2) for the Agricultural Workers and Respiratory Illness Impact Study, Guatemala, June 15, 2020–October 10, 2021, showing number of enrolled agricultural workers living in each municipality. A total of 1,819 persons had reported data. Inset map shows location of study area in Guatemala.

incidence densities for workers who were nucleocapsid IgG–negative at enrollment (n = 718) were 7.1/100 person-years and 2.3/100 person-years, respectively. For workers who were positive for nucleocapsid IgG positive at enrollment (n = 616), ILI incidence density was 4.5/100 person-years and COVID-19 incidence density 0.4/100 person-years. Older age was associated with greater risk for SARS-CoV-2–positive ILI compared with SARS-CoV-2–negative ILI (mean 35.0 years vs. 29.6 years; p = 0.001); there was no significant difference by sex, presence of any comorbidity, or obesity.

BioFire FilmArray RP2.1 testing (n = 40) on available specimens confirmed 9 of 9 SARS-CoV-2 infections tested and 1 of 1 RSV infection and identified an additional 8 picornaviruses (rhinovirus/enterovirus target on FilmArray) and 6 seasonal coronavirus (3 NL63, 1 OC43, and 2 N229E) ILI cases. The adult worker was usually the index case-pateint within the household for SARS-CoV-2 ILI (>80%) infections (Table 2, https://wwwnc.cdc.gov/EID/article/28/13/21-2303-T2.htm) and ILI (>85%) (Appendix Table 2).

Workers who had SARS-CoV-2–positive ILI had longer fever duration at the time of diagnosis (day 0; 3.3 days vs. 2.3 days; p<0.01) and increased frequency of anosmia (44.2% vs. 17.3%; p<0.01) and dysgeusia (48.8% vs. 24.6%; p<0.01), compared with SARS-CoV-2–negative workers (Table 2). SARS-CoV-2 case-patients were also more likely to have difficulty

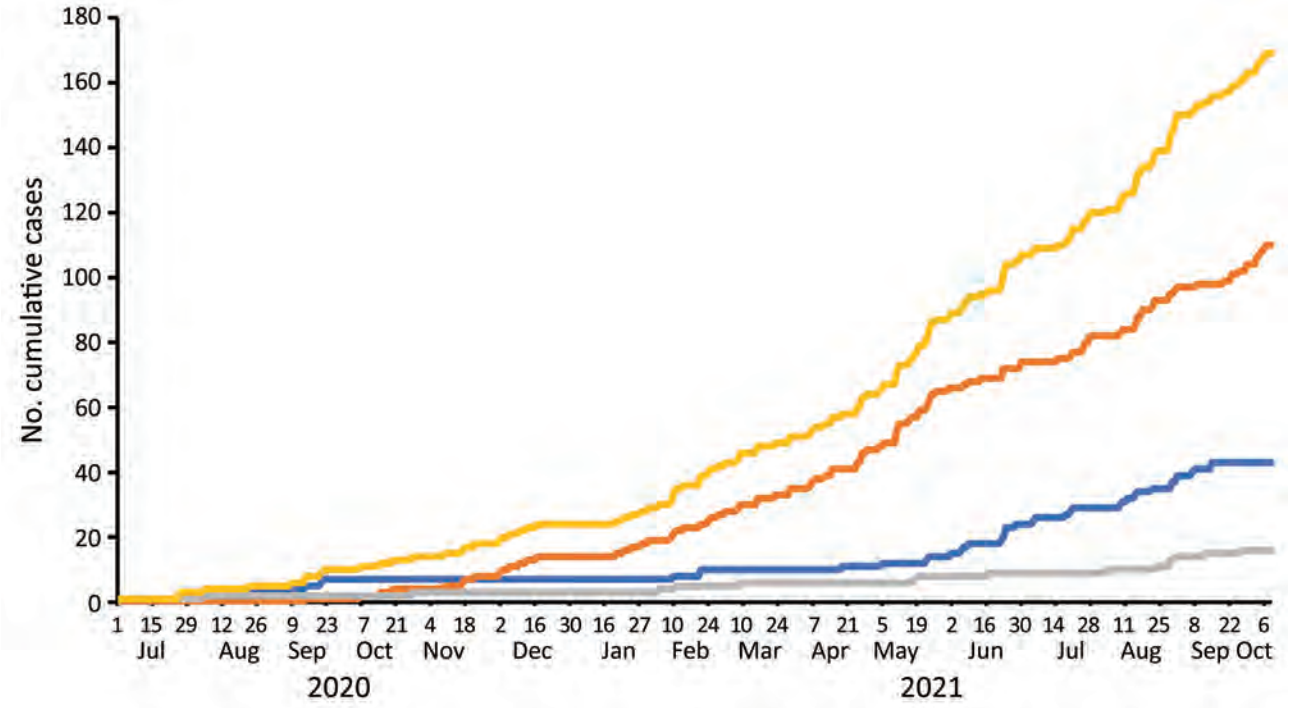

Figure 3. Cumulative influenza-like infections (ILI) among agricultural workers in the Agricultural Workers and Respiratory Illness Impact Study, Guatemala, June 15, 2020–October 10, 2021. During June 2020–October 2021, ILI was defined as cough and fever. During January 2021, the ILI case definition was expanded to cough or fever or shortness of breath. Includes all-cause ILI (yellow), SARS-CoV-2–positive ILI (blue), SARS-CoV-22–negative–ILI (orange), and ILI without testing obtained (gray).

concentrating (41.9% vs. 20.9%; p = 0.01), irritability (58.1% vs. 33.6%; p = 0.01), and dependence on others (37.2% vs. 20.9%; p = 0.04). SARS-CoV-2–positive workers had higher systemic FluiiQ severity scores (indicating greater disease severity) at diagnosis than did SARS-CoV-2–negative workers, but other differences in clinical scores remained nonsignificant. SARS-CoV-2–positive workers reported worse impact scores for daily activities (0.50 vs. 0.22; p = 0.01) and emotions (0.62 vs. 0.31; p<0.01) than for SARS-CoV-2–negative workers at diagnosis and worse impact on others score at day 7 (0.37 vs. 0.16; p = 0.03), but all other FluiiQ well-being scores showing a similar nonsignificant trend (Table 2; Figure 4). Among ILI cases, we found no significant difference in FluiiQ score based on age, sex, and presence of any comorbidity or obesity. We compiled clinical outcomes of workers who had ILI episodes versus asymptomatic controls (Appendix Table 2).

Economic Outcomes

Compared with SARS-CoV-2–negative workers who had ILI, SARS-CoV-2–positive workers had greater self-reported lost income (median US $127.10 vs. $0; p<0.01), and combined (healthcare, transportation, lost wages) total cost (US $147.90 vs. US $12.70; p<0.01) at day 7 (reported over the preceding 2 weeks) (Figure 5). Workers infected with SARS-CoV-2 also had more days of work absence (p<0.01); most (81.8%) had >5 days of work absence. Household expenditures on fruits/vegetables were higher at day 7 for SARS-CoV-2–positive workers vs. SARS-CoV-2–negative workers who had ILI (US $19.50 vs. US $13.00; p< 0.01). Differences for all other household expenditures between SARS-CoV-2 test-positive and test-negative workers were not statistically significant.

Discussion

As of October 10 2021, farm workers in Guatemala in this prospective cohort study experienced a substantial burden of acute respiratory illness during the COVID-19 pandemic, of which 1/4 tested positive for SARS-CoV-2; those with COVID-19 had greater disease severity, absenteeism, and economic losses than workers with SARS-CoV-2–negative ILI. Similar to limited data for the United States (*1*), farm workers in Guatemala were at risk for SARS-CoV-2 infection (3.1 cases/100 person-years) throughout 2020–2021. Nucleocapsid IgG at enrollment was protective against subsequent disease; additional analyses will explore this observation. Compared with other members of their households, the agricultural workers nearly

always had the index symptomatic case. These findings, along with the critical role agricultural workers play in Guatemala and global food security (*4*,*6*), lend support to the prioritization of vaccinating agricultural workers against COVID-19.

Although preliminary, our findings suggest COVID-19 illness was associated with greater overall clinical severity and impairment, which persisted at 7-day and 28-day after illness, than for non–SARS-CoV-2 ILI cases. COVID-19 symptoms were consistent with those reported elsewhere; higher frequencies of anosmia and dysgeusia and prolonged fever differentiating COVID-19 from other ILI cases. COVID-19 was strongly associated with irritability and difficulty concentrating, consistent with postacute sequelae of SARS-CoV-2 (long COVID) (*32*,*33*). The irritability and inability to concentrate, which persisted in some workers at both 7 and 28 days, might place workers at risk (e.g., when using machetes to harvest bananas and when operating heavy equipment). The FluiiQ well-being scores, which include socioemotional and functional activities, generally indicated more severe illness among workers who had COVID-19 compared with workers who had another ILI at the time of diagnosis and day 7; the trend was nonsignificant at 28 days. It is unknown to what extent symptoms or sequelae persist beyond 28 days in this population.

Agricultural workers in this cohort experienced a major economic impact from COVID-19. Self-reported data suggest a major difference in absenteeism, lost earnings, and total costs between COVID-19 and other ILI cases. Median monthly household income (US $363.20), already just below the mean basic monthly food basket price in Guatemala (US $386.30), was reduced greatly for workers who had COVID-19 (median lost income US $127.10, median total cost of illness US $147.90), placing these households at increased risk for food insecurity and economic hardship. Economic insecurity is one of the primary drivers of emigration from Guatemala (*34*,*35*); thus, the economic impact and policy implications of COVID-19 on these agricultural workers and their households, as well as others in similar settings, might extend beyond the borders of Guatemala.

Although SARS-CoV-2 was the most frequently detected respiratory pathogen among workers who had ILI, we detected no cases of influenza and only 6 cases of infection with RSV. Influenza and RSV circulate year-round in Guatemala and comprise a substantial proportion of ILI cases in population-based studies in Central and South America (*36*–*39*). The lower incidence observed in our cohort suggested mitigation strategies (primarily closing of schools, mask use, and some level of physical distancing) might have been effective in limiting some transmission of influenza and RSV. The observation cases of rhinovirus/enterovirus and seasonal coronaviruses (NL63, OC43, and N229E) in a subset of our cohort is consistent with other reports (*40*,*41*), although the reasons for these detections despite physical distancing measures merit further study. The AGRI cohort and similar studies will provide useful

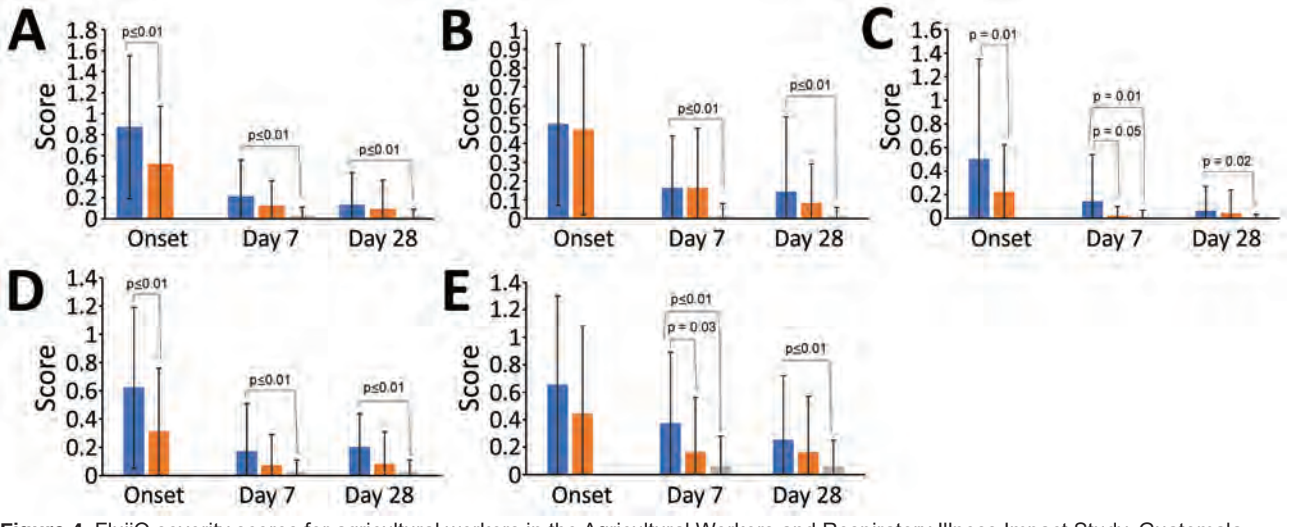

Figure 4. FluiiQ severity scores for agricultural workers in the Agricultural Workers and Respiratory Illness Impact Study, Guatemala, June 15, 2020–October 10, 2021. Scores (range 0–3), by subdomain, are shown for workers who had SARS-CoV-2–positive influenza-like illness (ILI), SARS-CoV-2–negative ILI, and asymptomatic controls. Higher score indicates greater clinical severity (A, B) or greater negative impact on well-being (C, D, E). A) Systemic score; B) respiratory score; C) impact on daily activities; D) impact on emotions; E) impact on others. Significant differences ($p<0.05$) are identified within each group. Blue indicates SARS-CoV-2–positive ILI, orange indicates SARS-CoV-2–negative ILI, and gray indicates asymptomatic control subjects. Error bars indicate means and SDs.

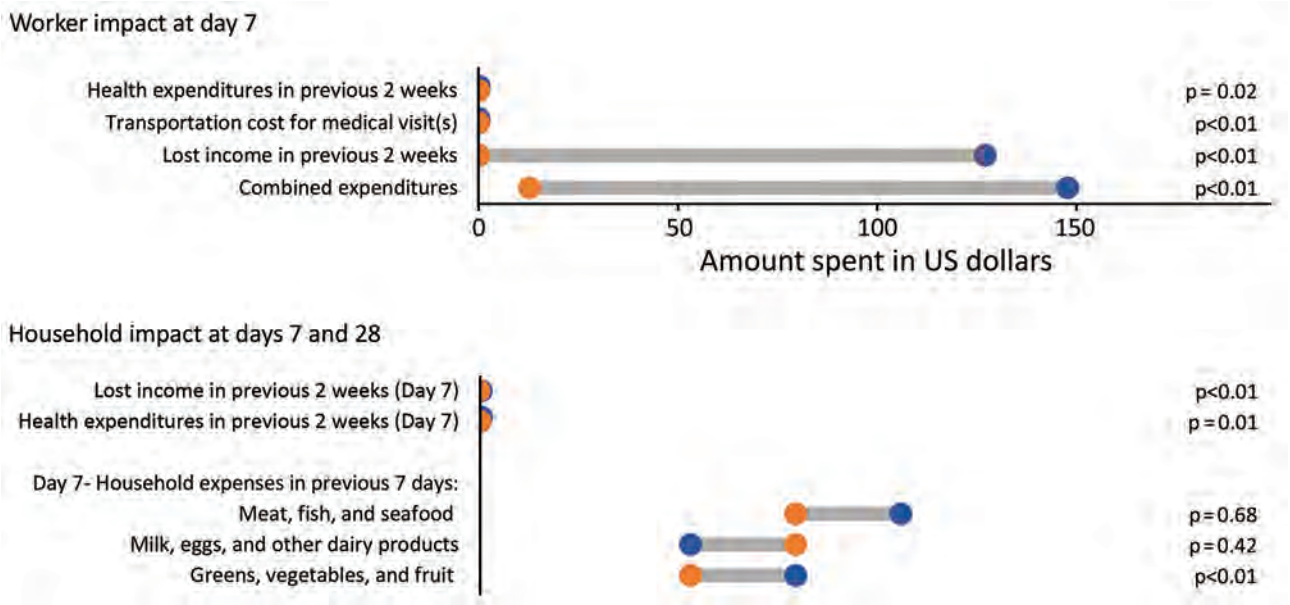

Figure 5. Differences in expenditures between SARS-CoV-2–positive and SARS-CoV2–negative agricultural workers who had influenza-like illness (ILI) in the Agricultural Workers and Respiratory Illness Impact Study, Guatemala, June 15, 2020–October 10, 2021. Workers who had SARS-CoV-2–positive ILI (dark blue circle) reported greater lost income and combined expenditures related to their illnesses in the week after their illness than SARS-CoV-2–negative workers who had ILI (orange circle).

observations on the effectiveness of population-based preventive measures, such as vaccines, on the burden of respiratory pathogens. Also, our data demonstrated that syndromic surveillance in the workplace is a feasible population-based approach to rapidly characterize an emerging pathogen.

The AGRI study design had some inherent strengths and limitations. Although the study included weekly visits to worksites to identify symptomatic ILI case-patients, it still required some level of self-reporting to study personnel, and therefore might underestimate incidence. Workers with laboratory-confirmed SARS-CoV-2 are required to isolate and might be incentivized to underreport illness to avoid lost wages, thus providing a bias toward lower incidence and more severe cases of disease being reported. Required isolation probably increased duration of absenteeism for workers who are SARS-CoV-2 positive, although it still reflected the consequences of COVID-19 in this population. Self-reported study outcomes are also subject to recall bias, which we aimed to minimize by including control subjects who had similar follow-up. Laboratory test results are provided to the worker when available; thus self-reported outcomes might be impacted by diagnostic bias.

We did not perform pathogen testing on controls. We used an antigen test for detection of SARS-CoV-2 infection and an ELISA for detection of nucleocapsid IgG, which might have decreased performance compared with PCR and virus neutralization assays, respectively. Testing was nearly always (>97%) performed within 7 days of symptom onset, and future studies will compare various testing approaches. Future studies will also include company-reported data, which will provide a more objective assessment of wages, enabling us to compare self-reported and company-reported metrics. Finally, to decrease the risk for healthy worker bias (*42*), the study collected postacute (28-day) outcomes on all ILI case-patients and will ultimately measure loss of employment (using company data) as an outcome measure of ILI.

In conclusion, preliminary data from the AGRI cohort suggest major clinical and socioeconomic impacts of respiratory illnesses, especially COVID-19, on agricultural workers in Guatemala. The study demonstrates the feasibility and value of conducting workforce-based syndromic surveillance during epidemic activity and uses several innovative approaches to measure disease outcomes in acute and postacute settings, such as active surveillance and molecular diagnostics within a large banana farm and company-reported economic measures. It also provides a more comprehensive assessment of how communicable diseases economically effect an essential, yet vulnerable, workforce population and their households. Given the high clinical and

economic burden of COVID-19 among agricultural workers, and their probable role in household transmission of COVID-19, our results support prioritizing persons working in the agricultural sector for vaccination against COVID-19, potentially through the workplace.

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D.O., M.C., M.L., F.H., H.M., K.E., L.S.N., and E.J.A. developed the study and methods, performed investigations, and wrote the paper; G.G., E.B., A.N.C., N.R., K.A., G.M., G.A.B., D.B., K.L., M.S., K.Q., and G.E. developed methods, performed investigations, and administered the study; M.L., M.G., J.M., A.N.C., C.I., L.M.D., E.Z., and E.A.B. analyzed data, visualized the study, and wrote the paper; and D.O., M.C., and E.J.A, supervised and administered the study.

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Outcomes after Acute Malnutrition Program Adaptations to COVID-19, Uganda, Ethiopia, and Somalia

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At the onset of the COVID-19 pandemic, protocols for community-based management of acute malnutrition (CMAM) were implemented to support continuity of essential feeding services while mitigating COVID-19 transmission. To assess correlations between adaptation timing and CMAM program indicators, we evaluated routine program data in Uganda, Ethiopia, and Somalia for children 6–59 months of age. We specifically analyzed facility-level changes in total admissions, average length of stay (ALOS), total children screened for admission, and recovery rates before and after adaptations. We found no statistically significant changes in program indicators after adaptations. For Somalia, we also analyzed child-level changes in ALOS and in weight and mid–upper arm circumference at admission and discharge. ALOS significantly increased immediately after adaptations and then decreased to preadaptation levels. We found no meaningful changes in either weight or mid–upper arm circumference at admission or discharge. These findings indicate that adapted CMAM programs can remain effective.

In 2020, severe acute malnutrition affected 13.6 million children <5 years of age (*1*), and those affected by severe acute malnutrition were 11.6 times more likely to die than those not affected (*2*). Community-based management of acute malnutrition (CMAM), a proven approach to treat undernutrition, comprises community outreach as well as outpatient and inpatient treatment programs for children with severe acute malnutrition and severe acute malnutrition with medical complications and targets supplementary feeding programs for children with moderate acute malnutrition (*3*). CMAM programs are operational in ≈70 countries worldwide (*4*).

After the COVID-19 pandemic was declared in early 2020, food insecurity was projected to affect childhood nutrition (*5*,*6*). To maintain essential services while mitigating transmission risk, the United Nations Children's Fund, the Global Nutrition Cluster, the Global Nutrition Cluster Technical Alliance, and the World Health Organization released guidance on CMAM operations during COVID-19 (*7*–*9*). Guidance included adapting normal CMAM protocols to reduce clinic visit frequencies and physical contact between staff and patients; adaptations included longer intervals between clinic visits, training of caregivers to measure the mid–upper arm circumference (MUAC) of their own child and self-refer as needed, and MUAC-only programming. Components of these adaptations have been evaluated in trials and controlled studies (*10*–*12*); however, neither the effect on nutrition outcomes of implementing multiple adaptations at scale nor the effect of all adaptations when implemented by routine programs outside the quality controls of 2-armed cohort trials have been evaluated (*10*).

Given the urgency posed by the COVID-19 pandemic, the adaptations were implemented by CMAM programs despite limited evidence regarding effectiveness (*13*–*17*). To provide information for CMAM programming, we evaluated changes in enrollment and treatment outcome indicators corresponding with implementation of program adaptations for COVID-19.

Methods

CMAM Program Data

We asked all outpatient therapeutic programs (OTPs) in Somalia and Ethiopia and all targeted supplemental feeding programs (TSFPs) in Uganda supported

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by Action Against Hunger USA for children 6–59 months of age to provide electronic data for all dates for which historical data were available via a secure file-sharing platform. Data for all countries ended in December 2020, and for Uganda, data began in January 2019; for Ethiopia, in July 2019; for Somalia at the facility level, in November 2019; and for Somalia at the child level, in January 2017. Analyses included facility-level (outpatient community clinics) indicators of enrollment and treatment outcomes for all 3 countries and child-level indicators for Somalia (Table 1). Program coordinators in each country provided information on the timing and type of protocol adaptations through a separate online survey conducted in July 2020 (*13*,*18*).

We evaluated several measures reported monthly by facilities, including total persons screened and total admitted, as well as 2 measures of treatment outcomes: recovery rate and average length of stay (ALOS). Total screened included the number of children for whom MUAC, weight and height, or both were measured at the facility or in the community to assess whether they were malnourished and eligible for admission. Total admissions included all children newly enrolled each month. ALOS was defined as the average number of days elapsed between admission and discharge for all children discharged as recovered, and recovery rate was defined as the percentage of children discharged from the treatment program meeting the discharge criteria by MUAC or weight-for-height z-score.

In Somalia, selected additional indicators were available for all children admitted into OTPs; indicators included length of stay (days) and anthropometric measurements. For each child, weight (kilograms) and MUAC (centimeters) were measured at admission and discharge. For a sensitivity analysis, we compared models testing weight with models testing weight-for-height z-score and weight-for-age z-score.

During the study period, several facilities experienced closures and stock outages. We excluded from analysis all outcomes for months when facilities did not have any children enrolled, and we did not calculate recovery rates for months when children were discharged en masse because of closures or stock outages. For months when a data point from some facilities was missing, we calculated aggregate or mean values for all remaining facilities.

Covariates

To account for typical increases in enrollment in CMAM programs during the seasonal period of increased food insecurity (lean season), we adjusted models for the timing of the lean season in each country. Similarly, to account for anticipated declines in care-seeking associated with national COVID-19 restrictions, we included as covariates in our models indicators of domestic lockdowns or travel restrictions to assess independent associations with measured program indicators. We extracted data for the period of the lean season in each country from

Table 1. Summary of analyzed CMAM program data and program adaptations implemented by each included program*

Country, level	Program type	No. facilities providing data	Dates data available; date adaptations began	Program outcome variables	Program adaptations
Uganda, facility	Targeted supplementary feeding program	5	Jan 2019–Dec 2020; Apr 2020	Total admissions, recovery rate	Family MUAC, suspension of community screening, reduced frequency of follow-up visits, modified admission/discharge criteria
Ethiopia (Oromia region), facility	Outpatient therapeutic program	81	Jul 2019–Dec 2020; May 2020	Total admissions, recovery rate	Family MUAC, suspension of community screening, reduced frequency of follow-up visits
Somalia					
Facility	Outpatient therapeutic program	12	Nov 2019–Dec 2020; Mar 2020	Total admissions, recovery rate, total screened, average length of stay	Family MUAC circumference, suspension of community screening, reduced frequency of follow-up visits
Child	Outpatient therapeutic program	8	Jan 2017–Nov 2020; Mar 2020	Average length of stay, admission/discharge weight, admission/discharge MUAC	

*Family MUAC trains caregivers to identify childhood malnutrition by using a MUAC tape. Suspension of community screening suspends case finding of childhood malnutrition by community healthcare workers. Reduced frequency of follow-up visits changes the clinic visit schedule for children enrolled in outpatient therapeutic programs and targeted supplemental feeding programs. Modified admission/discharge criteria alter the clinical benchmarks for children to be admitted to/discharged from CMAM programs. CMAM, community-based management of acute malnutrition; MUAC, mid–upper arm circumference.

Famine Early Warning Systems Network reports (*19*) and data on COVID-19 mitigation measures data from the Mitigation Tracker maintained internally by the Centers for Disease Control and Prevention (CDC). The Mitigation Tracker database was populated with data from reports and websites from the respective governments and United Nations agencies and media reports, shared with CDC or posted online. We coded COVID-19 mitigation measures and lean seasons as binary variables. We considered as an additional covariate confirmed COVID-19 cases/month but did not include it in the study because of variations in testing policy and surveillance sensitivity in each country.

Analyses

We constructed interrupted time series models to analyze CMAM program indicator data at the facility and child levels before and after protocol adaptations were put into place while accounting for lean seasons and COVID-19 mitigation measures. We analyzed indicators in individual linear segmented regression models for each country and each indicator.

We aggregated program indicators to the country level after data cleaning and modeled monthly admissions, total children screened, and ALOS as means. Means used as indicators were normally distributed and were robust to differences in the number of reporting facilities per country. We analyzed recovery rates as aggregate rates across all facilities per country.

Models included as fixed effects time, level, and trend changes since protocol adaptations; lean seasons; and COVID-19 mitigation measures. Child-level models also included a random effect for facilities to account for correlation between children in a given facility and baseline differences in indicator values between facilities. Because availability of prepandemic data differed by facility and by country, child-level models included data for all available dates for each facility that provided child-level data.

After the initial adaptations were made, Somalia further adapted protocol. For a sensitivity analysis, outcomes were first modeled with just the initial date of change and then with subsequent dates of protocol change, and results were compared. Models presented include only the initial date of program adaptations.

Two indicators (recovery rate and ALOS) were calculated at discharge and were therefore theorized not to be modified immediately after implementation of program adaptations. Models presented include no time lag in recorded recovery rates and ALOS; however, given an observed median length of stay of 42 (interquartile range 42–49) days, we conducted a sensitivity analysis using time lag periods of 1 and 2 months between the change in COVID-19 policies and those 2 outcomes (data not shown). All other indicators (total admissions, total children screened, and all child-level indicators) were captured at admission and analyzed with no lag.

We performed all data aggregation, cleaning, and analysis by using R version 4.0.3 (https://www.r-project.org). This activity was reviewed by CDC and was conducted consistent with applicable federal law and CDC policy (45 C.F.R. part 46.102(l)(2), 21 C.F.R. part 56; 42 U.S.C. Sect. 241(d); 5 U.S.C. Sect. 552a; 44 U.S.C. Sect. 3501 et seq).

Results

Five Uganda TSFP facilities, 81 Ethiopia OTP facilities, and 12 Somalia OTP facilities provided facility-level data. For Ethiopia, we dropped 78 facility months from the analysis of recovery rate because of data quality issues; for the facility months excluded, the tally of the total number discharged did not equal the tally of children discharged as recovered, transferred, defaulted, nonresponsive, and dead. Of the Somalia facilities, 8 provided child-level data for 11,719 children and the remaining 4 provided only facility-level data. For Somalia, we dropped 1 facility month from the analysis of total admissions and of total screened because of a complete facility closure and dropped 14 facility months from the analysis of recovery rate and 13 from the analysis of ALOS because of mass discharges resulting from stock outages.

The Uganda team implemented TSFP adaptations for moderate acute malnutrition treatment on April 2020; adaptations included modifying the frequency of TSFP clinic visits from once every 2 weeks to monthly, adding the family MUAC approach (training caregivers to use a MUAC measuring tape to identify malnutrition in their children), suspending community-based screening, and modifying admission and discharge criteria from an upper MUAC threshold of 12.5 cm to 12.9 cm (Table 1). In May 2020, the team working in the Oromia region of Ethiopia modified the frequency of OTP clinic visits from weekly to once every 2 weeks, suspended community-based screening, and began family MUAC. The Somalia team began adaptations in March 2020, modifying the frequency of OTP clinic visits from weekly to once every 2 weeks, suspending community-based screening, and scaling up the family MUAC approach for outreach screening. However, in May

2020, Somalia facilities reverted to using weight-for-height z-score for admissions, and in September 2020, they returned to their preadaptations follow-up visit schedule.

In Uganda, COVID-19 mitigation measures started in March 2020 and extended through the last date for which CMAM data were available (December 2020); measures included a national curfew, a temporary ban on public transit, and a 14-day national lockdown. In Ethiopia, COVID-19 mitigation measures began March 2020 and were still in place through the last date with available CMAM data (December 2020). In Somalia, COVID-19 mitigation measures started in April 2020 and extended through December 2020 and included a national curfew.

Facility-Level Data

Mean total admissions in Uganda, Ethiopia, and Somalia did not change significantly after program adaptations (Figure 1, panel A; Figure 2, panels A–C). In the month immediately after revised protocols began, compared with the month immediately before, monthly average total admissions increased in Uganda from 84.6 children to 93.4 children ($p = 0.58$); in Ethiopia, monthly average admissions increased from 4.4 children to 5.8 children ($p = 0.13$); and in Somalia, monthly average admissions decreased from 215.7 children to 204.7 children ($p = 0.73$). The month-to-month trend in mean total admissions after program adaptations compared with the trend in months leading up to program adaptations did not change significantly. In Uganda before adaptations, mean total admissions trended upward at a rate of 0.2 children/month; after adaptations, admissions trended downward by 1.9 children/month ($p = 0.62$). In Ethiopia, mean total admissions decreased at a rate of 0.2 children/month before protocol adaptations and 0.1 children/month after adaptations ($p = 0.87$). In Somalia, mean total admissions increased by 12.8 children/month before adaptations and decreased by 6.4 children/month after adaptations ($p = 0.28$). Our analyses showed no statistically significant effect of lean seasons, COVID-19 lockdowns, or movement restrictions on total admissions (Figure 1, panel A). Results were similar when we included additional variables accounting for subsequent protocol changes for Somalia.

Similarly, the models showed no significant change in recovery rates after program adaptations (Figure 1, panel B; Figure 3, panels A–C). Recovery rates for all 3 countries were high over the entire period, averaging 93.9% in Uganda, 94.6% in Ethiopia, and 99.0% in Somalia. In the month immediately after program adaptations were implemented, recovery rates dropped by 1.3% in Uganda ($p = 0.61$), 1.5% in Ethiopia ($p = 0.73$), and 1.00% in Somalia ($p = 0.14$); after program adaptations, the monthly trend in recovery rates changed (increased or decreased) by 0.2%/month in Uganda ($p = 0.75$), 0.8% in Ethiopia ($p = 0.21$), and 0.03% in Somalia ($p = 0.93$). However, the recovery rate among CMAM programs in Ethiopia was lower during the lean season, averaging 95.5% outside lean seasons and 92.5% in a lean season ($p = 0.022$). Results were similar at lags of 1 and 2 months and when additional variables accounting for subsequent protocol changes for Somalia were included.

Somalia was the only country that provided facility-level data on the total number of children screened and ALOS. Neither outcome indicated a statistically significant change after program adaptations (Figure 1, panels C–D; Figures 4, 5). The average total number of children screened increased from 1,624.8 to 1,708.6 in the month immediately after program adaptations ($p = 0.68$), and the ALOS increased from 46.0 days to 48.7 days ($p = 0.51$); neither increase was statistically significant. The rates of total children screened and ALOS were also not statistically significant ($p>0.05$), and we found no statistically significant effect of either lean season or COVID-19 mitigation measures on either of these outcomes in Somalia. Again, results were similar when we included additional variables accounting for subsequent protocol changes for Somalia.

Child-Level Data

Eight OTP facilities in Somalia provided data through November 2020 at the individual child level. Three facilities provided data from January 2017, four from October 2019, and one from November 2019. From January 2019 through December 2020, the average weight of children at admission was 6.9 kg and at discharge 8.2 kg; the average MUAC at admission was 111.8 cm and at discharge 120.6 cm. None of these metrics changed significantly immediately after program adaptations were implemented ($p>0.05$ for all comparisons). Changes in trends after adaptations were not statistically significant for MUAC at admission or weight at discharge (Table 2; Figures 6, 7). However, trend in MUAC at discharge changed significantly ($p = 0.050$), as did weight at admission ($p = 0.013$), although the effect sizes of both were not clinically relevant. Sensitivity analyses comparing admission weight-for-height and weight-for-age z-scores to admission weight showed similar results between all 3 outcomes (data

not shown). MUAC at discharge trended upward at a rate of 0.008 mm/month before program adaptations and switched to trend downward at a rate of 0.2 mm/month after program adaptations; weight at admission decreased by 0.01 kg/month before adaptations and increased by 0.04 kg/month afterward (Table 2; Figures 6–7). To put these results into context, before program adaptations, the proportion of children admitted by low weight-for-height only was 11.6%, similar to the 9.3% in the months

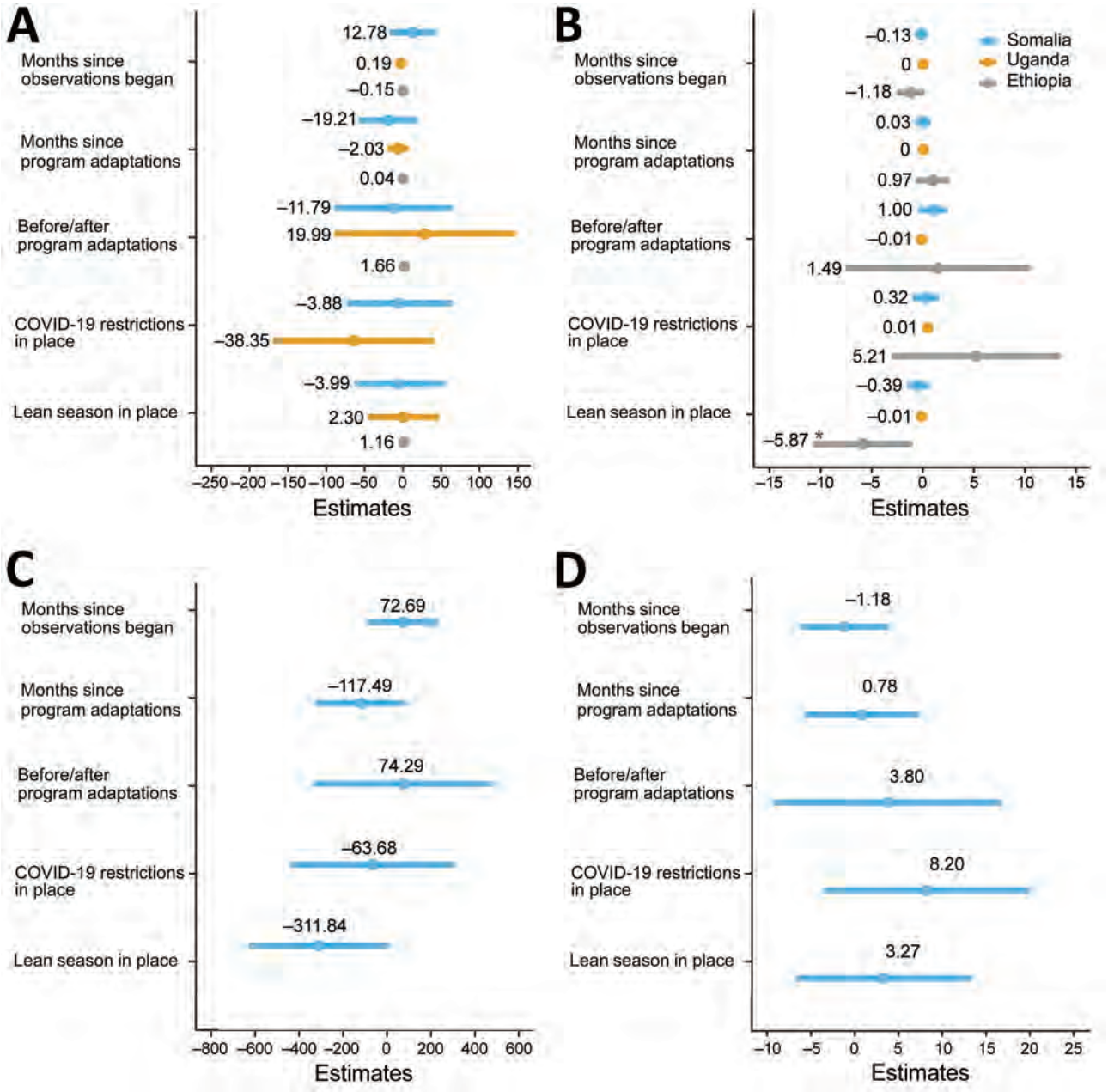

Figure 1. Summary and comparison of facility-level interrupted time series models used in study of outcomes after acute malnutrition programs were adapted for COVID-19 in 3 countries, showing the absolute difference in average total admissions (A), aggregate cure rate (B), average total screened (C), and average length of stay (D) in 12 Somalia outpatient therapeutic facilities, 5 Uganda targeted supplementary feeding program facilities, and 81 Ethiopia outpatient therapeutic program facilities attributed to immediate and long-term effects of program adaptations, lean seasons, and COVID-19 lockdowns. Circles (data markers) and lines indicate point estimates and 95% CIs. Point estimates are labeled, and the asterisk indicates fixed effects with statistically significant results ($p<0.05$). Total screened and average length of stay was analyzed for Somalia only. COVID-19 restrictions in place refers to COVID-19 mitigation policies that restrict movement, including restrictions on transportation, lockdowns, and curfews. Lean seasons refer to months of increased food insecurity. Time frame analyzed varies by country.

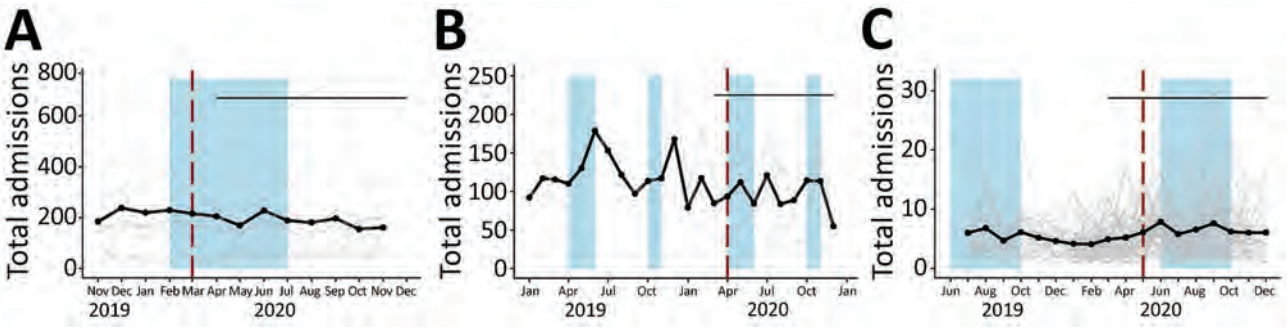

Figure 2. Average total admissions in study of outcomes after acute malnutrition programs were adapted for COVID-19 at 12 Somalia outpatient therapeutic programs (A), 5 Uganda targeted supplementary feeding programs (B), and 81 Ethiopia outpatient therapeutic programs (C) at community management of acute malnutrition facilities. Black dots and lines indicate the mean values across all facilities in each country. Gray lines indicate values for each facility. Red vertical dashed lines indicate dates that program adaptations began. Black horizontal lines indicate dates that COVID-19 restrictions were in place. Blue shading indicates lean seasons. COVID-19 restrictions in place refers to COVID-19 mitigation policies that restrict movement (e.g., restrictions on transportation, lockdowns, and curfews). Lean seasons refer to months of increased food insecurity. Time frame varies for each country.

after program adaptations. Of note, ALOS, which averaged 48.6 days before program adaptations, increased by an average of 12.3 days immediately after program adaptations ($p<0.001$) and decreased gradually at an average rate of 3.8 days/month, reaching an average of 40.1 days in October 2020 ($p<0.001$) (Table 2; Figure 8). As for all facility-level results, model outputs were similar for those including variables for subsequent protocol changes.

Discussion

For all 3 countries evaluated, changes in total admissions and total number of children screened after CMAM protocols were adapted for COVID-19 did not differ significantly. Although several facilities temporarily closed because of stock outages, these closures were short term, and after reopening, admissions and total number screened returned to preclosure levels. Modifications to CMAM programs—including family MUAC instead of active case finding by healthcare workers, revising enrollment criteria from either low MUAC or weight-for-height to low MUAC alone, and widening MUAC thresholds—were predicted to affect admissions, but it was not clear if they would cause admissions to rise or fall. Retrospective, observational studies in refugee camps in Cox's Bazaar, Bangladesh, and in Zambia showed increased total admissions after implementation of family MUAC and reduced frequency of follow-up visits (*14*,*15*). However, those analyses were only descriptive, without quantitative measures of change, limiting comparability. Most likely, the effects depend on context; for example, in select contexts, rising economic and food insecurity may increase underlying prevalence of acute malnutrition.

Our analyses further show no immediate or long-term change in the proportion of children discharged as recovered. Recovery rates were anticipated to deteriorate in programs that decreased the frequency

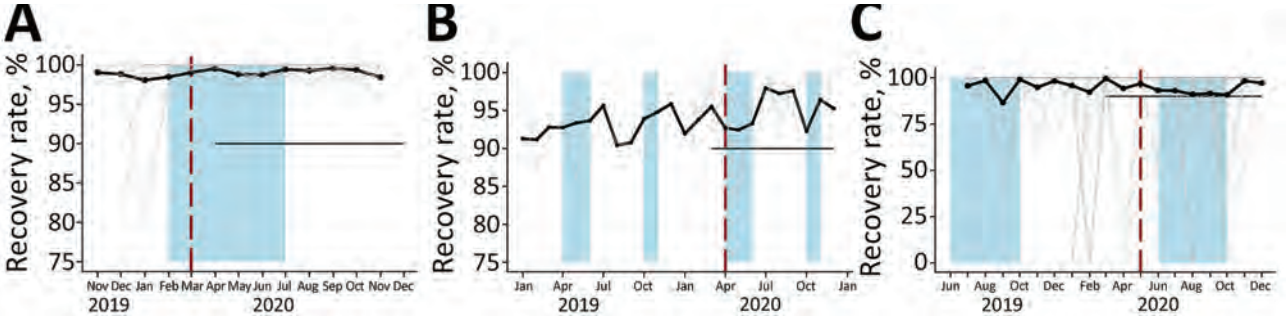

Figure 3. Recovery rates in 12 Somalia outpatient therapeutic programs (A), 5 Uganda targeted supplementary feeding programs (B), and 81 Ethiopia outpatient therapeutic programs (C) at community management of acute malnutrition facilities. Black dots and lines indicate the values across all facilities in each country. Gray lines indicate values for each facility. Red vertical dashed lines indicate date program adaptation began. Black horizontal lines indicate dates that COVID-19 restrictions were in place. Lean seasons are indicated by blue shading. COVID-19 restrictions in place refers to COVID-19 mitigation policies that restrict movement, including restrictions on transportation, lockdowns, and curfews. Lean seasons refer to months of increased food insecurity. Time frame varies for each country.

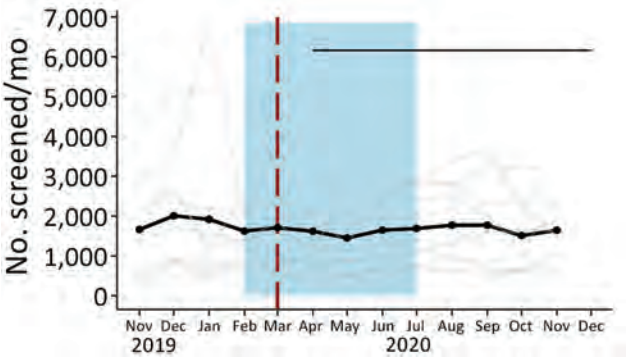

Figure 4. Total screened in community management of acute malnutrition facility outpatient therapeutic programs, Somalia, November 2019–December 2020. Black dots and line indicate the mean values across all facilities. The gray line indicates the raw values for each facility. Red vertical dashed lines indicate date program adaptations began. Black horizontal line indicates dates that COVID-19 restrictions were in place. Blue shading indicates lean seasons. COVID-19 restrictions in place refers to COVID-19 mitigation policies that restrict movement (e.g., restrictions on transportation, lockdowns, and curfews). Lean seasons refer to months of increased food insecurity.

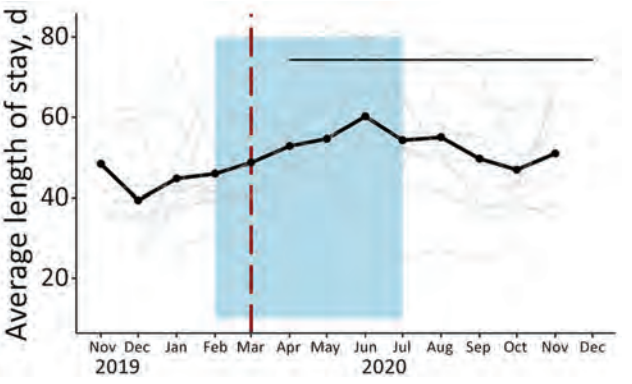

Figure 5. Average length of stay in community management of acute malnutrition facility outpatient therapeutic programs, Somalia, November 2019–December 2020. Black data marker and line indicate the mean value across all facilities. Gray line indicates raw values for each facility. Red vertical dashed lines indicate date program adaptations began. Black horizontal line indicates dates that COVID-19 restrictions were in place. Blue shading indicates lean seasons. COVID-19 restrictions in place refers to COVID-19 mitigation policies that restrict movement (e.g., restrictions on transportation, lockdowns, and curfews). Lean seasons refer to months of increased food insecurity.

of follow-up visits because the interval between nutritional and medical assessments would be longer, although ≥1 study has shown that reduced frequency of follow-up visits does not necessarily reduce treatment efficacy (*20*). Furthermore, sharing of rations among siblings, such that the malnourished child receives less than the intended amount, is a known outcome of providing supplementary rations through CMAM programs (*21*,*22*), and anecdotal evidence in multiple contexts reported that when larger portions were distributed to cover longer time intervals between facility visits, sharing and selling of rations increased (*13*), potentially lowering the caloric intake of the child. However, recovery rates across

Table 2. Summary of child-level interrupted time-series models showing correlation between program indicators and adaptations, lean seasons, COVID-19 lockdown at 8 Somalia community-based management of acute malnutrition facility outpatient therapeutic programs, Jan 2019 – Nov 2020*

Time in relation to program adaptation	Mid–upper arm circumference at admission, cm		Mid–upper arm circumference at discharge, cm		Weight at admission, kg		Weight at discharge, kg		Average length of stay, d	
	Estimate (95% CI)	p value	Estimate (95% CI)	p value	Estimate (95% CI)	p value	Estimate (95% CI)	p value	Estimate (95% CI)	p value
Months since start	0.0076 (−0.0040 to 0.019)	0.20	0.0082 (−0.019 to 0.036)	0.56	−0.012 (−0.017 to −0.0079)	**<0.001**	−0.014 (−0.020 to −0.0089)	**<0.001**	−0.17 (−0.29 to −0.044)	**0.0084**
Months since program adaptations	0.0038 (−0.093 to 0.10)	0.94	−0.23 (−0.47 to 0.0039)	**0.050**	0.049 (0.011 to 0.087)	**0.013**	0.0077 (−0.040 to 0.055)	0.75	−3.80 (−4.84 to −2.76)	**<0.001**
Before/after program adaptations	0.12 (−0.47 to 0.71)	0.69	0.99 (−0.41 to 2.39)	0.17	0.14 (−0.089 to 0.37)	0.24	0.28 (−0.0017 to 0.57)	0.055	12.30 (5.99 to 18.63)	**<0.001**
COVID-19 mitigations in place	−0.41 (−1.04 to 0.23)	0.21	0.23 (−1.28 to 1.73)	0.77	−0.26 (−0.51 to −0.053)	**0.043**	−0.12 (−0.43 to 0.18)	0.44	9.60 (2.81 to 16.40)	**0.0067**
Lean season in place	−0.26 (−0.51 to −0.017)	**0.039**	−0.20 (−0.79 to 0.38)	0.50	0.044 (−0.14 to 0.053)	0.38	−0.088 (−0.21 to 0.032)	0.16	−0.44 (−3.08 to 2.21)	0.75
Constant	111.26 (110.01 to 112.48)	**<0.001**	120.86 (118.88 to 122.86)	**<0.001**	7.08 (6.82 to 7.34)	**<0.001**	8.44 (8.11 to 8.75)	**<0.001**	53.54 (45.96 to 61.33)	**<0.001**

*Season refers to months of the year with increased food insecurity. COVID-19 mitigations in place refers to months with COVID-19 mitigating lockdowns and/or curfews in place. Boldface indicates statistical significance.

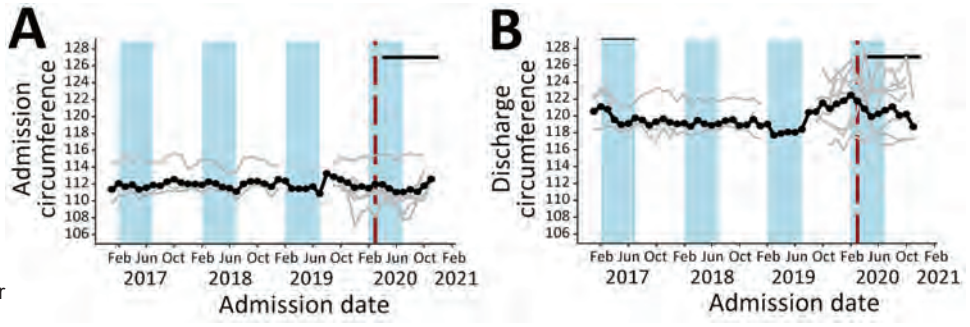

Figure 6. Admission (A) and discharge (B) mid–upper arm circumference at the child level in community management of acute malnutrition facility outpatient therapeutic programs, Somalia, November 2017–November 2020. Black data markers and lines indicate the mean value across all facilities. Gray line indicates raw values for each facility. Red vertical dashed lines indicate date program adaptations began. Black horizontal line indicates dates that COVID-19 restrictions were in place. Blue shading indicates lean seasons. COVID-19 restrictions in place refers to COVID-19 mitigation policies that restrict movement, including restrictions on transportation, lockdowns, and curfews. Lean seasons refer to months of increased food insecurity.

the entire observational period in all countries were well within the global CMAM threshold of >75% recovered recommended by Sphere, a global reference of minimum humanitarian standards (*23*). With the available data, it was not possible to test changes in default rates and nonresponse rates, which remains a topic for future evaluation.

Although the month-to-month trend in admission weight rose significantly after program adaptations, the magnitude of the change—an increase of 0.04 kg/month, or 0.3% of the weight of an average 36-month-old girl—is not programmatically meaningful. Sensitivity analysis accounting for height and age and admission weight also showed no meaningful changes after program adaptations. We may not have observed a meaningful increase in weight at admission because a similar proportion of children were admitted by MUAC only before facilities shifted to all admissions by MUAC only with COVID-19 adaptations. MUAC and weight at discharge, indicators of child profile and health, did not change meaningfully within the Somalia facilities that provided child-level data, consistent with expectations because no adaptations to discharge criteria were adopted. Monitoring future changes in discharge criteria may be useful because ≥1 study has shown that MUAC-based discharge can result in greater relapse rates (*24*).

Within Somalia, ALOS at the facility level did not change after program adaptations; however, in the subset of Mogadishu-based facilities providing child-level data, ALOS increased by an average of 12.3 days/month, peaking at 60.8 days in April 2020 immediately after program adaptations and then declining. Although the change in program adaptations overlaps with a lean season, potentially confounding the analysis, we found no evidence of such annual pattern in previous years among the 3 facilities providing multiple years of data. A similar immediate increase in ALOS in the month after frequency of follow-up was reduced was also observed in an observational study of OTP data in Nguenyyiel Refugee Settlement in Ethiopia in 2020; however, the program reinstated weekly visits the next month, limiting analysis of longer-term trends (*16*). One other study evaluating ALOS after COVID-19 mitigation adaptations were adopted lacks data from before adaptations were adopted (*14*). Because increasing length of stay can potentially affect programmatic resources, resulting in

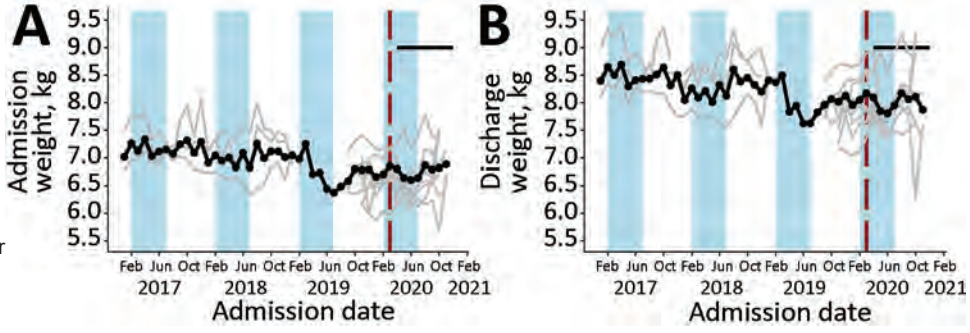

Figure 7. Admission (A) and discharge (B) weight at the child level in community management of acute malnutrition facility outpatient therapeutic programs, Somalia, November 2017–November 2020. Black data markers and line indicate the mean value across all facilities. Gray line indicates raw values for each facility. Red vertical dashed lines indicate date program adaptations began. Black horizontal line indicates dates that COVID-19 restrictions were in place. Blue shading indicates lean seasons. COVID-19 restrictions in place refers to COVID-19 mitigation policies that restrict movement, including restrictions on transportation, lockdowns, and curfews. Lean seasons refer to months of increased food insecurity.

greater caseloads, higher costs per child, and greater strain on resources as more children stay in programs longer, the need for additional research remains. It is possible that the observed effect of increased ALOS after program adaptations in the Mogadishu region resulted from COVID-19 restrictions implemented in this region, but we were unable to test this hypothesis because of lack of available data.

The first limitation of this study is that changes in trends observed for several outcomes were not statistically significant; lack of statistical significance may result from insufficient power based on limited time points (Table 1) and high variability of data. Although sample size guidance for interrupted time series models is scarce (*25*), 2 simulation-based power calculations for other interrupted time series designs did not achieve 80% power with 18 time points (*26*,*27*). Given seasonal variation, having ≥1 year of preintervention data would have been ideal for detecting changes that may be attributed to the COVID-19 protocol adaptations. However, despite limited statistical power, analyzing the magnitude and direction of change of CMAM indicators provides key insight for nutrition programs because the effects of adaptations were previously unknown, and there were multiple, conflicting hypotheses of how programs would be affected. Second, isolating the effects of CMAM program adaptations from other COVID-19 mitigation efforts was challenging because those efforts were implemented around the same time. Third, our data represent a limited number of country experiences; to draw more general conclusions, we would need a larger dataset covering a wide range of countries and program adaptations. Fourth, the lack of country-level average changes in program indicators does not mean that there was no effect in individual facilities. This concept is particularly true in the context of COVID-19, which may have affected use of CMAM facilities in multiple, unpredictable ways. Last, models do not capture the qualitative experience of putting program adaptations into practice. The full context of personnel, environment, and events that shape program success and the challenges facing staff, children, and caretakers are not measured by program indicators and cannot be fully modeled.

Overall, our results suggest that CMAM programs in Uganda, Ethiopia, and Somalia did not undergo consistent, significant changes in program indicators in the first months after adaptations began in response to COVID-19. This finding in turn suggests that CMAM programs may have been able to generally maintain their effectiveness with adapted protocols while continuing to provide service. Although no major or consistent changes were observed after adaptations in these countries in the limited set of indicators considered in this study, it is highly likely that the effects of these program adaptations on program indicators depend on context. Severe acute malnutrition affects 18.7 million children worldwide (*28*), many of whom rely on CMAM programs, so the ability to continue to provide critical services during a pandemic is crucial. As the COVID-19 pandemic has extended over multiple years, programs have experienced protracted staffing shortages and supply chain disruptions. Many of the mitigation measures adapted to reduce transmission may also help alleviate these challenges. Our data provide initial evidence that adaptations to CMAM programs did not significantly affect program efficacy when adopted in the context of the acute onset of the pandemic. However, revisions of global guidance will depend on prospective studies with greater power to evaluate how the revised protocols affect performance outcomes.

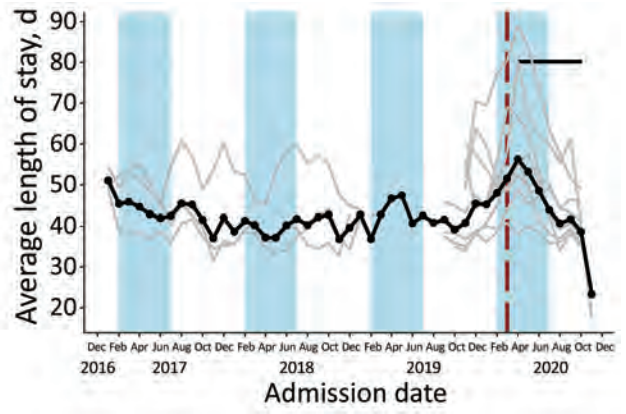

Figure 8. Average length of stay at the child level in community management of acute malnutrition facility outpatient therapeutic programs, Somalia, November 2017–November 2020. Black data markers and line indicate the mean value across all facilities. Gray line indicates raw values for each facility. Red vertical dashed lines indicate date program adaptations began. Black horizontal line indicates dates that COVID-19 restrictions were in place. Blue shading indicates lean seasons. COVID-19 restrictions in place refers to COVID-19 mitigation policies that restrict movement, including restrictions on transportation, lockdowns, and curfews. Lean seasons refer to months of increased food insecurity.

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Lessons from Nigeria's Adaptation of Global Health Initiatives during the COVID-19 Pandemic

Chikwe Ihekweazu

Nigeria receives funds from several global health initiatives that are aimed at addressing elevated risks and overall burden of infectious disease outbreaks. These funds include the Global Fund to Fight AIDS, Tuberculosis and Malaria; US President's Emergency Plan for AIDS Relief; US President's Malaria Initiative; and Global Polio Eradication Initiative. These initiatives have contributed to a substantial reduction in illness and death from HIV, tuberculosis, malaria, and polio. However, Nigeria has experienced mixed success with leveraging the capacities built through these donor-funded vertical programs to respond to new health threats. This report describes experiences using resources from vertical disease programs by the Nigeria Centre for Disease Control in response to the 2014–2016 Ebola outbreak in West Africa and the COVID-19 pandemic. Integrating resources from different disease programs with government-led systems and institutions will improve responses to endemic outbreaks and preparedness for future pandemics in Nigeria.

Similar to other countries in Africa, Nigeria receives substantial donor funds through global health initiatives aimed at addressing the high prevalence of infectious diseases and other public health threats (*1*). These initiatives include the Global Fund to Fight AIDS, Tuberculosis and Malaria; US President's Emergency Plan for AIDS Relief; US President's Malaria Initiative; and Global Polio Eradication Initiative. Together, these groups have contributed to a considerable reduction in illness and deaths from HIV, tuberculosis (*2*), malaria (*3*), and polio (*4*) in Nigeria. The Global Polio Eradication Initiative supported the establishment of a laboratory network, emergency operations center (EOC), 2 molecular laboratories, and enhanced vaccination efforts and provided substantial operational support for Nigeria's polio response (*5*). Similarly, the US President's Emergency Plan for AIDS Relief program has been the main funder of HIV-related activities in Nigeria, supporting the establishment of testing sites and laboratories, providing treatment to persons living with HIV, and accounting for 67% of the $532.4 million reported HIV spending in 2018 (*6*). By focusing resources, priorities, and policies on a single disease, these programs have achieved notable public health improvements for persons in Nigeria. A steady decline in HIV and malaria prevalence across the country has been observed, more persons are presently accessing disease testing and treatments compared with 2001 (*3*), and, in June 2020, Nigeria achieved wild polio virus–free status (*5*). However, Nigeria has experienced mixed success in using the capacities built through these donor-funded vertical programs to respond to new health threats, such as regional Ebola outbreaks and the global COVID-19 pandemic.

Although most global health initiatives are mainly focused on a single disease (*7*), program directions are largely driven by the respective donors. In some instances, these programs have created parallel systems for their respective disease(s). For example, separate sample transportation systems have been created for HIV and polio in parallel with other endemic diseases systems in Nigeria. Minimal intentional convergence of resources has been provided for these specific disease programs to strengthen the entire health system. Spillover effects on other programs have been marginal because many of the vertical programs have been implemented outside of the mainstream public health preparedness and response architecture in Nigeria.

Examples of spillover effects exist that might be instructive. During the 2014–2016 Ebola virus outbreak in West Africa, resources and experiences from the polio program in Nigeria were leveraged for Ebola response activities (*8*). The polio effort in Nigeria was well

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recognized worldwide (*9*), and the polio EOC was used as a coordination structure for the national response to the Ebola outbreak. In the years after that Ebola outbreak, however, polio resources were not leveraged further for other disease outbreaks and were refocused completely on the polio eradication program. Despite the prevalence of infectious diseases and annual outbreaks, Nigeria did not have a public health EOC 2 years after the Ebola response (*10*). In 2016, an integrated disease prevention and response mechanism was established through the evolution the Nigeria Centre for Disease Control (NCDC); however, responses to HIV, tuberculosis, malaria, and polio remained primarily vertical interventions and outside of NCDC's oversight.

When the COVID-19 pandemic began in 2020, NCDC negotiated individually with the different vertical disease programs for resources to support the response. GeneXpert systems (Cepheid, https://www.cepheid.com) originally purchased for tuberculosis testing were repurposed for SARS-CoV-2 testing, thereby contributing to the rapid expansion of the country's testing capacities (*11*,*12*), including increased near-patient testing and turnaround time for COVID-19 case confirmation. Specifically, GeneXpert tests provided results within a 2-hour turnaround time, compared with 6 hours for reverse transcription PCR testing. Similarly, a major HIV testing laboratory, established within NCDC's National Reference Laboratory with support from the US Centers for Disease Control and Prevention, was leveraged for high throughput testing for SARS-CoV-2, which increased testing capacity at this critical time. In Nigeria and across several countries, field epidemiologists from field epidemiology training programs were deployed to enhance the available workforce in response to the COVID-19 pandemic (*13*).

Efforts to leverage HIV and tuberculosis resources for the COVID-19 pandemic response were, however, not without challenges. For example, the tuberculosis program's procurement and distribution of cartridges, reagents, and supplies were largely dependent on support by external partners. Therefore, integrating GeneXpert testing supplies into the national unified supply chain for the COVID-19 response proved to be difficult. Faced with global supply shortages and increased demand, the government of Nigeria had to develop a strategy to manage the shortage of supplies in government-run laboratories and a separate strategy for other laboratories that were heavily donor-dependent. In addition, the reporting systems for HIV and tuberculosis laboratories were isolated from the national surveillance system, which required harmonization of reporting tools and reporting frequency across laboratories and additional training for laboratory staff. These challenges affected the completeness and timeliness of the epidemiologic analyses.

The experiences in Nigeria demonstrated that limited integration of donor-funded vertical programs with government systems jeopardizes the sustainability of these programs and complicates the use of program resources to support emergency responses to outbreaks. However, close partnerships with government agencies and good field collaboration improved the overall response. The effectiveness of global health initiatives will very likely be improved through better coordination between donor-supported programs and government-led systems and institutions for establishing initiative priorities, design, implementation, and evaluation. Specifically, investments through global health initiatives should be reviewed in the context of government-led systems and institutions. Individual initiatives should align with approaches for other endemic diseases, even if those diseases are not priorities of donor partners. Such an approach has the potential to provide an even higher level of return on investment for donors.

Nigeria's Presidential Task Force for COVID-19 provides an example of a government-led structure supported by donors during an emergency (*12*). The growth and increasing capacity of the National Public Health Institutes in Africa supported by the Africa Centers for Disease Control (*14*) provide an opportunity for improved convergence and coordination.

Investments in global health programs should be leveraged to improve preparedness for future pandemics. Several reports have shown that countries with higher investments in health security were better prepared to respond to the COVID-19 pandemic (*15*). Previous investments in preparedness coordinated by NCDC, such as the establishment of a public health EOC network and digitalization of the country's surveillance system, provided a foundation for Nigeria's COVID-19 response. Subsequent funding for HIV, tuberculosis, malaria, and polio programs should enable appropriate responses to future pandemics. Investments could potentially include the development of common standards that increase flexibility to use these funds in response to large outbreaks and pandemics, while ensuring continuity of program specific goals.

Our experience during the COVID-19 pandemic showed that pooling and unified governance of resources from various donors reduced fragmentation and increased the collective response to the

pandemic. Initiatives such as the United Nations Basket Fund (*16*) and the private sector task force Coalition Against COVID-19 (*11*) enabled government leadership to direct resources toward interventions that maximized pandemic responses while providing donors with opportunities to contribute their diverse expertise and maintain financial oversight. Using such approaches in future global health interventions, especially in large countries, could reduce the risk for fragmentation.

In conclusion, strong collaborations among partners that have governments at their core will prevent or mitigate the effects of the next pandemic. The World Health Organization Hub for Pandemic and Epidemic Intelligence (*17*) was established in response to this urgent collaborative need. For example, the Hub for Pandemic and Epidemic Intelligence has begun to develop a set of principles to support data sharing across countries and disciplines. Developing and sustaining a global health security architecture enshrined in the principles of mutual trust and equity for all is not only necessary but is a critical approach to mitigate the next pandemic.

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Vasundhara Tolia (1950–), *The World United*, 2020 (detail). Mixed media on canvas, 30 in x 20 in/76.2 cm x 50.8 cm. Digital image courtesy of the artist. Michigan, United States.

A United Response to COVID-19—an Artist's Perspective

Byron Breedlove, Cynthia H. Cassell, Pratima L. Raghunathan

During mid-March 2020, the World Health Organization (WHO) declared that the spread of COVID-19, the respiratory illness caused by SARS-CoV-2, was a pandemic. This novel emerging infectious disease spread insidiously and swiftly around the globe, undeterred by geographic borders. Countries reacted to COVID-19 with attempts to control transmission, including isolation and quarantine orders, social distancing recommendations, and mask requirements. Responses at the local, national, regional, and international levels involved public health experts, field epidemiologists (disease detectives), clinicians, researchers, policy makers, political leaders, and civil authorities.

Artists from across the globe also responded to the effects of COVID-19 in myriad ways, communicating a wide range of perspectives and experiences about the pandemic through imagery, music, dance, and writing. Efforts to collect and share some of this artistic output via online platforms helped connect artists and audiences to a greater degree than would otherwise have been possible during the pandemic. For example, in spring 2020 the *Washington Post* invited readers to submit artwork created during the early months of the COVID-19 outbreak. The paper featured 20 works, selected from more than 650 submissions, in the article "The Best Art Created by *Washington Post* Readers during the Pandemic."

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Michael Cavna, a writer-artist-cartoonist who penned the story, explained, "The Post considered not only the quality and creativity of the art, but also the fascinating accompanying backstories. Enduring quarantines, some artists rendered what isolation and loneliness felt like, while others depicted longed-for social scenes from a pre-pandemic time."

The World United, the cover art for this special supplement issue of *Emerging Infectious Diseases*, was among those finalists. Vasundhara Tolia, who created this image, took a somewhat different approach from other artists. Tolia, originally from India, is now a retired pediatric gastroenterologist and served as a tenured professor of pediatrics and as a consultant and attending physician at hospitals in the Detroit, Michigan, USA, area, where she currently lives. She has embarked on a second career as an artist, and her work has been shown in group exhibitions in several states, many online national exhibitions, and several solo shows. In that same *Washington Post* article, Tolia wrote about her painting, "Medicine has always been my first passion. And during these unprecedented, tumultuous times, it beckons me again as I watch helplessly from the sidelines now. Since my retirement as a physician, I've poured my creativity into art and poetry, so creating this kind of response came naturally to me."

Tolia recounted her inspiration for creating *The World United* in more detail. "The world did seem to have come together in response to dealing with the pandemic. In some ways we were cohesive, especially with the creation of the vaccine. To show this togetherness, I wanted to show the world combating this virus. I wanted to depict something new and different, so I made this hand gripping the virus although this elusive particle still escaped because of its invasive properties and ubiquitous presence. Rather than a map of the world, I chose to use stamps from as many countries of the world that I could fit on this hand. My sons used to collect stamps when young, so I looked in their collections and used some of them. That's how this painting was conceived" (V. Tolia, pers. comm., email, 2022 May 8).

More than 60 different stamps, each one a miniature painting, are rendered with such attention to detail that cancellation marks are visible on many. The hand clutches one of the coronaviruses as the others float away. Tolia's image, created during a time when the world was starting to come to grips with the pandemic, elicits a sense of esprit de corps reminiscent of the now famous "We Can Do It" posters Pittsburgh artist J. Howard Miller created to inspire American workers during World War II.

Since launching its response to the COVID-19 pandemic, the Centers for Disease Control and Prevention (CDC) has focused on learning about the disease how it spreads and how it affects people and communities in the United States and around the world. Drawing on CDC staff, funded programs, and partnerships with many countries, CDC's global COVID-19 response has provided epidemiologic surveillance, laboratory support, emergency preparedness and response, and immunization and clinical service delivery resources to countries and vulnerable populations.

The response exemplifies working collaboratively with global, national, and local public health leadership, including WHO, ministries of health, and community leaders. Those partnerships were strengthened at all levels as public health practitioners generated scientific knowledge, refined technical approaches to prevent and mitigate COVID-19, and identified areas for continued improvement and reassessment.

In an interview with writer and artist Linda Sienkiewicz, Tolia discussed her views on art: "All the ways we separate ourselves, be it by our age, ethnicity, culture, geography and even interests; all of these boundaries melt away when we take in and connect with art and creative forms of expression." Art and science can connect people regardless of place or origin. During the pandemic, people turned to art and science to understand and make sense of the world, and both disciplines remind us that unity is possible.

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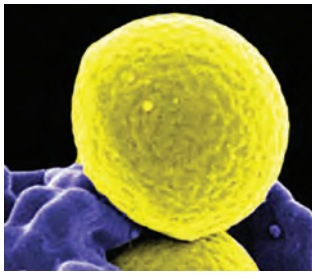
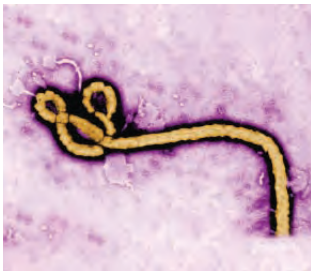
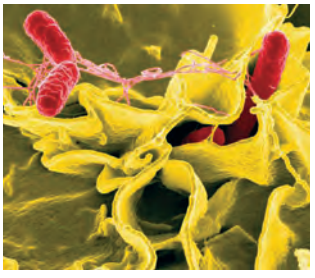
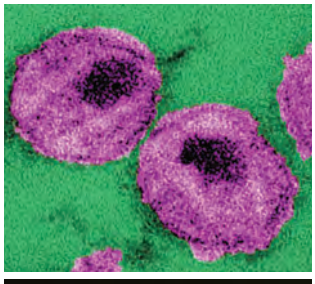
Emerging Infectious Diseases

Spotlight Topics

Antimicrobial resistance
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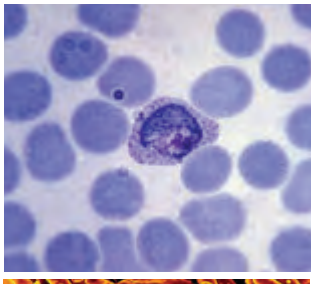
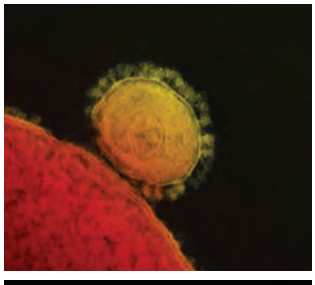
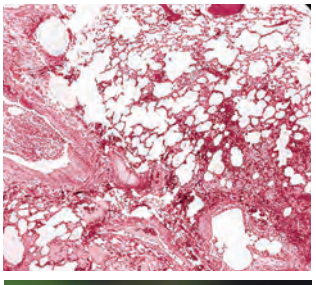
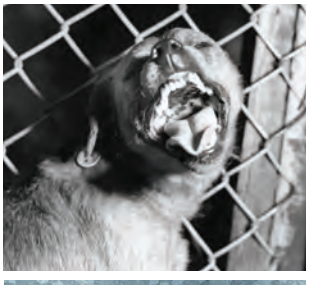



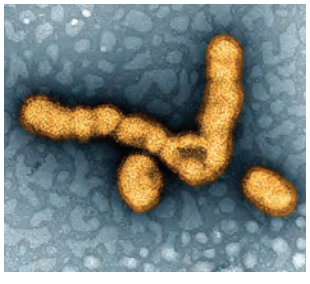
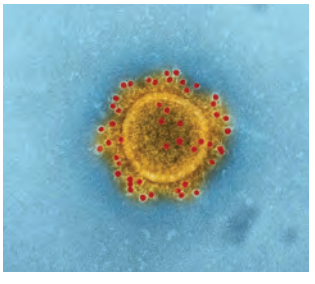

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