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CDC's Response to the 2014–2016 Ebola Epidemic — West Africa and United States

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Foreword

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The 2014–2016 Ebola virus disease (Ebola) epidemic in West Africa required a massive international response by many partners to assist the affected countries and tested the world's readiness to respond to global health emergencies. The epidemic demonstrated the importance of improving readiness in at-risk countries and remaining prepared for Ebola and other health threats. The devastation caused by Ebola in Guinea, Liberia, and Sierra Leone is well recognized; what is less widely recognized is that in these countries more people probably died *because* of Ebola than from Ebola. The epidemic shut most health care systems and derailed programs to prevent and treat malaria, tuberculosis, vaccine-preventable diseases, and other conditions (*1*,*2*).

How close the world came to a global catastrophe is even less well recognized. If Ebola had not been rapidly contained in Lagos, Nigeria, a densely populated city with many international airline connections, the disease most likely would have spread to other parts of Nigeria, elsewhere in Africa, and possibly to other continents. Even more people would have died from Ebola, and the disruption of health care systems would have threatened a decade of progress in Africa in vaccine programs and prevention and control of human immunodeficiency virus, tuberculosis, malaria, maternal mortality, and other health conditions; changed the way ill travelers from all affected countries would be assessed; and undermined already fragile systems for health, social, and economic development. This catastrophe was averted through effective response in Lagos, led by Nigerian public health leaders, particularly the CDC-supported polio eradication staff and their implementation of CDC technical guidance for Ebola outbreak investigation, contact tracing, infection control, risk communication, border protection measures, and Ebola subject-matter expertise (*3*).

When CDC activated its Emergency Operations Center on July 9, 2014, the situation was ominous: Ebola cases in West Africa were increasing exponentially. Without a massive, well-organized global response, a devastating epidemic could have become a global catastrophe. No matter what steps CDC took, and no matter how quickly the world took action, the epidemic was not going to end quickly. At the end of July, CDC pledged to put an unprecedented 50 staff in the field within 30 days. The agency not only exceeded this goal, but as the epidemic intensified, launched the largest response in its history.

At the peak of the response, CDC maintained approximately 200 staff per day in West Africa and approximately 400 staff per day at its Atlanta headquarters dedicated to the response. Overall, approximately 1,897 CDC staff were deployed to international and U.S. locations, for approximately 110,000 total work days, and more than 4,000 CDC staff worked as part of the response. In 2016, CDC staff remain on the ground in Guinea, Liberia, and Sierra Leone in newly established CDC country offices to improve surveillance, response, and prevention for Ebola and other health threats.

In addition to their work in West Africa, CDC staff played a critical role protecting the United States by aiding state and local health departments in their preparedness activities and their response to the country's first imported Ebola cases. CDC helped international, federal, and state partners establish airport risk assessment of travelers departing and arriving from affected countries, monitored travelers and other potentially exposed persons for 21 days, and helped hospitals across the country prepare to manage a possible case of Ebola through intensive training and preparedness activities.

The response illustrated the need for speed and flexibility. The arrival in a Dallas, Texas, hospital of a traveler from Liberia with Ebola and its subsequent transmission to two nurses working there led to rapid changes in domestic preparedness and response recommendations and practices. The deployment of large numbers of CDC staff to West Africa emphasized the agency's response capacity. Longer and more repeat deployments would have improved effectiveness but were difficult to achieve because of the unprecedented need for large numbers of highly skilled staff, including French speakers to work in Guinea. At times, responders faced health, safety, and security risks while overseas, and after returning to the United States responders and their families were sometimes irrationally stigmatized.

Through CDC's collaboration with national and international partners, surveillance, contact tracing, diagnostic testing, community engagement and ownership, infection prevention and control, border health, emergency management, and vaccine evaluation all improved steadily. The implications of sporadic cases during the epidemic tail are still being assessed. Above all, this epidemic underscored the need for the new Global Health Security Agenda, a program designed to build stronger national and global capacities to prevent, detect, and respond to health threats (*4*).

This *MMWR* supplement presents reports that chronicle major aspects of CDC's unprecedented response to the Ebola epidemic. Written by CDC staff who played key roles, these reports summarize the agency's work, primarily during the first year and a half of the epidemic. From the start, CDC focused on providing proven public health measures to assist affected countries to defeat Ebola. Some of these key activities included:

- Supporting the incident management systems of Guinea, Liberia, and Sierra Leone to permit effective action to stop Ebola.
- Establishing CDC teams in Guinea, Liberia, and Sierra Leone, which have transitioned into permanent CDC country offices.
- Improving case detection and contact tracing to stop Ebola transmission.
- Strengthening surveillance and response capacities in surrounding countries to reduce the risk for further spread.
- Improving infection control in Ebola treatment units and general health care facilities to stop spread of Ebola. This effort included training tens of thousands of health care workers in Guinea, Liberia, and Sierra Leone to safely care for Ebola patients and working to ensure the provision and correct use of personal protective equipment.
- Promoting the use of safe and dignified burial services to stop spread of Ebola.
- Conducting detailed epidemiologic analyses of Ebola trends and transmission patterns in communities and health care facilities to target and optimize epidemic control.
- Supporting laboratory needs at CDC's Viral Special Pathogens Branch (Division of High-Consequence Pathogens and Pathology, National Center for Emerging and Zoonotic Infectious Diseases) in Atlanta and transferring CDC laboratory expertise to the field (e.g., establishing an Ebola laboratory in Bo, Sierra Leone).
- Reducing the likelihood of spread of Ebola through travel, including working with international partners and federal and state health officials to establish exit and entry risk assessment and management procedures, as well as helping establish protocols to track travelers arriving in the United States from affected countries until 21 days after their last potential exposure.
- Disseminating risk communication materials designed to help change behavior, decrease rates of transmission, and confront stigma, both in West Africa and the United States.
- Assisting state health departments in responding to domestic Ebola concerns, including the response in Dallas after the first U.S. case of Ebola imported in a traveler from Liberia.
- Establishing trained and ready hospitals in the United States capable of safely assessing, managing, and caring for possible Ebola patients.
- Modeling, in real time, predictions for the course of the epidemic, which helped galvanize international support and enabled CDC to act on and align global action to reach goals for control to quickly shift the course of the epidemic.
- Providing logistic support for the most ambitious CDC deployment in history.
- Fostering hope for a long-term solution for Ebola, including rollout of Sierra Leone Trial to Introduce a Vaccine against Ebola (STRIVE).

Although this supplement tells the story of CDC's contributions to the Ebola response, partnerships have been, and remain, indispensable to CDC's activities (http://www.cdc.gov/vhf/ebola/outbreaks/2014-west-africa/partners.html). Throughout the response, CDC assisted the governments of affected countries and worked closely with key international partners, including the World Health Organization, Médecins Sans Frontières, the African Union, other nations, and many local and international nongovernment and nonprofit organizations, including the CDC Foundation. Partnerships with many U.S. government agencies, particularly the Office of Foreign Disaster Assistance of the U.S. Agency for International Development, the U.S. Department of Defense, the Customs and Border Protection service of the U.S. Department of Homeland Security, and ambassadors from affected countries, as well as state and local health departments and hospitals and health care workers, were critical. Achieving zero new Ebola cases in West Africa can be understood only in light of these effective collaborations with international partners, as well as collaborations from throughout the U.S. government and substantial emergency funding from the U.S. Congress.

At the time this supplement went to press, widespread transmission of Ebola had ended. On March 29, 2016, the World Health Organization declared that Ebola in West Africa was no longer a Public Health Emergency of International Concern, and the CDC Ebola Response was deactivated on March 31, 2016. This deactivation does not mean support from the international community will end. CDC and partners remain in the region and CDC staff continue to be deployed internationally to support ongoing efforts to improve detection, response, and prevention through the Global Health Security Agenda (4). Even though the 2014–2016 Ebola epidemic has been declared over in Guinea, Liberia, and Sierra Leone, much important work remains to be done, and CDC staff will continue to address a wide range of issues, including resuming and strengthening core public health and health

care services, particularly vaccination programs and malaria prevention, treatment, and control initiatives in the aftermath of the largest Ebola outbreak in history.

Future progress requires renewed international focus on global health security to ensure that another preventable epidemic—whether of Ebola or another health threat—does not again get out of control. Documenting CDC's experiences in responding to the Ebola epidemic is intended to promote understanding and action on the valuable global experience gained to improve the prevention, detection, and response to the next health crisis.

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Overview, Control Strategies, and Lessons Learned in the CDC Response to the 2014–2016 Ebola Epidemic

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Summary

During 2014–2016, CDC, working with U.S. and international partners, mounted a concerted response to end the unprecedented epidemic of Ebola virus disease (Ebola) in West Africa. CDC's response, which was the largest in the agency's history, was directed simultaneously at controlling the epidemic in West Africa and strengthening preparedness for Ebola in the United States. Although experience in responding to approximately 20 Ebola outbreaks since 1976 had provided CDC and other international responders an understanding of the disease and how to stop its spread, the epidemic in West Africa presented new and formidable challenges. The initial response was slow and complicated for several reasons, including wide geographic spread of cases, poor public health and societal infrastructure, sociodemographic factors, local unfamiliarity with Ebola, and distrust of government and health care workers. In the United States, widespread public alarm erupted after Ebola cases were diagnosed in Dallas, Texas, and New York City, New York. CDC, in collaboration with its U.S. and international counterparts, applied proven public health strategies as well as innovative new approaches to help control the Ebola epidemic in West Africa and strengthen public health readiness in the United States. Lessons learned include the recognition that West African and other countries need effective systems to detect and stop infectious disease threats, the need for stronger international surge capacity for times when countries are overwhelmed by an outbreak, and the importance of improving infection prevention and control in health care settings.

The activities summarized in this report would not have been possible without collaboration with many U.S. and international partners (http://www.cdc.gov/vhf/ebola/outbreaks/2014-west-africa/partners.html).

Introduction

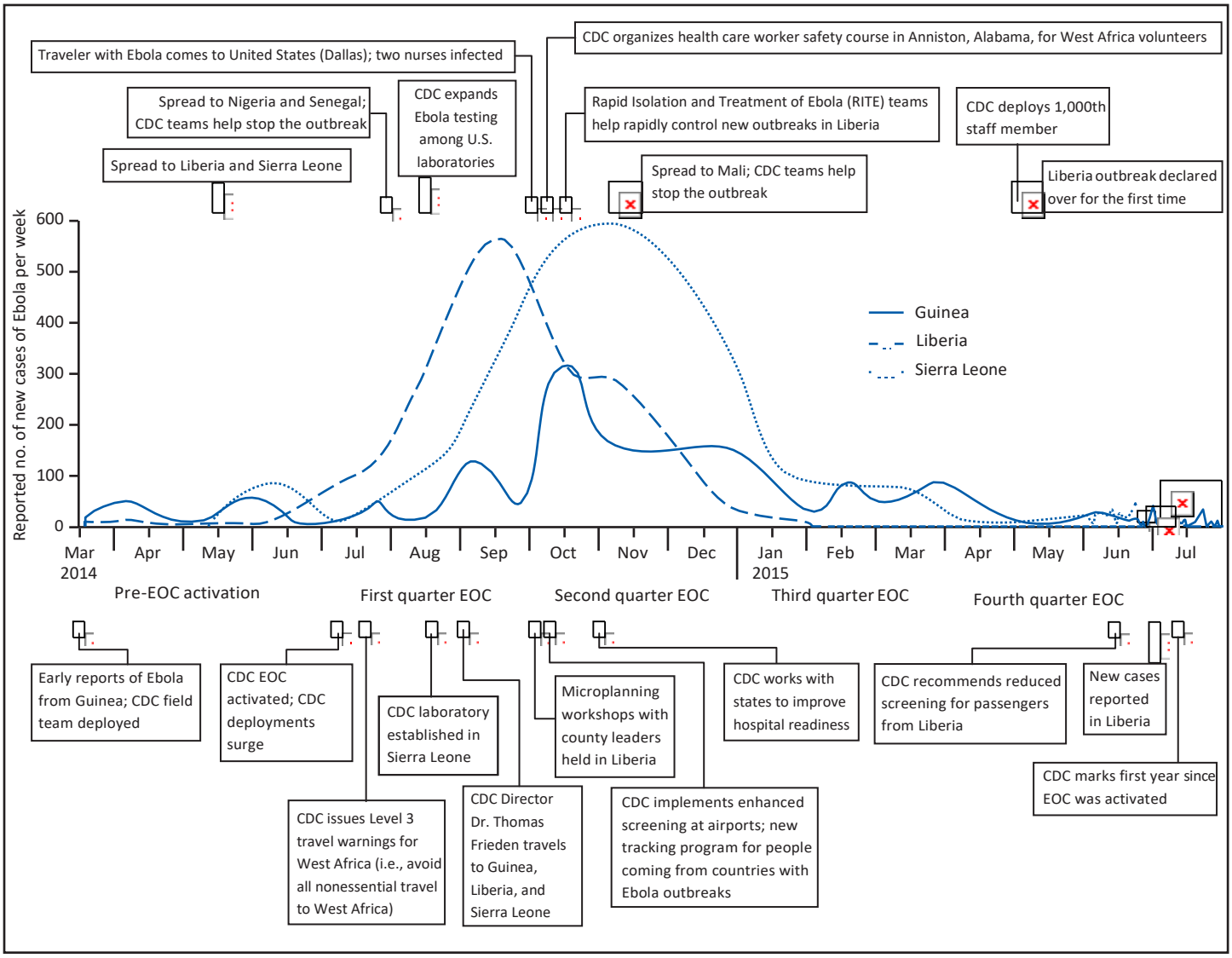
In response to the emergence, rapid spread, and sustained transmission of Ebola virus disease (Ebola) in West Africa during 2014–2016, CDC worked closely with other U.S. government agencies, ministries of health (MoHs), the World Health Organization (WHO), and other international partners as part of an intensive effort to end the epidemic (Figure 1). Multiple factors led to the unprecedented scale of this epidemic, including the wide geographic spread of cases, slow response by the international community, population intermixing and mobility, disease transmission in densely populated urban areas, poor public health and societal infrastructure, local unfamiliarity with the disease, and distrust of government authorities and health care workers (HCWs). As of March 31, 2016, WHO had reported 28,652 suspected, probable, and confirmed Ebola cases, including 11,325 deaths, far exceeding the combined total number of cases reported in approximately 20 previous outbreaks since the 1970s (Table). This report presents an overview of previous Ebola outbreaks and the 2014–2016 epidemic and observations about the epidemic's implications for future public health responses.

Background

Ebola Outbreaks and Control Strategies, 1976–2014

Ebola is a rare and often fatal illness caused by viruses of the family *Filoviridae*, genus *Ebolavirus*, which has five viruses: Ebola virus (EBOV), Sudan virus, Bundibugyo virus,

FIGURE 1. CDC's response to the Ebola epidemic, from the first reported cases through the first year after CDC's EOC was activated, and approximate number of reported new cases of Ebola per week — Guinea, Liberia, and Sierra Leone, March 2014–July 2015



Abbreviations: Ebola = Ebola virus disease; EOC = Emergency Operations Center.

Taï Forest virus, and Reston virus. All viruses cause disease in humans except Reston virus, which has caused asymptomatic infections in humans but disease in nonhuman primates only. The natural wildlife host of EBOV has not been definitively identified; however, evidence suggests fruit bats of the family *Pteropodidae* might be a reservoir. Ebola was first recognized in 1976 during two near-simultaneous outbreaks: one caused by EBOV in Zaire (now Democratic Republic of the Congo [DRC]) that comprised 318 cases and 280 deaths (case-fatality rate [CFR] = 88%), and the other caused by Sudan virus in Sudan that comprised 284 cases and 151 deaths (CFR = 53%). These and subsequent sporadic outbreaks of Ebola in Eastern and Central African nations (DRC, seven; Uganda, five; Gabon, four; and Republic of the Congo and Sudan [now South Sudan], three each) had CFRs of approximately 25%–90%; occurred in resource-poor settings where health care, transportation, and other services are limited; and lasted from several weeks to approximately 3 months (*1*) (Table).

EBOV is thought to be introduced into humans when a person has direct contact with blood, body fluids, or organs of infected animals (e.g., fruit bats, chimpanzees, or gorillas) or prepares meat from infected animals. Infection in human communities is sustained through person-to-person contact, often from symptomatic persons to caregivers in homes and health care settings, where infection-control practices are inadequate and personal protective equipment is unavailable

TABLE. Number of cases and deaths during Ebola outbreaks, excluding the 2014–2016 epidemic — worldwide, 1976–2014

Country	Year	Town	No. of cases	No. of deaths	Species
Democratic Republic of the Congo	2014	Multiple	66	49	*Zaire ebolavirus*
Uganda	2012	Luwero District	6*	3*	*Sudan ebolavirus*
Democratic Republic of the Congo	2012	Isiro Health Zone	36*	13*	*Bundibugyo ebolavirus*
Uganda	2012	Kibaale District	11*	4*	*Sudan ebolavirus*
Uganda	2011	Luwero District	1	1	*Sudan ebolavirus*
Democratic Republic of the Congo	2008	Luebo	32	15	*Zaire ebolavirus*
Uganda	2007	Bundibugyo	149	37	*Bundibugyo ebolavirus*
Democratic Republic of the Congo	2007	Luebo	264	187	*Zaire ebolavirus*
South Sudan†	2004	Yambio	17	7	*Zaire ebolavirus*
Republic of the Congo	2003	Mbomo	35	29	*Zaire ebolavirus*
Republic of the Congo	2002	Mbomo	143	128	*Zaire ebolavirus*
Republic of the Congo	2001	Not specified	57	43	*Zaire ebolavirus*
Gabon	2001	Libreville	65	53	*Zaire ebolavirus*
Uganda	2000	Gulu	425	224	*Sudan ebolavirus*
South Africa	1996	Johannesburg	2	1	*Zaire ebolavirus*
Gabon	1996	Booue	60	45	*Zaire ebolavirus*
Gabon	1996	Mayibout	37	21	*Zaire ebolavirus*
Democratic Republic of the Congo§	1995	Kikwit	315	250	*Zaire ebolavirus*
Côte d'Ivoire	1994	Tai Forest	1	0	*Taï Forest ebolavirus*
Gabon	1994	Mekouka	52	31	*Zaire ebolavirus*
South Sudan†	1979	Nzara	34	22	*Sudan ebolavirus*
Democratic Republic of the Congo§	1977	Tandala	1	1	*Zaire ebolavirus*
South Sudan†	1976	Nzara	284	151	*Sudan ebolavirus*
Democratic Republic of the Congo§	1976	Yambuku	318	280	*Zaire ebolavirus*

Source: CDC. Outbreaks chronology: Ebola virus disease. Atlanta, GA: CDC; 2015. http://www.cdc.gov/vhf/ebola/outbreaks/history/chronology.html
Abbreviation: Ebola = Ebola virus disease.
* Numbers reflect laboratory-confirmed cases only.
† Formerly part of Sudan.
§ Formerly Zaire.

or in short supply. In some previous outbreaks (e.g., Kikwit, Zaire, in 1995), the infection cycle was amplified by explosive spread of disease in overcrowded local hospitals, underscoring the role of nosocomial transmission. Because corpses have high viral loads, funerals and burials accompanied by ceremonial washing and touching of deceased persons often are responsible for multiple chains of transmission.

During the first reported Ebola outbreak in Zaire in 1976, an international response team developed an early strategy to stop the outbreak, focusing on the identification, isolation, and care of persons with Ebola symptoms; meticulous contact tracing; engagement with community leaders; culturally sensitive and safe burials; effective infection control; and reliable laboratory testing (2). This strategy, further refined with accumulated experience, has been used to successfully control approximately 20 Ebola outbreaks, including DRC's seventh outbreak in November 2014 (3).

Ebola Symptoms, Tests, Treatment, and Transmission

Ebola patients typically experience fever, fatigue, muscle pain, and headache, followed by variable signs and symptoms that include vomiting, diarrhea, rash, and hemorrhagic diathesis resulting in external bleeding, internal bleeding, or both. In severe cases, multiorgan dysfunction (e.g., hepatic damage, renal failure, and central nervous system involvement) can develop, leading to shock and death (4). The incubation period is 2–21 days; symptoms usually appear within 8–10 days after exposure to EBOV. In the initial clinical phase, Ebola can be difficult to distinguish from other infectious diseases, including malaria, typhoid fever, and Lassa fever.

EBOV infection most commonly is confirmed by testing blood by using a real-time reverse transcription polymerase chain reaction (RT-PCR) assay. Genetic sequencing is increasingly useful for describing the molecular epidemiologic characteristics and other features of Ebola outbreaks. No proven vaccine or specific treatment for Ebola exists; however, human trials of potential vaccines and therapies are under way. Early supportive care with rehydration (e.g., providing intravenous fluids and balancing electrolytes) and treatment of specific symptoms improve chances for survival.

Human-to-human transmission of EBOV occurs through direct contact with the blood or body fluids (e.g., urine, saliva, sweat, feces, vomit, breast milk, or semen) of symptomatic or deceased persons or with objects (e.g., needles and syringes) contaminated with body fluids from an infected person. An infected person becomes contagious once symptoms appear, and the level of infectivity increases dramatically as the disease progresses and the infected person's viral load increases. The

fluids, skin, and other tissues of persons who die of Ebola are extremely infectious and pose a hazard to anyone who has unprotected contact with the body, including caregivers and people preparing the body for burial. EBOV can be found in the semen of some men who have recovered from the disease, and CDC has recommended that contact with semen from male survivors be avoided until more is known about infectivity of body fluids. If male survivors have sex, they are advised to use a condom correctly and consistently (*5*).

Emergence in West Africa: A Regional and Global Threat

The first Ebola cases in West Africa were reported by WHO on March 23, 2014, in the forested rural region of southeastern Guinea bordering Liberia and Sierra Leone, where multiple unrecognized chains of transmission had festered for months (*6*). The lack of surveillance systems and other public health infrastructure impeded the ability of affected countries to effectively detect and respond to the rapidly evolving outbreak. As the outbreak spread to urban areas and expanded into an epidemic, the number of cases quickly overwhelmed the limited isolation and treatment capacity in the three countries affected, exacerbated by strained laboratory testing capacity. Poor infection control resulted in transmission in health care facilities, including a large number of infections and deaths among HCWs, and collapse of the health care system. Inadequate disease surveillance and reporting further hampered control efforts, resulting in incomplete information about the extent of the outbreak, particularly in difficult-to-reach areas. Sociodemographic factors that contributed to virus spread included high mobility and intermixing of populations (e.g., ease of travel across land and river borders) and general unfamiliarity with Ebola and how to respond to Ebola outbreaks. By late July, Ebola had reached the urban and densely populated capitals of all three countries, the first time the disease had caused widespread transmission in crowded metropolitan areas. On August 8, 2014, with case counts steadily increasing, WHO declared the escalating Ebola situation a Public Health Emergency of International Concern (*7*). By March 2016, WHO had reported cumulative cases throughout Liberia and Sierra Leone and most of the prefectures in Guinea (Figure 2).

CDC's Role and Accomplishments

CDC's response to the Ebola epidemic was the largest emergency response in the agency's history (*8*). During CDC's activation of its Emergency Operations Center (EOC) during July 9, 2014–March 31, 2016, approximately 4,000 CDC staff members directly participated in the response, and of these, 1,897 deployed to Guinea, Liberia, Sierra Leone, and other African countries affected by the epidemic (e.g., Nigeria and Mali). CDC's deployed teams included specialists in epidemiology, infection control, laboratory analysis, medical care, emergency management, information technology, health communication, behavioral science, anthropology, logistics, planning, and other disciplines.

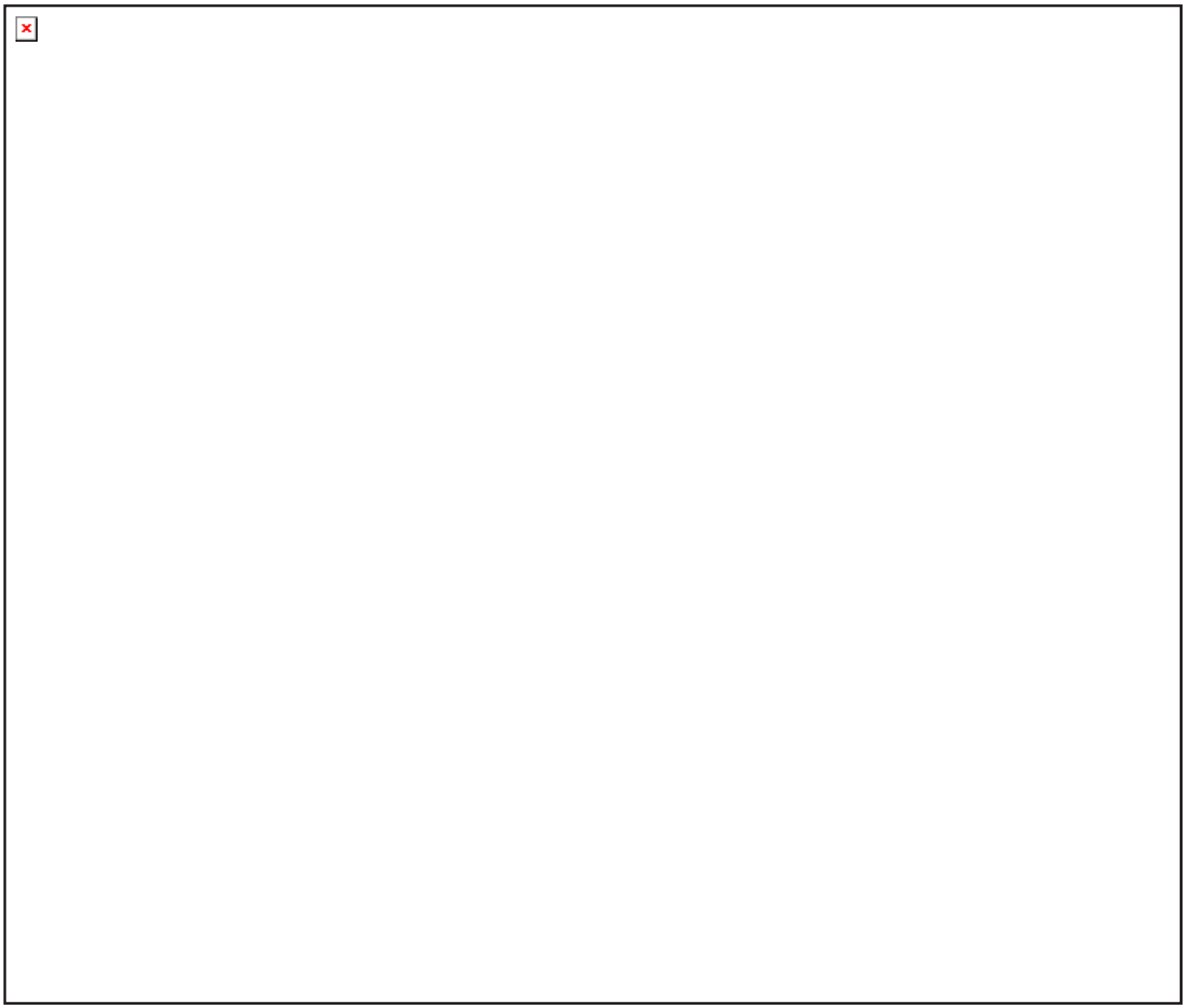
Response in Guinea, Liberia, and Sierra Leone

Before the Ebola epidemic, CDC's presence in Guinea, Liberia, and Sierra Leone was limited to technical support for a small number of disease-specific disease control programs (e.g., malaria and polio) and vaccination campaigns (e.g., measles and yellow fever). In Liberia, CDC also supported the collection of reproductive health data to improve family planning, maternal health, and gender-based violence, as well as programs to help United Nations peacekeepers avoid human immunodeficiency virus infection. In Sierra Leone, CDC evaluated the impact of community case management of childhood diseases programs. Though these programs provided some support for public health systems, they did not include efforts to strengthen infectious disease surveillance with laboratory diagnostic testing. Therefore, CDC's response in these three countries required that CDC experts mobilize from other international and U.S. CDC locations. CDC teams deploying to West Africa early in the response established working relationships with each country's MoH, WHO, and other international partners. In addition to CDC country teams, CDC staff members in West Africa were part of the Disaster Assistance Response Teams (DARTs) of the U.S. Agency for International Development's Office of Foreign Disaster Assistance, with CDC leading the public health and medical care teams within the DARTs.

A priority was to make response activities faster and more effective. To strengthen coordination among various government and partner organizations in Guinea, Liberia, and Sierra Leone, CDC helped set up national EOCs by using an incident management system (IMS) (*9*). Teams specializing in areas such as surveillance, case management, infection control, and social mobilization* met daily to report the status of assigned tasks and provide updates on the epidemic to an incident manager, who in turn updated country leaders. Support for EOC buildings, staffing, and operations was provided in large part by the CDC Foundation and by the DARTs and WHO.

*Social mobilization is a process that uses dialogue to encourage communities and help them work together to overcome a disease or achieve a social objective.

FIGURE 2. Number of cumulative confirmed Ebola cases during the 2014–2016 Ebola epidemic, by county (Liberia), district (Sierra Leone), and prefecture (Guinea) — Guinea, Liberia, and Sierra Leone, as of March 27, 2016*



Source: World Health Organization. Ebola situation reports. Geneva, Switzerland: World Health Organization. http://apps.who.int/ebola/ebola-situation-reports
Abbreviation: Ebola = Ebola virus disease.
* After March 27, 2016, an additional three confirmed cases were reported in Liberia, and three probable cases were reported in Guinea.

Drawing on experience from previous Ebola responses, CDC worked with governments and partners to detect and break chains of transmission and end the epidemic. Because lack of reliable epidemiologic data was a major challenge from the outset, the teams quickly began to improve surveillance, laboratory, and information management systems to collect, analyze, and report data needed to guide response actions (*10*). CDC field teams regularly traveled to districts and villages to work with community teams on patient identification and isolation, contact tracing, infection control, social mobilization, and safe burials. However, as the epidemic in West Africa evolved, the large numbers of new cases and contacts each day overwhelmed response efforts. Effective isolation of patients became increasingly difficult as hospitals, clinics, and temporary Ebola treatment units (ETUs) were filled beyond capacity; persons with new suspected cases, as

well as symptomatic contacts, frequently were turned away from ETUs, thereby fostering new chains of transmission. Suspicion of ETUs as a possible source for infection was common, making some persons reluctant to seek care even when beds were available. In addition, many HCWs became infected and died, contributing to the collapse of an already limited and compromised health care system. The growing numbers of contacts inundated response teams' capacity to identify and monitor contacts. Chains of Ebola transmission evolved rapidly, and responders often were unable to identify how cases were epidemiologically linked.

In September 2014, CDC published results of a modeling analysis that estimated that approximately 555,000 Ebola cases (1.4 million cases when corrected for underreporting) could occur in Liberia and Sierra Leone by January 20, 2015, if approximately 70% of all persons with new cases were not effectively isolated (*11*). The model also showed that the speed with which this 70% target was reached would profoundly affect the total number of cases attributable to the epidemic. As the situation worsened in the three countries that were most heavily affected, these estimates contributed to the decision to massively scale up U.S. resources, including deployment of approximately 3,000 U.S. Department of Defense personnel to Liberia to build ETUs and support other response activities. Other countries and organizations increased their response efforts as well; for example, the African Union mobilized nearly 1,000 African health care staff members to support the response.

CDC teams were integral to each country's EOC in several ways (*12*). First, they responded rapidly to reports of new cases, helped place symptomatic persons into ETUs, and identified and monitored contacts by creating teams dedicated to targeted and rapid response (e.g., as part of the Rapid Isolation and Treatment of Ebola [RITE] strategy developed in Liberia) (*13*) and assigning field staff to districts. Second, previous Ebola responses, as well as evidence of widespread transmission in health care settings in the three countries most affected, emphasized the importance of infection control in breaking the chains of EBOV transmission. CDC provided infection-control training to approximately 24,600 HCWs and others; helped establish a system of infection control points of contact in health care facilities in Guinea, Liberia, and Sierra Leone; and conducted 3-day hands-on training in Anniston, Alabama, for approximately 650 U.S. HCWs and other staff scheduled for deployment to West Africa. Third, CDC laboratory experts worked closely with IMS and other response teams to expand and coordinate the availability of laboratory testing of clinical specimens and collaborated to develop faster diagnostic assays. Fourth, social mobilization was used to promote awareness of the epidemic and marshal community religious and political leaders, and CDC health communication experts worked with response teams to help educate local populations about Ebola. Finally, CDC helped each country's MoH develop border and airport exit-screening programs. Teams at national airports screened all passengers before the passengers boarded commercial flights and retained and evaluated travelers with febrile illness to minimize the risk for exportation of Ebola to other countries.

Response in Other African Countries

In July 2014, a traveler with Ebola flew from Monrovia, Liberia, to Lagos, Nigeria, where multiple responders had unprotected contact with him and were infected, raising the specter of an Ebola epidemic in Africa's most populous city (21 million). The Nigerian government promptly launched an emergency response supported by an existing EOC and IMS structure for polio eradication, Nigerian trainees and graduates of a CDC Field Epidemiology Training Program, and CDC response officials. The IMS response established an ETU within 2 weeks, trained approximately 2,000 Ebola caregivers, identified approximately 890 contacts, and completed 19,000 contact tracing home visits (*14*). The rapid response helped contain the outbreak to just 19 cases in two cities and averted a public health catastrophe, not only for Nigeria (population approximately 180 million) but also for the entire African continent. WHO declared Nigeria Ebola-free on October 20, 2014.

CDC provided support to Senegal and Mali after separate importations of Ebola into those countries by travelers. Vigorous responses, including meticulous contact tracing, were implemented rapidly, and only a small number of cases occurred (one confirmed in Senegal and eight reported [seven confirmed] in Mali). CDC also worked with WHO and national MoHs to improve Ebola preparedness for all at-risk West African countries by helping to plan for EOCs, isolation capacity for patients with suspected Ebola, disease surveillance, laboratory testing, public awareness, and other related activities.

Response in the United States

As its response in West Africa evolved during the summer of 2014, CDC worked closely with U.S. federal, state, and local public health and clinical partners to prepare for the possible introduction of Ebola into the United States. CDC issued guidance (*15*) and alerted health care workers to consider a diagnosis of Ebola if patients had compatible symptoms and had visited an affected country within the previous 3 weeks. To facilitate rapid testing, CDC provided staff, training, and support to qualify 56 state and local public health laboratories to perform Ebola reverse transcription polymerase chain reaction (RT-PCR) testing for Ebola.

The introduction of Ebola into the United States triggered intense national media attention and widespread public alarm. In September 2014, a man flew from Liberia to Dallas, Texas and became ill with Ebola after his arrival; he died in a Dallas hospital. Two nurses who cared for him became infected with Ebola, were hospitalized, and recovered. A fourth U.S. case was confirmed in an HCW who returned from West Africa to New York City in October 2014, was hospitalized there, and recovered; no secondary infections were reported. In addition to these four U.S. patients, seven persons with Ebola symptoms, including six HCWs, were transported by charter aircraft from West Africa to U.S. hospitals; six of these patients recovered.

After the laboratory confirmation of Ebola in the Dallas patient, CDC developed expert teams (i.e., CDC Ebola Response Teams) to deploy where needed anywhere in the United States to assist with the response. To strengthen the preparedness of hospitals nationwide, CDC defined three tiers of hospital readiness, consisting of frontline health care facilities,† Ebola assessment hospitals, and Ebola treatment centers (*16*). CDC teams with expertise in infection control, occupational health, and laboratory diagnosis visited 81 facilities in 21 states and the District of Columbia (DC) to evaluate their readiness to care for patients with Ebola. By July 2015, a total of 55 hospitals in 17 states and DC were designated by state health departments as Ebola treatment centers.

To improve protection against importation of Ebola into the United States, CDC worked closely with the U.S. Customs and Border Protection (CBP), the U.S. Department of Homeland Security, and state and local public health departments to establish a system to screen and follow up all travelers returning from Ebola-affected countries in West Africa. Travelers arriving from these countries were routed to one of five U.S. airports, triaged by CBP agents, screened for febrile illness, provided with CARE (Check and Report Ebola) kits (consisting of a thermometer, prepaid cell phone, and educational materials), and given an opportunity to have any questions answered by CDC. These returning travelers were then tracked by state and local health departments for any symptoms consistent with Ebola during the 21-day incubation period. During October 2014–December 2015, approximately 29,000 persons were monitored. Health departments also implemented plans to facilitate safe transport of travelers to a hospital ready to assess them for Ebola if fever or other compatible symptoms developed.

†Facilities able to identify and triage persons under investigation and isolate them, notify the appropriate authorities, and transfer patients to an assessment hospital or treatment center.

Conclusion

The Ebola epidemic of 2014–2016 took a profound toll on the lives of men, women, and children of Guinea, Liberia, and Sierra Leone who were affected by a disease that had never been seen in their part of the world. Although an earlier and more robust response most likely would have controlled the epidemic sooner, the affected West African nations and the international community that responded were not prepared for an epidemic of this magnitude. This epidemic in the three countries and its introduction to seven other countries illustrates how all countries are connected and that a threat in one country is a threat everywhere. Readiness to detect and respond to outbreaks of infectious disease such as Ebola is the goal of the Global Health Security Agenda (GHSA) (*17*), an initiative supported by countries, government agencies, and international organizations to assist countries with attaining compliance with the International Health Regulations (*18*) and accelerate progress toward detecting and mitigating infectious disease threats quickly and effectively (*19*,*20*). The U.S. government has committed to working in at least 30 countries to implement GHSA, including Guinea, Liberia, and Sierra Leone, where CDC has established new country offices to provide direct technical assistance with implementation. One of the most important lessons of the epidemic is that building these foundational capacities beyond Ebola in the three countries that were most heavily affected and more broadly is pivotal to preventing a similar disaster in the future.

CDC's technical expertise and in-country presence and close collaboration with MoHs and international partners were vital to controlling the epidemic. By using information gleaned from participation in approximately 20 previous Ebola outbreaks, CDC's Ebola experts and laboratory scientists, emergency management and response specialists, epidemiologists, database developers and managers, health communicators, experts in infection prevention and control and border issues, and numerous dedicated field workers all contributed unique and essential skills. Through rigorous field work to identify and follow up with ill persons and their contacts and innovative and focused epidemiologic analyses, response teams helped demonstrate that the epidemic was more widespread than initially thought and that more extensive and targeted control measures were needed. CDC laboratory scientists staffed field laboratories and helped to boost testing capacity in the three countries that were most heavily affected. CDC worked to strengthen critical control strategies, including case management, meticulous contact tracing, early treatment with supportive care, and social mobilization, and helped to develop

creative new strategies relevant to this epidemic (e.g., the RITE strategy in Liberia, which enhanced the capacity of county health teams to investigate and lead coordinated responses to outbreaks in remote areas) (*13*). In-country scientists and public health experts were integral to these activities. CDC's Public Health Ethics Unit staffed the Ethics Desk within the EOC and facilitated consultation on ethical issues.

The epidemic highlighted how much more still needs to be learned about Ebola and the importance of partnerships, including with in-country scientists, in addressing research questions. Some areas of research include less common modes of virus transmission, virus persistence, virus reservoirs, clinical sequelae and disease spectrum, development of faster reliable laboratory tests and genetic analysis methods for virus characterization, improved information technology systems for use in the field, and effectiveness and safety of Ebola therapeutic drugs and vaccines, such as the Sierra Leone Trial to Introduce a Vaccine against Ebola (*21*).

Guinea, Liberia, and Sierra Leone will move beyond the epidemic and rebuild with resources they lacked before this epidemic, including EOCs, stronger laboratories and surveillance systems, improved infection control in hospitals and health care centers, and better public awareness of the threats posed by infectious diseases. CDC in-country offices have been established and will continue to work with MoHs and other partners to further strengthen public health systems through GHSA.

CDC's response to the Ebola epidemic in West Africa was made possible by the tireless work, unbridled dedication, and extraordinary resilience of thousands of agency staff members overseas and in the United States. To sustain CDC's readiness to respond to future epidemics, emphasis must continue to be on building capacity and having a strong in-country presence; meticulous field work, technical rigor, and expertise; partnerships with MoHs, WHO, and other international organizations; and a commitment to effective evidence-based strategies.

Acknowledgment

CDC Ebola response staff in Atlanta and in affected countries.

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CDC's Response to the 2014–2016 Ebola Epidemic — Guinea, Liberia, and Sierra Leone

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Summary

CDC's response to the 2014–2016 Ebola virus disease (Ebola) epidemic in West Africa was the largest in the agency's history and occurred in a geographic area where CDC had little operational presence. Approximately 1,450 CDC responders were deployed to Guinea, Liberia, and Sierra Leone since the start of the response in July 2014 to the end of the response at the end of March 2016, including 455 persons with repeat deployments. The responses undertaken in each country shared some similarities but also required unique strategies specific to individual country needs. The size and duration of the response challenged CDC in several ways, particularly with regard to staffing. The lessons learned from this epidemic will strengthen CDC's ability to respond to future public health emergencies. These lessons include the importance of ongoing partnerships with ministries of health in resource-limited countries and regions, a cadre of trained CDC staff who are ready to be deployed, and development of ongoing working relationships with U.S. government agencies and other multilateral and nongovernment organizations that deploy for international public health emergencies. CDC's establishment of a Global Rapid Response Team in June 2015 is anticipated to meet some of these challenges.

The activities summarized in this report would not have been possible without collaboration with many U.S. and international partners (http://www.cdc.gov/vhf/ebola/outbreaks/2014-west-africa/partners.html).

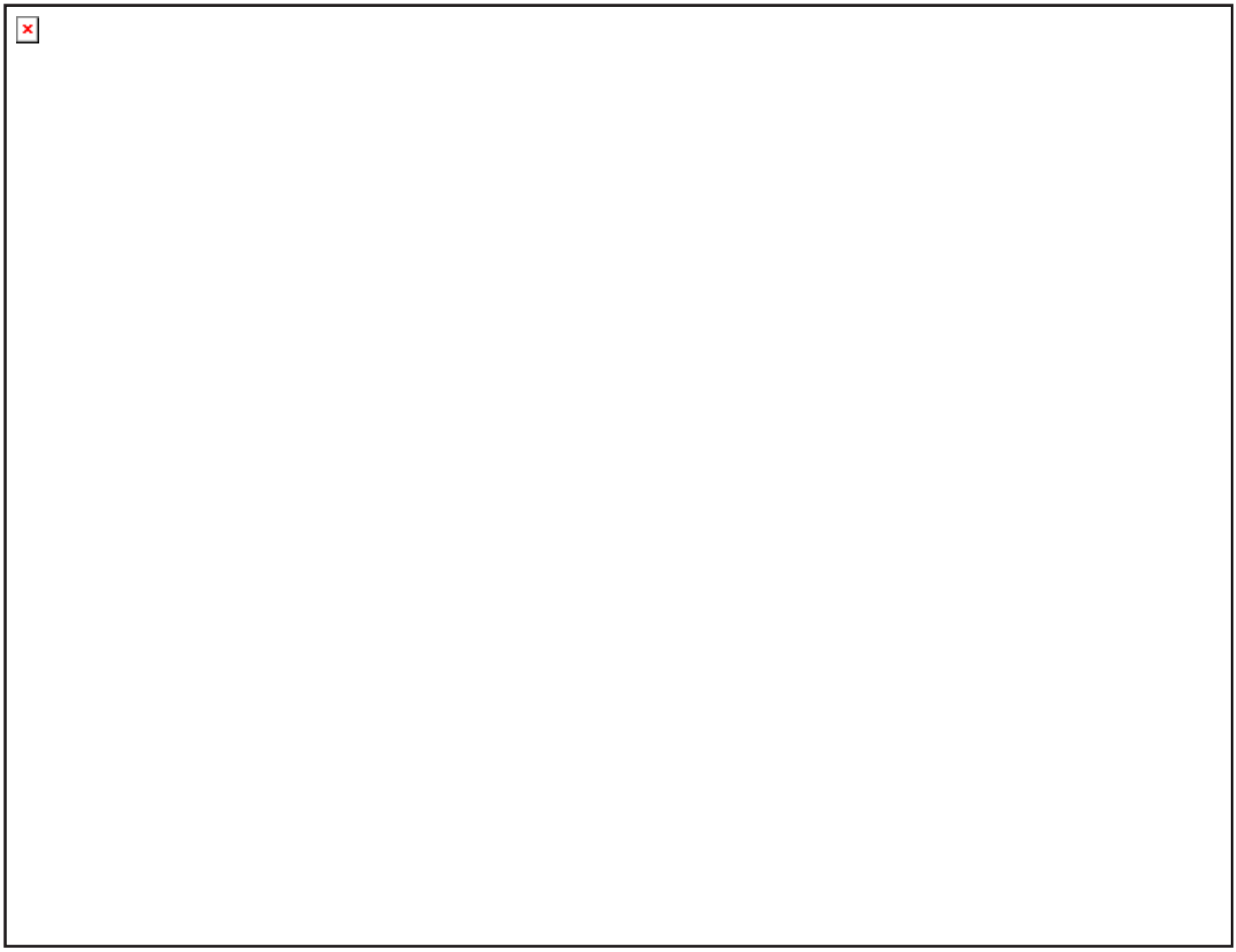
Overview of Response

The Ebola virus disease (Ebola) epidemic in West Africa (Figure 1) began in late 2013 in Guinea (*1*) and quickly spread to neighboring countries during early 2014. The epidemic is believed to have originated as an epizootic case of Ebola in Guinea (*1*) that led to local person-to-person spread of disease, initially in remote semirural areas of West Africa. However, with subsequent introductions of Ebola into urban areas, new cases occurred rapidly, and contacts moved across borders, facilitating uncontrolled spread.

Early international aid provided by the World Health Organization (WHO), Médecins Sans Frontières (MSF), and CDC initially appeared to help curtail the outbreak in March and April 2014. However, with movement of untracked contacts across borders facilitating uncontrolled spread, public health authorities realized in June that the outbreak was not contained. By mid-2014, the situation had evolved into an international public health crisis as the first documented multicountry Ebola epidemic. Ongoing transmission occurred in multiple districts in Guinea, Liberia, and Sierra Leone, including in these countries' densely populated urban areas (2).

Before this epidemic, CDC presence in all three countries was very limited, and most early support for the response was provided through short-term (4- to 6-week) assignments of staff from headquarters in Atlanta, Georgia, and CDC's international country offices. In response to the evolving crisis, on July 9, 2014, CDC activated its Emergency Operations Center (EOC) and committed agency support to assist the governments of Guinea, Liberia, and Sierra Leone. Deployed staff comprised epidemiologists, data managers, public health advisors, laboratory

FIGURE 1. Number of Ebola cases per 100,000 population — Guinea, Liberia, and Sierra Leone, December 2013–March 31, 2016



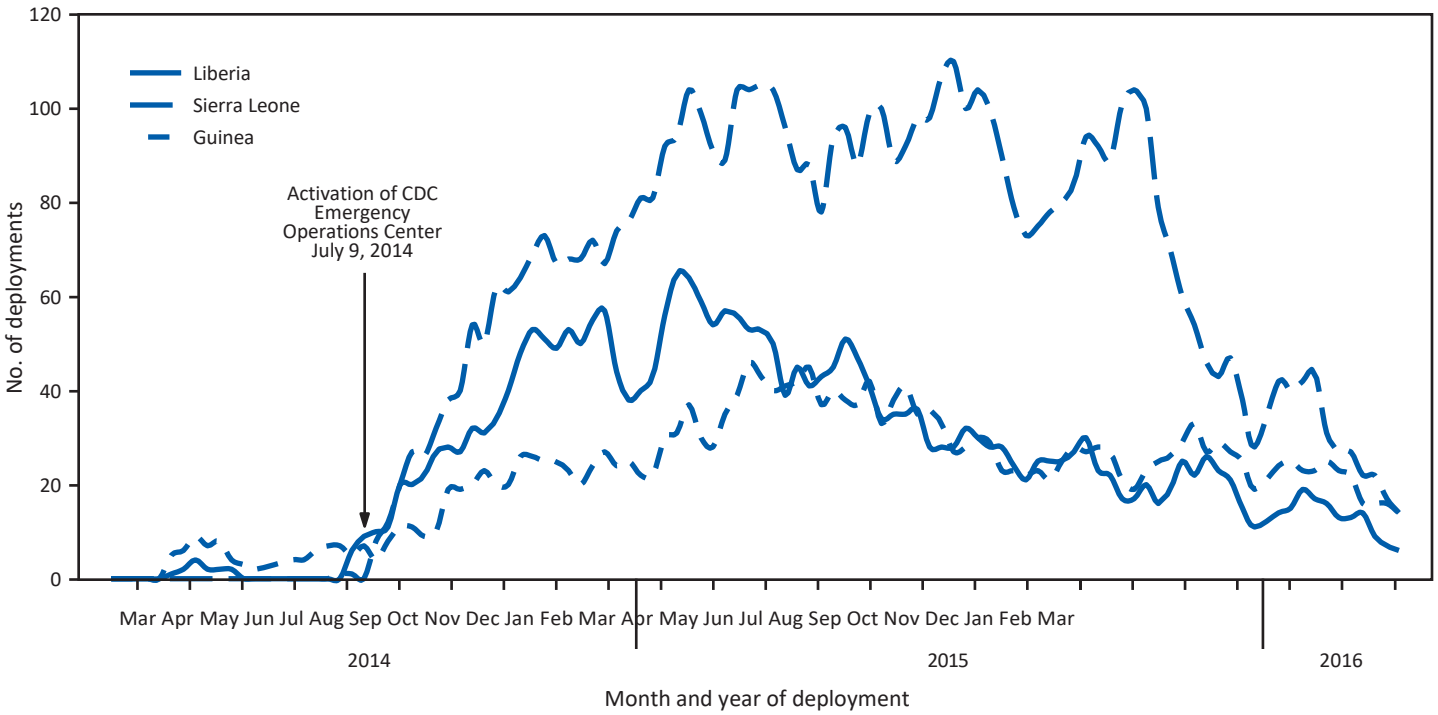
Abbreviation: Ebola = Ebola virus disease.

scientists, communication experts, logistic and administrative support staff, and diverse technical support staff (*3*).

CDC established in-country Ebola teams in collaboration with the U.S. Agency for International Development (USAID) Disaster Assistance Response Team. This team worked with host country governments and partners as a key advisor on overall response management, including support for establishing EOCs by using an incident management system (IMS) (*4*). External partners working with this IMS (and with each other) included CDC, WHO, MSF, USAID, and United Nations agencies. The concept of a unified command to manage the response was new in all three of the countries most heavily affected, and the governments of these countries had no previous experience managing a complex outbreak that evolved into a humanitarian crisis. CDC teams worked within this unique and evolving structure to tailor activities to individual country needs, collaborating closely with WHO and the lead epidemiologist in the ministries of health.

CDC staff were deployed to Guinea and Liberia in March 2014 (Figure 2); in July, deployments were increased through the activation of CDC's EOC. In each country, CDC staff provided technical support and guidance to the working groups involved with epidemiology and surveillance; case investigation; laboratory capacity; safe transport of patients suspected of having Ebola, dead bodies, and laboratory specimens; infection control; community engagement; and safe burials. As the response evolved and the number of CDC staff in each country increased (Figure 2), CDC-supported

FIGURE 2. Number of staff deployments by CDC for the Ebola epidemic, by country and month — Guinea, Liberia, and Sierra Leone, March 2014–March 2016



Abbreviation: Ebola = Ebola virus disease.

staff (3) were deployed to outbreak areas to support ministry of health teams conducting case investigations, outbreak investigations, and various field surveys in collaboration with WHO, UNICEF, and MSF; epidemiologists were deployed through the African Union. CDC played an important role in case finding in all three countries by training staff to conduct surveillance activities and by training lead surveillance persons at the county (Liberia), district (Sierra Leone), and prefecture (Guinea) level. CDC did not send staff to provide direct patient care but did organize a training course and center for clinicians who had been deployed to work in Ebola treatment units (ETUs) in the countries affected by Ebola (5).

To maintain the large number of personnel for a long period, CDC drew on staff from its headquarters in Atlanta, Georgia, and from other CDC offices and institutes across the United States (e.g., the National Institute for Occupational Safety and Health in Cincinnati, Ohio, and the National Center for Health Statistics in Hyattsville, Maryland) and from the many CDC offices in countries around the world. In addition, CDC recruited domestic public health professionals from state health departments, fellowship programs in the United States, and other agencies within the U.S. Department of Health and Human Services. For the response in Guinea, the number of French-speaking CDC experts was augmented substantially with the deployment of colleagues from the Public Health Agency of Canada (PHAC) and graduates of the Field Epidemiology Training Program (FETP), particularly from the Democratic Republic of the Congo. Given CDC's need to continue its ongoing work in many other areas of public health, many of the CDC experts were deployed on 4- to 6-week rotations; 455 persons were deployed more than once.

In all three countries, the general response emphasized active surveillance, rapid case investigation, referral of patients with suspected Ebola for treatment in ETUs, contact ascertainment and follow-up, infection control, and safe burials. Although the responses in the three countries were often similar, important differences and approaches also existed in accordance with the stage of the epidemic in each country, the unique cultural influences and language barriers, and variable levels of international aid and partners available in each country.

Guinea

The Ebola epidemic is believed to have begun as a small outbreak in the Guéckédou prefecture of Guinea in late 2013, and cases spread to the capital city, Conakry, by March 2014 (2). CDC teams arrived in March to work with WHO and the Guinean government. CDC staff stayed through April, when the outbreak seemed to be waning. However, cases occurred

again, and CDC orchestrated a more robust response to assist the Guinean government and other partners. CDC Guinea team numbers fluctuated daily and ranged from two in May 2014 to 38 in March 2015 (Figure 2). By March 31, 2016, CDC had made 568 deployments to Guinea (Table).

Several different ministries of the Guinean government managed the early response; CDC, WHO, and other partners offered primarily technical support. In September 2014, the response was reorganized into an IMS structure in which CDC and WHO provided technical assistance. The response was organized into five activities known as pillars, each of which was co-led by a Guinean national alongside an experienced partner: surveillance (WHO), care and treatment (MSF), sanitation (International Federation of Red Cross), communication (UNICEF), and research (a Congolese professor). The pillar co-leads convened technical working groups to support the needs of the response. The former head of the Epidemiology and Disease Surveillance section of Guinea's Ministry of Health and Public Hygiene led the National Ebola Coordination Cell. Although WHO was the main surveillance lead, CDC staff provided substantial technical leadership at both central and prefectural levels, focusing on support for case finding, contact tracing, case investigation, contact listing, investigation and documentation of chains of transmission, and support for improving rigor and oversight in investigating cross-prefecture and cross-border movements of contacts. Early in the epidemic, CDC staff assisted Guinean officials with exit screening at Conakry Airport; once that was effective, they shifted to monitoring terrestrial movements (especially between Forécariah prefecture and Kambia district in Sierra Leone and Boké prefecture and in Tombali region of Guinea-Bissau). CDC, challenged by a limited number of French-speaking staff in Atlanta, recruited French-speaking staff internally within the U.S. government from other CDC country offices, CDC locally employed staff, and the U.S. Department of Health and Human Services and externally through PHAC and Democratic Republic of the Congo FETP graduates and residents. The external partnerships with PHAC and Democratic Republic of the Congo FETP yielded particularly experienced and effective staff who were linguistically and culturally well adapted to the fluid field epidemiology environment.

In Guinea, as in Liberia and Sierra Leone, CDC staff did not play a direct role in Ebola treatment but did collaborate with health care workers and health care facilities on surveillance and community outreach. MSF, the French Red Cross, the African Union in collaboration with the Cuban Brigade, and Alliance for International Medical Action were the primary operators of the ETUs in Guinea. The French military also established and ran a 10-bed ETU designated for Ebola-infected care providers (e.g., medical staff, ambulance drivers, and traditional healers) (*6*). The U.S. Embassy and USAID's Office of U.S. Foreign Disaster Assistance played key roles in negotiating locations and funding new ETU construction.

TABLE. Number of confirmed (with date), probable, and suspected Ebolacases; numberofdeaths; andnumberof CDCstaffdeployments during the Ebola epidemic — Guinea, Liberia, and Sierra Leone, March 2014–March 20, 2016

Characteristic	Guinea	Liberia	Sierra Leone
Date of first confirmed case	March 2014	March 2014	May 2014
No. of confirmed, probable, and suspected cases	3,811	10,675	14,124
No. of deaths	2,543	4,809	3,956
No. of CDC staff deployments	568	627	1,100

Abbreviation: Ebola = Ebola virus disease.

A marked reticence among Guinean residents to report suspected Ebola cases hampered an early effective response; when the initial outbreak seemed to be waning, cases probably were unreported (*7*,*8*). Community resistance at times challenged the response and accessibility to villages. Deep-seated distrust of the government and outsiders and misconceptions in the country about the disease and the responders drove lack of reporting and, in some cases, hostility toward responders. In September 2014, villagers killed eight response workers, comprising WHO staff, doctors, and journalists (*9*), an event that underscored the dangerous nature of working in an atmosphere driven by fear, disbelief in the existence of the disease, and distrust of authorities. To address the reticence, several approaches were undertaken by the response IMS, including working with village elders, engaging Conakry residents who had family in the villages, deploying social anthropologists as members of investigation teams, and using security forces to maintain the peace.

In Guinea, WHO, CDC, and MSF advocated community outreach, active case finding, contact tracing, and rapid transport of patients suspected of having Ebola to ETUs rather than the widespread construction of unstaffed ETUs. This strategy markedly differed from the strategy adopted in Liberia and Sierra Leone, where construction of ETUs was a primary international focus. In Guinea, the national strategy of enhanced surveillance was anchored by the hiring of teams of recently graduated Guinean doctors who were deployed in each prefecture under the leadership of a prefectural lead. CDC and WHO deployed staff to the prefectures heavily affected by Ebola to offer technical and supervisory assistance. In the early stages, case finding was conducted through prefecture-wide door-to-door sensitization visits to raise community awareness of the urgent need to report patients suspected of having Ebola. Later, Ebola case finding in Guinea was intensified to include door-to-door monitoring in high-incidence subprefectures.

At this stage, contacts of Ebola patients were monitored with daily temperature checks but were not physically or socially restricted from traveling to other prefectures.

The continued seeding of new chains of transmission in prefectures that had previously been free of Ebola led the Guinean National Ebola Response to adopt an approach called cerclage to contain the outbreak (*10*). This approach was an attempt to limit the movement of contacts of recent Ebola patients and their associated communities through social pressure and encouragement to remain within a circumscribed area (home or their village). To ensure community participation with the restrictions on movement, the national Ebola response provided some essential medical services, as well as supplemental food and hygiene materials. Village leaders were engaged and asked whether they agreed to participate in the cerclage. Prefectural Ebola response teams continued to directly observe the contacts each day during the 21-day follow-up period to rapidly isolate newly symptomatic patients. This approach was partially adapted from the Rapid Isolation and Treatment of Ebola (RITE) strategy (*11*,*12*) in Liberia and the quarantine village approach from Sierra Leone.

WHO declared Guinea free of Ebola transmission on December 29, 2015, after the last Ebola patient in Guinea was discharged from an ETU on November 16, 2015. On March 17, 2016, a new case of Ebola was reported in Guinea, and related cases were subsequently identified in both Guinea and Liberia. CDC expected that sporadic cases of Ebola could occur, even after the epidemic had ended, and cases have indeed occurred in Guinea, Liberia, and Sierra Leone since the epidemic was declared over in each country.

Liberia

A team of seven CDC staff members arrived in Monrovia in mid-July 2014 after a request for assistance from Liberia's Ministry of Health and Social Welfare. Events in late July that drew the world's attention to the emergency in West Africa included travel by an infected person from Monrovia to Lagos, Nigeria, initiating a secondary outbreak there, and Ebola infection in U.S. and other expatriate health care workers and their subsequent international evacuation (*13*). Within weeks, considerable additional staff were deployed; by September 2014, the CDC team in Liberia comprised approximately 40 persons. Initial investigations in July 2014 focused on determining the extent and magnitude of the outbreak, including among health care workers; clarifying and strengthening data systems and reporting; coordinating enhancement of laboratory capacity; and providing overall support for the Liberian response (*14*–*16*).

In early August 2014, the gravity of the situation was recognized. The U.S. ambassador declared a disaster, the president of Liberia declared a state of emergency (*14*–*16*), and WHO called the Ebola epidemic a public health emergency of international concern (*14*). An important contribution by the CDC team in late July 2014 was advising the Ministry of Health and Social Welfare on establishing a focused IMS to replace the previous Liberian Ebola Task Force, a task force that was large and included high-level officials within the government (*17*,*18*). After formation of the IMS, the following priorities were established: 1) early detection and isolation of persons with Ebola, 2) safe transport of patients with suspected Ebola, 3) support of infection control to prevent transmission within the health care system, and 4) safe burials. Isolation of patients with suspected Ebola was the most immediate and overriding objective. The strategy did not include treatment of patients within existing health facilities (but supported home-based care instead) and did not use involuntary quarantine for contacts of patients. Involuntary quarantine by the authorities of a particularly impoverished community in Monrovia in mid-August 2014 resulted in violence, was not supported by technical partners, and was not repeated (*19*).

IMS proved critical to consolidate, communicate, and ensure broad support for technical and policy interventions. However, the system remained larger than ideal. Therefore, the incident manager set up an inner core of advisors comprising representatives from WHO, CDC, and the UN Mission for Ebola Emergency Response, who conferred daily to discuss priority activities and make key decisions. The Liberian EOC organized a series of microplanning (county-level response) workshops with key county health officials and partners to assist in planning and developing response capacity.

WHO co-chaired the case management working group, and CDC played an important role in supporting the evolving case management strategy. U.S. government efforts focused on building ETUs to manage the increasing caseload of patients, although those efforts were not managed by CDC staff. Several partners contributed to the building of ETUs; however, delays in construction and mobilization of resources to staff and supply the ETUs hampered efforts. In response to the increasing number of patients suspected of having Ebola and requiring urgent management and care, CDC and others supported establishment of community care centers in areas without ETUs. The increase in available isolation beds and expanded efforts to ensure rapid and safe burials markedly reduced Ebola incidence, and by late September 2014, national bed capacity exceeded demand (*20*).

During late October and early November 2014, numerous outbreaks occurred in remote areas of Liberia. The need for flexible, mobile, and rapid teams that could quickly reach new hot spots, conduct assessments, and implement early control

measures was recognized, leading to development of the RITE strategy (*11*,*12*). RITE teams were deployed at the first report of new suspected outbreaks, and team members focused on village-level isolation and management of patients until safe referral to ETUs could be established. The enhanced capacity of county health teams to investigate outbreaks in remote areas provided a faster, more tailored response to the local needs.

In addition to supporting the national surveillance office, CDC deployed staff and tried to maintain a presence in all counties within Liberia that had ongoing Ebola virus transmission. Much of the work at the county level focused on developing surveillance and data management capacity of the county health team and supporting contact tracing and outbreak investigations. Effort also went into health communication (*17*).

By November 2014, the epidemic was characterized by continued low-level transmission in Monrovia and surrounding Montserrado County, which resulted in sporadic cases in remote, rural locations. Cases had declined substantially, enabling focus on individual transmission chains. The last known chain, in a community near Saint Paul River Bridge, was investigated and contained in early 2015 (*21*). Although Liberia appeared on the way to being declared Ebola-free, one case occurred unexpectedly in Monrovia in March 2015. A detailed investigation found that the patient most likely acquired Ebola through sexual intercourse with an Ebola survivor who had been ill approximately 6 months previously (*22*,*23*).

Liberia was first declared free of Ebola transmission by WHO on May 9, 2015, and on two subsequent occasions (September 3, 2015, and January 14, 2016), only to have other clusters or cases subsequently detected and contained. CDC staff are now concentrating on strengthening epidemiology, laboratory capacity, infection prevention and control, and restoration of routine health services.

Sierra Leone

The first cases of Ebola in Sierra Leone were detected in May 2014. Transmission increased from the eastern Kailahun and Kenema districts early in the outbreak to eventually affect all 14 districts. CDC's first deployment to Sierra Leone occurred in July 2014 (Figure 2); 1,100 deployments supported CDC activities in the country through March 20, 2016 (Table).

CDC provided technical assistance to the government of Sierra Leone and many partners to implement outbreak management activities. To support these activities, CDC staff were embedded into the local response teams at the District Ebola Response Centres and into the national-level National Ebola Response Centre and Ministry of Health and Sanitation (MoHS).

CDC supported establishment and management of the national and district databases and provided data management and technical assistance for Ebola surveillance, case investigation, contact tracing, and other outbreak control activities. CDC staff helped with training and supportive supervision of case investigators, contact tracers, and data managers and contributed subject-matter expertise to the investigations of nosocomial Ebola outbreaks and infections among health care workers and frontline responders. The MoHS used CDC's concept of Ring Infection Prevention and Control (Ring IPC) (*24*), and CDC was integral to implementing the strategy; this strategy supported improved screening, isolation, referral for treatment, use of hand hygiene and personal protective equipment, waste management, and cleaning and decontamination practices for health care facilities and health care workers at highest risk for Ebola exposure and infection. CDC staff commonly coordinated Ring IPC activities in collaboration with WHO, the United Kingdom's Department for International Development, and nongovernment organizational partners. Finally, CDC staff supported rapid behavioral assessments to inform ongoing response activities and improve community engagement.

The MoHS, the International Organization for Migration, and CDC worked to strengthen screening at the international airport and seaports and along land borders. CDC also supported development of guidelines, training of screeners and management staff, periodic assessments with support to address gaps identified, and exercises to maintain procedures throughout the epidemic.

Unlike in Guinea and Liberia, in Sierra Leone CDC established, managed, and staffed an Ebola testing laboratory. Initially the laboratory was in Kenema district but was later relocated to Bo district, with an MSF ETU. The CDC Bo Laboratory maintained capacity to test up to a peak of 180 samples in a single day. The laboratory played a considerable role in Ebola virus diagnostic laboratory testing in Sierra Leone, processing more than one third of all specimens during the epidemic, and had tested approximately 26,000 specimens when it was closed in October 2015. In addition to diagnostic testing, the CDC Bo Laboratory also tested semen samples collected as part of the Virus Persistence Study among Ebola survivors (*25*). CDC supported laboratory coordination, assisted with the development of sample transport and data reporting systems, and provided support to MoHS to conduct proficiency testing of international Ebola laboratories in Sierra Leone. As of March 31, 2016, CDC continued to provide technical assistance to the government of Sierra Leone and other partners to sustain laboratory capacity for Ebola virus testing and to strengthen government of Sierra Leone laboratory systems at the Central Public Health Reference Laboratory in Freetown.

Throughout the epidemic, CDC collaborated with MoHS and the Ebola Response Consortium, which comprised nongovernment organizations, to enhance screening, isolation, and referral capacity at non-Ebola health care facilities. Activities reached 1,188 government clinics and resulted in training of 4,264 health care workers on infection-control procedures (*26*) relevant to the outpatient setting, including screening, isolation and temporary management, referral for testing, hand washing, use of recommended personal protective equipment, waste management, and cleaning and decontamination. At government hospitals, CDC supported MoHS and WHO in the placement and training of IPC focal persons and committees (*5*). Within MoHS, CDC and WHO assisted with establishing the National IPC Unit, led by a national IPC coordinator. The National IPC Unit is responsible for expanding Ebola IPC activities to all public and private health care facilities and to include practices to reduce nosocomial transmission of pathogens other than Ebola virus.

With MoHS and other partners, CDC participated in several studies during the Ebola response, including the Sierra Leone Trial to Introduce a Vaccine against Ebola (*27*). In addition, with MoHS and WHO, CDC initiated the Virus Persistence Study to assess the length of Ebola virus shedding in the semen of survivors (*25*). A second phase of the study is enrolling survivors of both sexes to determine the persistence of Ebola virus in body fluids. A household transmission study was conducted in Freetown to better understand the dynamics of Ebola virus transmission (CDC, unpublished data, 2015). Four surveys of knowledge, attitudes, and practices were conducted with CDC support at different stages during the epidemic to improve understanding of how Sierra Leone residents perceived the Ebola epidemic and response and what activities might improve community engagement. CDC also collaborated with the National Institutes of Health to implement a randomized trial of the investigational therapeutic drug ZMapp (*28*).

Sierra Leone had two new cases beginning in January 2016, more than 2 months after WHO declared the end of the epidemic in Sierra Leone on November 7, 2015. Rapid and effective contact tracing, as well as implementation of control measures, quickly controlled the sporadic clusters that have occurred.

Challenges and Lessons Learned

Key challenges to the countries affected by Ebola as the epidemic accelerated included response coordination, initial clinical management and isolation of patients suspected of having Ebola, development of a reliable alert system to report suspected cases, development of a skilled workforce for field epidemiologic investigation, and the need for infrastructure to manage and isolate contacts. Early in the epidemic, all three countries found it challenging to reach a consensus among partners on specific strategies for the overall response. Other challenges included 1) developing treatment protocols and scaling up health systems' capacity to manage the growing number of patients; 2) deciding whether to use existing facilities or build new facilities for clinical care, whether to support home-based care, and the role of quarantine in managing cases and contacts; 3) developing communication strategies; 4) determining how to engage communities and enlist their support; and 5) deciding how to respond to the increasing humanitarian crisis. Another challenge included producing reliable descriptive epidemiologic data, which underscored the need for standardization of data collection and management between the three countries.

A major issue for all three countries was the extensive and substantial effect of the epidemic on basic health care services. For example, nosocomial transmission led to Ebola virus infection among staff members, routine vaccination campaigns were canceled, samples from persons suspected of having polio were unable to be transported out of the countries, and 75% fewer caesarean sections reportedly were performed than before the Ebola epidemic (*29*,*30*). As the epidemic has waned, the need to rebuild the health care sector has become apparent.

Many unique staffing challenges and solutions were encountered during this historic response, the largest in CDC's history. Approximately 1,400 CDC staff were placed in the three countries during the 21 months of the EOC activation, during July 2014–March 2016. This long-term need for international deployment of staff highlighted that CDC's traditional approach to international work (deployments of approximately 30 days) might need to be reconsidered for future responses of this magnitude and length. Positive relationships with different partners must continue to be fostered, and clear objectives for CDC roles and responsibilities for outbreak responses should be determined before the next outbreak.

The 2014–2016 Ebola epidemic in West Africa underscores the importance of ongoing partnerships with ministries of health in resource-limited countries and regions. The rapid response to the initial introduction of Ebola into Nigeria, where CDC had an established presence (*3*), contrasts considerably with that of the early CDC response in Guinea, Liberia, and Sierra Leone. Issues to consider while attempting to enhance CDC's capacity in overseas public health emergency responses of this magnitude include providing effective, internationally focused emergency response training; maintaining a cadre of culturally and linguistically fluent, highly experienced staff who are ready to be deployed to other countries; and developing ongoing working relationships with U.S. government agencies and other multilateral and nongovernment organizations that

deploy during international public health emergencies. CDC's establishment in June 2015 of the Global Rapid Response Team, which includes staff members who are on call and ready to deploy at any given time to Africa, the Middle East, and Asia, is anticipated to meet many of these challenges.

Conclusion

The response to the Ebola epidemic in Guinea, Liberia, and Sierra Leone varied by country and involved many international partners working with government ministries. However, across the region, CDC staff were primarily engaged in offering subject-matter expertise on the core principles for control, including ensuring and enhancing surveillance efforts across the region, and ensuring prompt, efficient, and complete contact tracing practices. In addition, CDC provided technical support in other areas, offering guidance, training, and support for infection-control and health communication. Although the response varied among countries and changed as the epidemic shifted, a common goal, to reach zero new Ebola cases, drove the response within each country and among all partners, as did the belief that such a goal was attainable.

A CDC operational presence earlier in the epidemic might have led to a more effective response. Therefore, CDC has established country offices in Guinea, Liberia, and Sierra Leone to help the ministries of health better prepare for future disease outbreaks. These new in-country offices will focus on building surveillance capacity by strengthening the public health infrastructure, expanding the workforce, improving laboratories, and continuing to develop emergency response capability.

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Early Identification and Prevention of the Spread of Ebola in High-Risk African Countries

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Summary

In the late summer of 2014, it became apparent that improved preparedness was needed for Ebola virus disease (Ebola) in at-risk countries surrounding the three highly affected West African countries (Guinea, Sierra Leone, and Liberia). The World Health Organization (WHO) identified 14 nearby African countries as high priority to receive technical assistance for Ebola preparedness; two additional African countries were identified at high risk for Ebola introduction because of travel and trade connections. To enhance the capacity of these countries to rapidly detect and contain Ebola, CDC established the High-Risk Countries Team (HRCT) to work with ministries of health, CDC country offices, WHO, and other international organizations. From August 2014 until the team was deactivated in May 2015, a total of 128 team members supported 15 countries in Ebola response and preparedness. In four instances during 2014, Ebola was introduced from a heavily affected country to a previously unaffected country, and CDC rapidly deployed personnel to help contain Ebola. The first introduction, in Nigeria, resulted in 20 cases and was contained within three generations of transmission; the second and third introductions, in Senegal and Mali, respectively, resulted in no further transmission; the fourth, also in Mali, resulted in seven cases and was contained within two generations of transmission. Preparedness activities included training, developing guidelines, assessing Ebola preparedness, facilitating Emergency Operations Center establishment in seven countries, and developing a standardized protocol for contact tracing. CDC's Field Epidemiology Training Program Branch also partnered with the HRCT to provide surveillance training to 188 field epidemiologists in Côte d'Ivoire, Guinea-Bissau, Mali, and Senegal to support Ebola preparedness. Imported cases of Ebola were successfully contained, and all 15 priority countries now have a stronger capacity to rapidly detect and contain Ebola.

The activities summarized in this report would not have been possible without collaboration with many U.S and international partners (http://www.cdc.gov/vhf/ebola/outbreaks/2014-west-africa/partners.html).

Background

In the late summer of 2014, it became apparent that improved preparedness was needed for Ebola virus disease (Ebola) in at-risk countries surrounding the three West African countries that were most highly affected (Guinea, Sierra Leone, and Liberia). The potential for Ebola to spread from these countries to other countries in Africa was of particular concern. Côte d'Ivoire, Guinea-Bissau, Mali, and Senegal were considered at greatest risk for Ebola importation because each shared a land border with Guinea or Liberia. The World Health Organization (WHO) identified these four bordering countries and 10 others in the WHO Africa Region (Benin, Burkina Faso, Cameroon, Central African Republic, Ethiopia, The Gambia, Ghana, Mauritania, Niger, and Togo) as the highest priority countries for technical assistance for Ebola preparedness; two additional countries (Nigeria and Democratic Republic of the Congo) were identified as at high risk for Ebola introduction because of strong trade and travel links with the affected countries (*1*).

Recognizing the importance of rapid response to an Ebola importation, CDC established the High-Risk Countries Team (HRCT) in the International Task Force of the CDC Ebola response in August 2014. Its purpose was to enhance the capacity of identified high-priority African countries to rapidly detect and contain an imported case of Ebola. To facilitate the enhancement of the capacity for rapid Ebola detection and containment, the Atlanta, Georgia–based HRCT, in close collaboration with CDC country offices in Africa, focused on building epidemiologic and laboratory capacity, particularly Ebola surveillance and alert systems, Ebola specimen transport, contact tracing, border/points-of-entry screening, and implementation of rapid response teams.

When the HRCT was deactivated in May 2015, CDC had provided technical assistance for Ebola preparedness to 15 of the 16 at-risk countries (the exception was the Central African Republic) (Figure 1). CDC also assigned staff to the WHO Africa Regional Office in Brazzaville, Congo, and WHO headquarters in Geneva, Switzerland. In-country members of the HRCT worked directly with ministry of health (MoH) officials or persons who worked for organizations designated responsible for the country's Ebola preparedness activities. The team also collaborated with WHO and other international organizations, such as the International Organization for Migration, Médecins Sans Frontières (MSF), and the International Committee of the Red Cross. Key in-country partners included U.S. Embassy staff, particularly U.S. Agency for International Development and CDC country office staff.

CDC staff already had been working in nine of the 15 countries and were intensely involved in Ebola preparedness and response; seven of these countries (Cameroon, Democratic Republic of the Congo, Ethiopia, Ghana, Côte d'Ivoire, Mali, and Nigeria) had CDC country offices, and the two other countries (Benin and Senegal) had in-country CDC malaria resident advisors involved in the President's Malaria Initiative (Figure 1). Because CDC in-country staff already had built relationships with public health staff in their countries, they were able to more rapidly assist these countries with Ebola preparedness.

A total of 128 CDC staff provided in-country technical support to these countries and to WHO Africa Regional Office and WHO headquarters. An additional 30 CDC staff members in Atlanta supported personnel deployed in the field. Countries that received the highest levels of CDC in-country technical support were the three countries that had imported cases of Ebola: Nigeria, Senegal, and Mali.

CDC Technical Assistance in Ebola Preparedness and Response

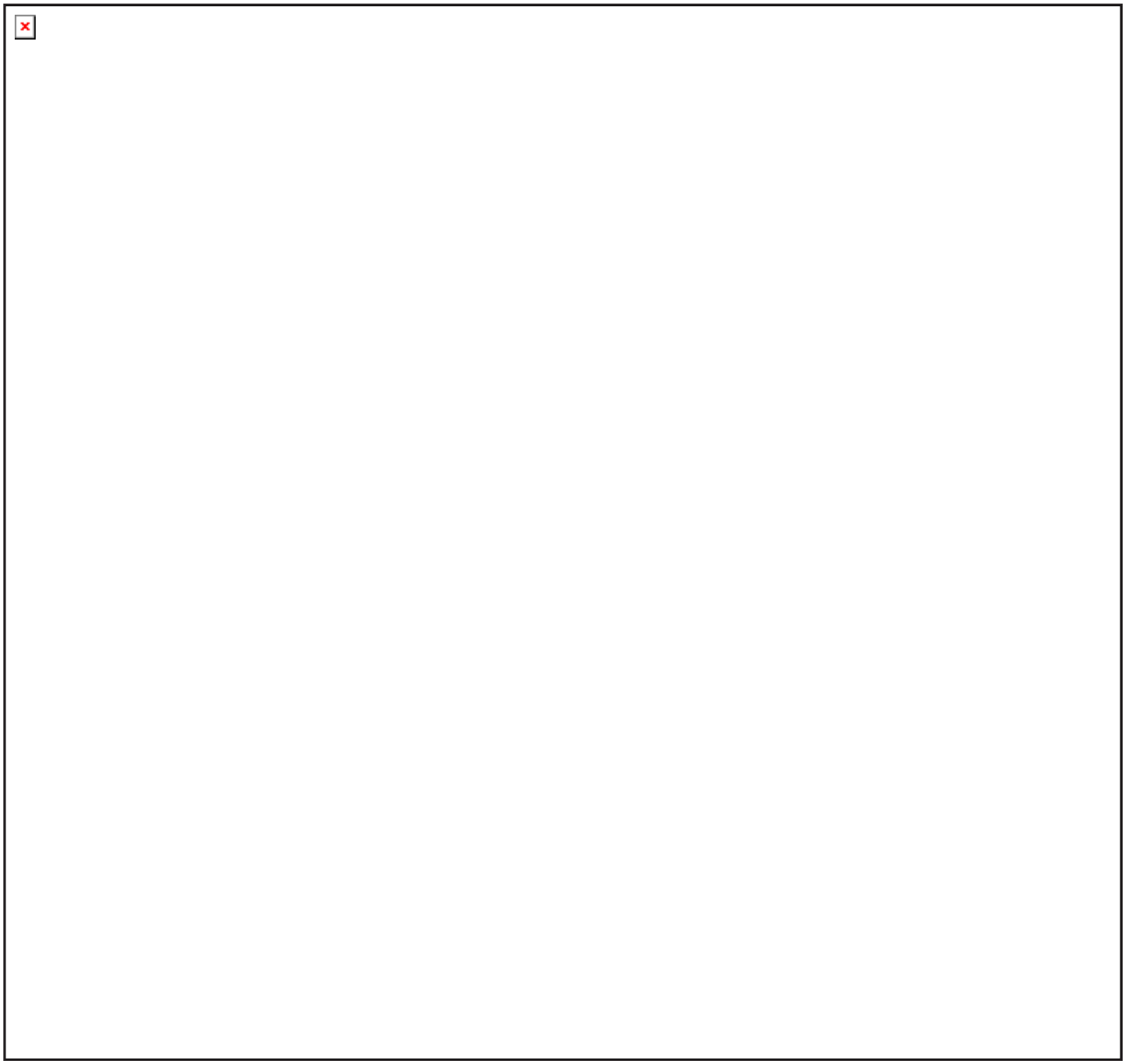
Nigeria

On July 20, 2014, an airline passenger with symptoms consistent with Ebola (index case-patient) traveled from Liberia to Lagos, Nigeria, and subsequently was confirmed to have Ebola (*2*). Thirteen direct contacts of the index case-patient, including nine health care workers, contracted Ebola; these cases represent first-generation spread of Ebola in Nigeria (*2*). Three of these case-patients transmitted Ebola to other persons (second-generation spread), including a physician in Port Harcourt, Nigeria, who was infected after treating a patient who had traveled to Port Harcourt from Lagos seeking private care (*2*). An additional three persons who had contact with the Port Harcourt physician contracted Ebola, representing third-generation spread of Ebola in Nigeria (Figure 2). Ultimately, the July Ebola importation into Nigeria resulted in 20 cases (19 confirmed and one probable) and eight deaths (*2*).

Given the population and the international airline connections in Lagos, as well as the economic and geographic importance of Nigeria, the introduction of Ebola into Nigeria represented a critical juncture in the response to Ebola. Immediately after being notified about the index case, the Lagos State MoH, with technical assistance from CDC Nigeria and the Nigerian Polio Eradication Program, activated an Ebola Incident Management (IM) center that eventually became the national Emergency Operations Center (EOC) (*2*). Within 72 hours after being notified of the index case, CDC personnel and Nigerian Field Epidemiology Training Program (FETP) staff previously assisting the MoH with polio elimination were deployed to provide technical assistance to Nigeria's MoH and were incorporated into the EOC (*2*). The EOC in Lagos was built on an existing IM structure, developed as part of the Nigerian Polio Eradication Program (*2*,*3*). A major partner in the response in Nigeria was the FETP, which facilitated field work, particularly contact tracing. After Ebola was confirmed in Port Harcourt, an EOC was established there.

Approximately 890 persons who had been exposed to Ebola (contacts) were identified and monitored, 19,000 home visits were conducted, and 150,000 airline passengers were screened in Nigeria (*2*,*3*). CDC team members were involved in planning, health communication, infection control, and surveillance, as well as in coordinating support from other sources (*2*). WHO declared Nigeria Ebola-free on October 20, 2014.

FIGURE 1. African countries where CDC provided technical assistance for Ebola preparedness — August 2014–May 2015*

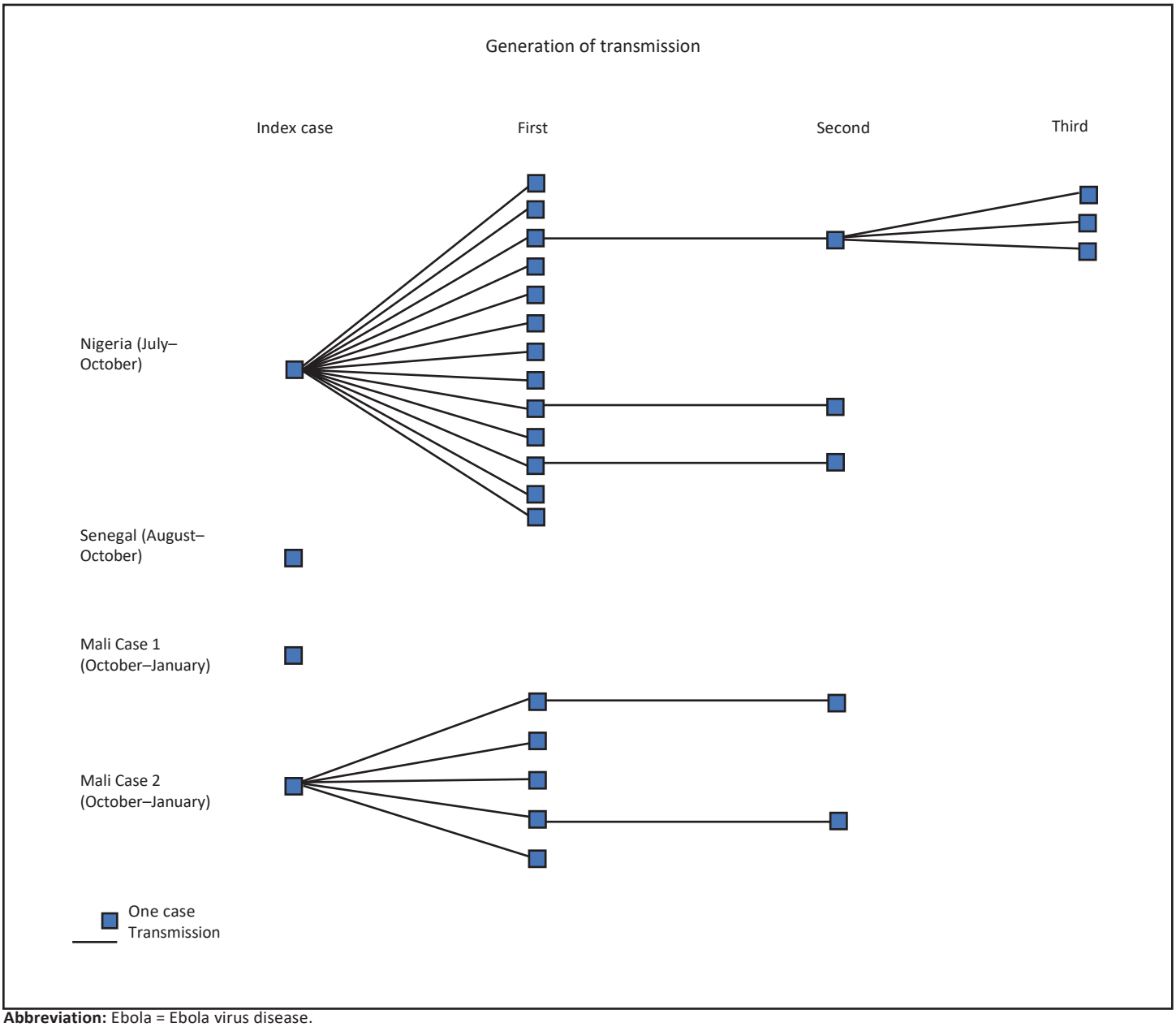


Abbreviation: Ebola = Ebola virus disease.
* The High-Risk Countries Team was active from August 2014 through May 2015.

Senegal

Seven weeks into the Ebola outbreak in Nigeria, on August 29, 2014, Senegal confirmed its first Ebola case in a student aged 21 years who had traveled from Guinea in mid-August to visit family in Dakar, Senegal (index case-patient) (4). At the request of Senegal's MoH, CDC quickly deployed staff, who partnered with the CDC malaria resident advisor in-country to assist the MoH with rapid Ebola containment through robust contact tracing, including 21-day active monitoring. The HRCT, which was developed shortly before cases in Senegal were recognized, facilitated the CDC response. A total of 74 contacts of the index case-patient were identified and followed through the 21-day monitoring period (4). No further Ebola transmission occurred in Senegal from this case (Figure 2) (4).

FIGURE 2. Number of Ebola cases for each generation of transmission following each importation of Ebola — Nigeria, Senegal, and Mali, July 2014–January 2015*



Abbreviation: Ebola = Ebola virus disease.
* The World Health Organization declared Nigeria free of Ebola on October 20, 2014; Senegal on October 17, 2014; and Mali on January 18, 2015.

The Dakar airport, a major West African hub, was a critical corridor for transporting aid into and out of the countries that were most heavily affected. Before the Ebola importation, Senegal no longer permitted air travel to or from Senegal and Guinea, Liberia, or Sierra Leone, which limited the transport of critical supplies into the countries that were heavily affected. CDC provided point-of-entry screening technical assistance at Dakar's airport, and this assistance contributed to the creation of an "air corridor" for humanitarian assistance whereby vital supplies and personnel could be transported to Liberia via the Dakar International Airport. CDC also assessed Senegal's Ebola surveillance system and provided recommendations to strengthen the system. WHO declared Senegal Ebola-free on October 17, 2014.

Mali

Mali confirmed its first imported Ebola case on October 20, 2014 (5). The index case-patient was a girl aged 2 years who

traveled from Guinea to Kayes, Mali, transiting through Bamako, Mali's capital (*5*). Members of the HRCT, who were already in-country supporting a WHO Ebola preparedness mission, assisted Mali MoH staff with the response by drafting standard operating procedures and contact tracing guidelines. They also helped to institute an IM structure. No subsequent transmission occurred in Mali from this Ebola importation (Figure 2).

On November 10, 2014, Mali was notified of a second Ebola importation. This index case-patient was a man aged 70 years from Guinea who arrived at a Bamako clinic on October 25 with symptoms consistent with Ebola (*6*). The case investigation, immediately initiated by Malia's MoH, revealed that this man did not share an epidemiologic link with the index case-patient of the first Ebola importation (*6*). Concern about the potential spread of Ebola in Bamako led to immediate deployment of additional CDC staff, who provided technical assistance for contact tracing, active surveillance, and border/points-of-entry screening. The team collaborated with Mali's MoH and WHO to identify 332 contacts of the index case-patient of the second importation; 93% of these persons completed 21-day active monitoring without missing a daily visit by the contact tracing team. The Ebola outbreak from the second Ebola importation was controlled within two generations of transmission. Five first-generation cases and two second-generation cases occurred in Mali; all second-generation cases were identified through active monitoring (Figure 2) (*6*). WHO declared Mali Ebola-free on January 18, 2015.

Guidance on Contact Tracing

CDC has continuously emphasized the importance of contact tracing as the single most effective tool for containing imported Ebola cases (*7*). As part of response and preparedness training, CDC supported development of national and local contact tracing guidelines and provided contact tracing training, particularly for rapid response teams. The rapid identification and isolation of contacts with symptoms consistent with Ebola reduces the risk for exposure to other persons, effectively breaking chains of transmission and halting Ebola transmission (*7*). However, contact tracing is effective only if it is initiated immediately after a case is identified and it is performed consistently and comprehensively.

Implementing and managing contact tracing during the 2014–2016 Ebola epidemic in West Africa posed serious challenges, including lack of a standardized approach. In response, CDC created a guidance document that detailed a systematic method for contact tracing implementation and management, "CDC Methods for Implementing and Managing Contact Tracing for Ebola Virus Disease in Less-Affected Countries" (*8*). The content derived from responders' experiences supporting MoHs in Ebola preparation in the high-risk countries, as well as through the responders' direct involvement in contact tracing in the affected countries.

Team members also partnered with WHO to create joint comprehensive contact tracing guidelines applicable to all countries. These guidelines expanded on the previously published CDC document and WHO Africa Region's "Contact Tracing During an Outbreak of Ebola Virus Disease" guideline, detailing the contact tracing process, addressing common challenges, and describing contact tracing monitoring and evaluation methods (*7*,*8*). The joint guidelines are intended to support contact tracing during the current epidemic and to operate as guidelines to prepare for and address future Ebola outbreaks.

Additional Activities and Training for Ebola Preparedness

In addition to providing contact tracing technical support and training to 450 persons, CDC trained approximately 1,500 persons on infection prevention and control, 300 on point-of-entry screening, and 120 on the Epi Info database used for Ebola surveillance. CDC developed guidelines, standard operating procedures, forms, and protocols for point-of-entry screening, Ebola surveillance, alert planning, preparedness, and 72-hour rapid response. CDC also facilitated introduction of the Emergency Management Development Team, which enabled initiation of public health emergency management capacity development, including development of EOCs, in seven high-risk countries: Cameroon, The Gambia, Ghana, Côte d'Ivoire, Mali, Nigeria, and Senegal.

Beginning in January 2015, to further strengthen field epidemiology capacity at all levels of the public health systems in West Africa, CDC's FETP Branch partnered with the CDC HRCT and the MoHs in Guinea-Bissau, Côte d'Ivoire, Mali, and Senegal; WHO Training Programs in Epidemiology and Public Health Interventions Network; and the African Field Epidemiology Network to implement Surveillance Training for Ebola Preparedness (STEP) (*9*), a 5-week program designed to rapidly strengthen surveillance skills among surveillance officers in districts bordering Ebola-affected countries.

STEP combined the Integrated Disease Surveillance and Response framework, widely used in Africa, with the FETP model of mentorship and field work. The training has three phases: 1) 1 week of classroom instruction about basic surveillance data analysis, interpretation, and reporting, including an Ebola-focused day covering surveillance case definitions and contact tracing; 2) a 3-week mentored field experience; and 3) a 3-day workshop on field work. During

the field work component, participants visit surveillance sites in their home districts to audit data quality. Participants from highest risk districts, such as border districts or potential point-of-entry districts, are equipped with cell phones to report through a daily short message service (text message) the number of new suspected Ebola cases from the previous day. Data are uploaded in real time by using a Web-based mobile platform.

A total of 188 participants have been trained in STEP: 56 participants from 25 districts in Côte d'Ivoire (two sequential cohorts), 53 participants from 13 regions in Guinea-Bissau (two cohorts), 52 participants from 21 districts in Senegal (two cohorts), and 27 participants from 10 districts in Mali (one cohort). In addition to surveillance officers, STEP participants included nurses, laboratory technicians, statisticians, and chief medical officers.

CDC's partners have widely acknowledged that STEP provided critically needed field epidemiology training. STEP is evaluated 3–6 months after each training to assess changes in surveillance practice by using indicators collected at the start of each training. Experience gained during the Ebola response indicates that the STEP training model could be adapted to rapidly scale up surveillance capacity in future epidemics.

Conclusion

Members of the CDC HRCT, in partnership with MoHs and WHO, provided technical assistance for Ebola preparedness through in-country and headquarters support that assisted with the rapid containment of several imported Ebola cases. In collaboration with many partners, particularly CDC's FETP Branch, CDC supported development of the public health workforce in high-risk countries by providing field epidemiology trainings and enhanced in-country future response capabilities by facilitating development of IM capacity.

In addition to building country-specific epidemiology and surveillance capacity, country and regional capacity in West Africa needs to be strengthened. National borders do not prevent the spread of disease, as evidenced by the importations of Ebola in this epidemic. Mechanisms for information sharing to effectively address future outbreaks also need enhancement. As described in the newly launched Global Health Security Agenda (*10*), such public health capacity building and information sharing are essential worldwide for all countries to meet the goal of the International Health Regulations (*11*) to rapidly detect and respond to public health events of international importance.

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Incident Management Systems and Building Emergency Management Capacity during the 2014–2016 Ebola Epidemic — Liberia, Sierra Leone, and Guinea

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Summary

Establishing a functional incident management system (IMS) is important in the management of public health emergencies. In response to the 2014–2016 Ebola virus disease (Ebola) epidemic in West Africa, CDC established the Emergency Management Development Team (EMDT) to coordinate technical assistance for developing emergency management capacity in Guinea, Liberia, and Sierra Leone. EMDT staff, deployed staff, and partners supported each country to develop response goals and objectives, identify gaps in response capabilities, and determine strategies for coordinating response activities. To monitor key programmatic milestones and assess changes in emergency management and response capacities over time, EMDT implemented three data collection methods in country: coordination calls, weekly written situation reports, and an emergency management dashboard tool. On the basis of the information collected, EMDT observed improvements in emergency management capacity over time in all three countries. The collaborations in each country yielded IMS structures that streamlined response and laid the foundation for long-term emergency management programs.

The activities summarized in this report would not have been possible without collaboration with many U.S and international partners (http://www.cdc.gov/vhf/ebola/outbreaks/2014-west-africa/partners.html).

Background

A functional incident management system (IMS) provides a flexible and scalable approach to managing public health emergencies and includes principles such as modular organization, incident action planning, manageable span of control, resource management, integrated communication, and chain of command (*1*). Before the 2014–2016 Ebola virus disease (Ebola) epidemic in West Africa, limited capacity existed in Guinea, Liberia, and Sierra Leone for public health emergency management, which the epidemic strained further. CDC applied its IMS experience to help these countries establish IMS systems to respond to the Ebola outbreak and to future public health emergencies (*2*,*3*).

CDC's Role and Work with Partners

In September 2014, as part of its response to the Ebola epidemic in West Africa, CDC established the Emergency Management Development Team (EMDT) within its IMS structure. This team coordinated and provided technical assistance to build emergency management capacity in Guinea, Liberia, and Sierra Leone, as well as in high-risk unaffected countries (Gambia, Guinea-Bissau, Mauritania, Togo, Benin, and Nigeria). EMDT was formed to address gaps in emergency management capacity in the affected and at-risk countries. For the most part, international partners who focused on emergency management had not arrived in country by this time, and a clear and pressing need was identified to begin organizing the response using established emergency management principles.

EMDT was managed at CDC's headquarters in Atlanta, Georgia, by the Office of Public Health Preparedness and Response, Division of Emergency Operations, with leadership and subject-matter expertise from the Center for Global Health, Division of Global Health Protection. CDC staff members deployed through EMDT were drawn from the ranks of emergency management specialists within the Division of Emergency Operations and technical experts from the Center for Global Health and other CDC programs and centers. Staff also were deployed from external partners, principally Public Health Agency of Canada (PHAC), which provided assistance and leadership to the team in Guinea. EMDT members, deployed staff, and others supporting the mission to build emergency management capacity also worked closely with Ebola response partners, including the World Health Organization (WHO), CDC Foundation, United Kingdom Department for International Development, Public Health England, eHealth Africa, International Organization for Migration, and Milken Institute School of Public Health at George Washington University.

EMDT members, deployed staff, and partners provided expertise in assisting country ministries of health and other government entities in building core IMS functions, such as emergency response planning, operations, and logistics. Deployed staff and partners enhanced emergency management capacity in three key domains:

1. Staff: Trained emergency management specialists and technical advisors able to work under a standardized organizational response structure, which promotes rapid integration of personnel and resources (2);
2. Systems: Standardized policies, processes, and procedures that are the codified basis for response activities and tasks; and
3. Infrastructure: A fully equipped emergency operations center (EOC) that facilitates, supports, and coordinates management and executive response decisions and activities for a public health emergency response. "Fully equipped" means, at a minimum, primary and redundant power supply, audio/visual functionality, computers, telephones, and Internet access.

Contributions and Impact

Sources of Information and Data Collection

To monitor progress toward key programmatic milestones and assess changes in emergency management and response capacities over time, EMDT collected information from three sources in each country: coordination calls, weekly written situation reports, and an emergency management dashboard tool. EMDT headquarters staff monitored activities and progress in emergency management capacity building primarily through coordination calls and weekly situation reports, which were generated and submitted by CDC staff deployed to West Africa. To supplement this information, EMDT obtained approval from incident management leadership to develop and use a new dashboard tool based on the three emergency management capacity domains (i.e., staff, systems, and infrastructure). Although a few assessment tools and checklists already existed, EMDT determined that a response-focused assessment tool, scaled to assess basic emergency management capacities, was needed. The initial intent of the dashboard tool was to facilitate a comprehensive evaluation of basic emergency management capacity–building activities and accomplishments. However, a scaled-down version of the tool was more appropriate, not for use as the main source of data for assessing capacity but rather as one of multiple sources to monitor progress in key areas simply and quickly.

The tool consists of the three domains of staff, systems, and infrastructure. Each domain comprises several elements developed by EMDT leadership to reflect the essential components necessary to execute basic emergency response operations. To reflect incremental increases in capacity, each element within each domain was rated on a 6-point qualitative ordinal scale, ranging from "domain element non-existent" (lowest rating) to "basic requirement met" (highest rating). Because all three countries had little to no emergency management capacity before the Ebola epidemic, "basic requirement met" was the highest achievable rating for any given element (Table 1).

Data Collection and Analysis

Deployed staff participated in coordination calls and submitted situation reports and administered the dashboard tool. To administer the tool, deployed staff assigned one of six qualitative ratings to each domain element. Although situation reports were submitted weekly, the frequency of administration of the dashboard tool fluctuated between countries. In Liberia, the tool was administered an average of twice per month during September 2014–June 2015 and was used to assess the emergency management capacity of the Ministry of Health. In Sierra Leone, it was administered an average of twice per month during August 2014–June 2015 and assessed the progress of the National Ebola Response Centre (NERC). In Guinea, the tool was administered an average of nearly three times each month during September 2014–April 2015 and assessed the National Coordination Cell (known as Cellule), an entity reporting directly to the country's president.

TABLE 1. Dashboard tool used for measuring emergency management capacity domains and elements and definitions of"basic requirement met" rating for each element during the 2014–2016 Ebola epidemic in West Africa

Domain	Domain element	"Basic requirement met" definition (highest rating)
Staff	Incident management	IM has authority to direct activities of all assigned response staff.
	Response organization	Response staffing increases or decreases as required in a timely manner.
	Operations	Operations chief has authority to run the response in the IM's absence; additional staff are available for response operations.
	Watch desk	Trained watch staff routinely produces situation reports or spot reports.
	Logistics	Chief is trained in IM principles and best practices; additional staff are available for response operations.
	Finance/Administration	Chief is trained in IM principles and best practices; additional staff are available for response operations.
	Plans	Chief is trained in IM principles and best practices; additional staff are available for response operations.
	Technical	At a minimum: epidemiology, laboratory, medical management, migration/population movement, and community engagement/health education teams or task forces staffed adequately to meet response need.
	Public affairs	Officer has authority to serve as spokesperson in the IM's absence (or dedicated spokesperson is appointed).
	Liaison	Officers are routinely used to address requests for information and requests for assistance.
	Response teams	Teams routinely report back to the EOC from the field according to established protocols.
Systems	Meeting management	IM enforces meeting discipline.
	Incident action plans	Situation reporting system routinely used by planning staff to capture progress and report to national authorities and WHO.
	Accountability	Task tracking system routinely used for task management by operations staff; reports are generated for IM.
	Operational support	Situational awareness products are kept current and posted within the EOC.
	Administrative support	Centralized stock of office supplies available as needed.
	Financial support	Expenditures are tracked and categorized to enable subsequent reimbursement.
	Logistics support	Response teams are supplied as needed to sustain field operations.
	Staffing support	Procedures exist for occupational safety and health screening of staff postresponse.
	Communication support	Media management system is in place to service media inquiries responsively.
Infrastructure	EOC facility	Breakout space is available for ≥1 teams; all space is assigned or scheduled by EOC staff.
	Power	Facility has operational power redundancy in place.
	Communications infrastructure	Communication infrastructure is routinely used to triage calls from, as well as communicate with, both subnational levels and WHO (note: video teleconferencing capability is not included).
	Information infrastructure	Operations staff have training on and can use all available IM infrastructure elements.
	Data processing and visualization infrastructure	Data display screen(s) and associated processors used within the EOC to maintain situational awareness.

Abbreviations: Ebola = Ebola virus disease; EOC = emergency operations center; IM = incident manager; WHO = World Health Organization.

Dashboard tool–derived information was stored in a central data repository and shared with CDC Ebola response leadership and other programs within CDC. Deployed EMDT staff and headquarters staff used the information to coordinate activities at the national level in Guinea, Liberia, and Sierra Leone; address gaps in IMS capabilities; and inform decisions on resource allocation within each country. These data also provided information to agency leadership and higher levels.

EMDT reviewed situation reports and analyzed key programmatic accomplishments and milestones. To analyze dashboard data, ratings were converted from the six-point qualitative ordinal scale to quantitative scores ranging from 0 to 5. For each country, a score was calculated for each domain equal to the median of its constituent element scores for each month during August 2014–June 2015. Data were analyzed using Microsoft Excel.

Changes in Capacity for Emergency Management

During August 2014–June 2015, basic emergency management capacity improved in all three countries. Weekly updates revealed improved capability in demonstrating IMS principles; key events and accomplishments are listed in Table 2. Dashboard scores generally reached and maintained their highest levels during October–December 2014 (Table 3), although additional gains and losses occurred after this period, some of which might be attributable to lower staffing levels over the December holiday season. Early in the response, some elements of capacity building were deemed high priority in all countries, such as appointing an incident manager, identifying and establishing an EOC facility, and ensuring response teams and logistic support were in place and used appropriately. Scores for other elements, such as administrative support and meeting management, did not improve as quickly; these were addressed later after more crucial elements were in place.

Liberia

EMDT began supporting the Liberian government's Ebola response on August 3, 2014. As of March 31, 2016, a total of 17 EMDT members had provided 914 person-days of in-country technical support. When EMDT first became involved, Liberia's president already had appointed an incident manager, but the response was not following standard IMS principles, such as chain of command, incident action planning, and resource

TABLE 2. Timeline of events in Ebola epidemic response — Liberia, Sierra Leone, and Guinea, August 2014–June 2015

Date	Country	Activity
2014		
August 3	Liberia	Emergency Management Development Team begins work in country.
August 10	Sierra Leone	Emergency Management Development Team begins work in country.
September 18	Liberia	Use of interim EOC begins.
September 22	Guinea	Emergency Management Development Team begins work in country.
October 7	Sierra Leone	National Ebola response coordinator approves plans for PH NEOC.
October 20	Sierra Leone	United Kingdom takes over command of the response.
October 23	Guinea	Renovations of the national public health EOC start.
October 27	Sierra Leone	Response operations move to operate under the National Ebola Response Centre.
November 1	Guinea	All partner meetings begin to be held at the PH NEOC.
November 12	Liberia	Ground breaking on permanent PH NEOC.
November 29	Guinea	Inaugural reception for the National Ebola Response Call Center.
December 13	Sierra Leone	Ground breaking on permanent PH NEOC.
2015		
February 5	Liberia	IMS workshop for 30 medical and public health students from the Young Liberian Professionals group (potential surge staff for the response).
February 10	Liberia	First 3-day EOC operations and IMS workshop for 35 subnational and national EOC staff and county health officers.
February 13	Guinea	Incident manager approves Ebola staffing plan.
February 18	Liberia	Second 3-day EOC operations and IMS workshop for 31 subnational and national EOC staff and county health officers.
March 17	Sierra Leone	Half-day EOC management workshop for key MoHS staff on EOC management and organizational structure.
March 18	Sierra Leone	Signing and deed gifting ceremony for PH NEOC to the MoHS from CDC Foundation.
March 20	Guinea	Implements new strategy for response meeting coordination.
April 27	Guinea	PH NEOC establishes central e-mail address.
May 10	Liberia	Completion of preliminary construction of PH NEOC.
June 1	Guinea	Clearance and distribution protocols for recommendations from PH NEOC to subnational response staff are established.
June 16	Liberia	All response operations move into the PH NEOC.
June 22	Sierra Leone	All NERC and MoHS staff and partners begin operating out of the PH NEOC.

Abbreviations: Ebola = Ebola virus disease; EOC = Emergency Operations Center; IMS = Incident Management System; MoHS = Ministry of Health and Sanitation; PH NEOC = Public Health National EOC.

TABLE 3. Domain scores* on a dashboard tool for measuring emergency management capacity, by month — Guinea, Liberia, and Sierra Leone, August 2014–June 2015

	Domain scores										
Country/Domain	August 2014	September 2014	October 2014	November 2014	December 2014	January 2015	February 2015	March 2015	April 2015	May 2015	June 2015
Guinea†											
Staff	—§	1	2.5	4	4	4	4	3	3	—	—
Infrastructure	—	1	1	3	3	3	3	4	4	—	—
Systems	—	2	2	3	3	3	3	3	3	—	—
Liberia¶											
Staff	—	2	3	3	—	3	3	3	3	3	3
Infrastructure	—	1	3	3	—	2.5	2	2	2	3	3
Systems	—	1	2	3	—	3	3	3	3	3	3
Sierra Leone											
Staff	2	2	3	4	4	4	—	4	4	4	4
Infrastructure	1	1	2	3	3	3	—	3	3	3	3
Systems	0	1	3	3	4	4	—	4	4	4	4

* Domain scores are on a 0 to 5 ordinal scale, which reflect lowest to highest capacity.
† The dashboard tool was only used from September 2014 to the beginning of May 2015 because of implementation of other monitoring methods more suitable for Guinea's incident management system.
§ No data were collected.
¶ The dashboard tool was not used until September 2014.

management. In addition, the response was being managed from space that was too small and lacked key technologic infrastructure. Early challenges included an insufficient number of trained logistic staff and a span of control too large for response leadership to manage effectively. Other challenges included difficulty mobilizing resources and insufficient coordination among response partner organizations. Initially, deployed EMDT staff supported Liberia's Ministry of Health in establishing an incident management structure and providing training on IMS principles (*4*).

Liberia's Ministry of Health opened an interim EOC on September 18, 2014, with guidance and technical assistance from EMDT. During the first few months of the response, EMDT supported establishment of the national Ebola response call center, which was developed with sufficient technical infrastructure to be repurposed into a national dispatch center or EOC watch desk after the Ebola response. EMDT also supported the Ministry of Health in creating a task tracker for Liberian Ebola response leadership and a template to facilitate management during response updates. In addition, deployed EMDT staff conducted and coordinated four in-progress reviews (i.e., mid-response assessments) for Liberia's Ebola response leadership in November and December 2014.

In September 2014, deployed EMDT staff began to coordinate the building of a permanent national public health EOC facility with CDC partners in Liberia. The facility opened on June 16, 2015; it was used for all response meetings and has helped response staff coordinate activities and streamline communication among staff working in various technical areas.

Most work in Liberia focused on building capacity to coordinate emergency response by establishing subnational EOCs in the country's 15 counties. In February 2015, two 3-day emergency management training sessions were held for 48 subnational personnel, 10 national personnel, and eight county health officers focusing on IMS principles and approaches to coordinating national and subnational emergency management. To reinforce this training, EMDT supported Liberian Ebola response staff in developing and collecting situation reports to streamline communication between county and national EOCs. In May 2015, this staff and infrastructure, including subnational EOCs, supported a large measles vaccination campaign in country.

Emergency management capacity improved quickly in Liberia. Dashboard scores for the staff and infrastructure domains peaked (median: 3) by October 2014, with the systems domain following close behind (Table 3). Scores for staff and systems remained at these levels while the infrastructure score dropped in January 2015, recovering a few months later.

Sierra Leone

Since August 10, 2014, deployed EMDT staff and partners have supported efforts by the Sierra Leone Ministry of Health and Sanitation (MoHS) to build response capacity for public health emergency management in Sierra Leone. As of March 31, 2016, at total of 17 CDC staff (deployed through EMDT) provided 905 person-days of in-country technical support. These staff provided technical assistance to the Ebola response in Sierra Leone and focused on building emergency management capacity through engagements with the NERC, the MoHS, and other international partners, including WHO, Public Health England, and the United Kingdom Department for International Development.

Early in the response, deployed EMDT staff supported establishment of an IMS in Sierra Leone by providing technical assistance to strengthen the ministry's organizational response structure and recommending ways to expand response functions, such as setting up an Ebola response call center. Team members helped build system capacity by developing terms of reference for IMS staff (e.g., a document identifying mission, role-specific objectives, and responsibilities), an EOC operations guidebook, and standard operating procedures to streamline the submission of requests and proposals from field staff to the EOC. Throughout the response, deployed EMDT staff engaged the MoHS in building staff capacity by training ministry staff to enhance their knowledge of public health emergency management functions and EOC management and operations. These training sessions included three half-day workshops, six training sessions for district health medical teams, and one training session for MoHS national-level staff, reaching a total of 120 persons.

Originally, all response-related activities operated out of the WHO country office. In September 2014, as the response expanded with additional partners, deployed EMDT staff guided and coordinated establishment of an interim EOC at a Sierra Leone Armed Forces facility. In October 2014, the government of Sierra Leone established NERC, and a former Sierra Leone Minister of Defence assumed command of Ebola response activities. The Sierra Leone Office of National Security, Ministry of Defence, and the United Kingdom Department for International Development provided substantial assistance in support of the response. Deployed EMDT staff supported transition of the interim EOC to the United Nations Special Court compound in Freetown, which temporarily housed NERC, enabling closer coordination with international partners. NERC subsequently established 10 subnational level District Ebola Response Centres to support surge response to localized outbreaks. The national MoHS and subnational district health medical teams supported the response by providing technical scientific expertise to NERC and District Ebola Response Centres.

Throughout the response, deployed EMDT staff served as liaisons among CDC IMS leadership, NERC, and other MoHS officials while helping the MoHS develop its emergency management capacity. In addition to national-level response coordination, EMDT assisted NERC in completing assessments of IMS capabilities developed at a subnational level in the District Ebola Response Centres and helped the MoHS and other partners assess the long-term IMS and response capabilities of the district health medical teams.

Although response operations continued under NERC, EMDT personnel acted as technical advisors to such partners as WHO and the CDC Foundation. The CDC Foundation funded a public health national EOC (PH NEOC) and on March 18, 2015, a deeding and gifting ceremony transferred ownership of the facility to the MoHS. In coordination with WHO, deployed EMDT staff helped the MoHS develop a strategy and a staffing model for the PH NEOC. In May 2015, CDC began assisting the NERC Transition Move Project, supported by the United Kingdom Joint Interagency Task Force, to develop plans to co-locate the Disease Prevention and Control Division of the MoHS and core Office of National Security functions with NERC in the PH NEOC. This colocation enabled the building of additional emergency management capacity for the MoHS by leveraging response skills from NERC for future operations; in June 2015, the MoHS and NERC officially began Ebola response operations from the PH NEOC. Full transition of emergency operations capability to the PH NEOC, led by the Office of National Security and the MoHS, occurred on January 1, 2016. Finally, deployed EMDT staff are now supporting the MoHS in developing a 1-year strategic plan to position MoHS to engage in long-term capacity building for public health emergency management.

Overall, the dashboard revealed marked gains across the three targeted domains of emergency management capacity building. The median score for the systems domain rose from 0 in August 2014 to 4 in December 2014 with a steep increase from September to October (Table 3). Scores for the staff and infrastructure domains also rose quickly. The median staff score began at 2 in August 2014 and increased to 4 in November 2014, and the infrastructure score rose from 1 to 3 during the same period. In addition, unlike the scores for Liberia and Guinea, scores for Sierra Leone either increased or remained steady; none ever declined.

Guinea

The first emergency management deployments to support Guinea's Ebola response began in country September 22, 2014. To help fulfill Guinea's need for French-speaking emergency managers, CDC partnered with PHAC, which led in-country technical assistance. When possible, PHAC staff were supported by additional deployed staff from CDC and the U.S. Department of Health and Human Services (HHS). As of March 31, 2016, the 29 persons deployed (9 from CDC, 2 from HHS, and 18 from PHAC) provided 1,374 person-days of in-country technical support in Guinea. These staff provided guidance and technical assistance to Cellule.

Through funding by the CDC Foundation, a call center was established and a government-owned building was renovated to function as the national EOC facility. Deployed staff assisted the call center through the development of standard operating procedures, scripts, and training sessions for call center staff and assisted Cellule by developing basic emergency management administration and other office systems for a streamlined and coordinated response. The systems created for the EOC of Cellule include a task tracker system used in national coordination meetings for increased accountability, standard operating procedures for CDC staff to submit mission orders to Cellule before traveling outside Conakry, a standard template for Cellule incident management meetings, and a functional e-mail box for Cellule staff and priority prefecture EOCs.

Deployed staff and partners supported capacity development for Guinea response staff by conducting ad hoc training of Cellule employees on foundational workplace skills, such as using e-mail, Microsoft PowerPoint, and Excel, and by embedding deployed staff and partners into critical response technical areas such as logistics. This support also created an environment in which the daily coordination of meetings and management of functional e-mail boxes is performed by Guinean staff.

Since March 2015, through a collaboration between PHAC, CDC, the International Organization for Migration, and George Washington University, all of the five communal and 18 prefectural EOC structures put in place by the International Organization for Migration have been assessed, an emergency management curriculum and a train-the-trainer program developed, and principles of emergency management formally introduced to key leadership within Cellule. The national coordinator approved the proposed rollout of the emergency management program, which started in January 2016.

The dashboard tool highlighted gains in emergency management capacity in Guinea. The median score for the staff domain quickly increased from 1 in September 2014 to its maximum of 4 just 2 months later (Table 3). Likewise, the score for infrastructure increased from 1 in September 2014 to 4 in March 2015, but with two plateaus in the interim (from September 2014 to October 2014, when the median score was 1, and again from November 2014 to February 2015, when the median score was 3). Unlike the infrastructure score, which either rose or remained constant, the staff score declined from 4 in February 2015 to 3 in March 2015. The systems score began at 2 in September 2014 and increased to 3 in November 2014, where it remains.

Conclusion

CDC staff and partners deployed through EMDT provided emergency management technical assistance and guidance to

the national Ebola responses in Guinea, Liberia, and Sierra Leone. This assistance included developing IMS goals and objectives, identifying gaps in response capabilities, and recommending strategies for coordinating response activities. EMDT staff, deployed personnel, and partners assisted all three countries in prioritizing foundational emergency management activities during the Ebola epidemic. As countries carried out activities, such as locating and equipping adequate work spaces, training response staff on IMS principles, and establishing basic plans and processes for public health emergency management, EMDT staff, deployed personnel, and partners provided support and technical expertise wherever needed.

The information provided in this report highlights the rapidity with which rudimentary emergency management capacities can be established with the application of focused technical assistance yet also reveals the challenge of progressing beyond basic staff, systems, and infrastructure. Integrating these capacities into a sustained and functional operation is difficult in any context, but all the more so in a resource-limited setting containing a vulnerable public health and health care system and experiencing a widespread infectious disease outbreak. Likewise, balancing long-term capacity building with the need to execute actions quickly also proved challenging.

EMDT used the dashboard tool as one of multiple methods to capture progress in emergency management capacity-building efforts. The response context presented many challenges for effective assessment, and key limitations and areas for improvement emerged while using the dashboard and reviewing collected data. The response priorities and IMS functional groups varied from country to country and were at times not consistent with the domains listed in the dashboard. This variation was especially marked in Guinea, where formal IMS principles were not introduced until later in the response, and the day-to-day work was not always captured by the dashboard items. In addition, the constant turnover of deployed staff and the lack of standardized definitions within and across domains led to inconsistent interpretation of the indicators. Finally, although the tool was intended to help prioritize key IMS principles, the collected information was not always analyzed quickly enough to inform technical assistance. Now that this tool has been used for the first time in real-world conditions, it can be revised and improved.

A lesson learned is to not assume that the benefits of emergency management and IMS are easily observed at the outset of a crisis or emergency. During the early stages of this response, neither the principles of emergency management nor the benefits of implementing the system in country were well understood in the West African countries affected by Ebola. However, once the benefits of IMS were noticeable, country leadership requested additional assistance in emergency management; the requests for additional assistance also indicated that real-world use of IMS is the most effective way to demonstrate its value. As CDC continues to support the Global Health Security Agenda (*5*) in countries around the world, highlighting precisely how IMS enables a country to respond efficiently and effectively to a public health event or emergency is becoming increasingly important. In Liberia, Sierra Leone, and Guinea, the IMS structures for this response could become the foundational framework for a long-term public health emergency management program that has the staff, infrastructure, and systems in place to successfully prepare for and respond to public health events and emergencies.

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Ebola Surveillance — Guinea, Liberia, and Sierra Leone

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Summary

Developing a surveillance system during a public health emergency is always challenging but is especially so in countries with limited public health infrastructure. Surveillance for Ebola virus disease (Ebola) in the West African countries heavily affected by Ebola (Guinea, Liberia, and Sierra Leone) faced numerous impediments, including insufficient numbers of trained staff, community reticence to report cases and contacts, limited information technology resources, limited telephone and Internet service, and overwhelming numbers of infected persons. Through the work of CDC and numerous partners, including the countries' ministries of health, the World Health Organization, and other government and nongovernment organizations, functional Ebola surveillance was established and maintained in these countries. CDC staff were heavily involved in implementing case-based surveillance systems, sustaining case surveillance and contact tracing, and interpreting surveillance data. In addition to helping the ministries of health and other partners understand and manage the epidemic, CDC's activities strengthened epidemiologic and data management capacity to improve routine surveillance in the countries affected, even after the Ebola epidemic ended, and enhanced local capacity to respond quickly to future public health emergencies. However, the many obstacles overcome during development of these Ebola surveillance systems highlight the need to have strong public health, surveillance, and information technology infrastructure in place before a public health emergency occurs. Intense, long-term focus on strengthening public health surveillance systems in developing countries, as described in the Global Health Security Agenda, is needed.

The activities summarized in this report would not have been possible without collaboration with many U.S and international partners (http://www.cdc.gov/vhf/ebola/outbreaks/2014-west-africa/partners.html).

Introduction

Accurate, timely surveillance data are critical during public health emergencies because these data can provide the information needed for appropriate resource allocation, assessment of the success of response, and planning for staffing and resource needs. This was especially true during the 2014–2016 Ebola virus disease (Ebola) epidemic in West Africa. During the epidemic, CDC, along with many other organizations, overcame challenges to conducting effective surveillance in the three countries that were heavily affected (Guinea, Liberia, and Sierra Leone) and had limited public health infrastructure.

Establishing, Maintaining, and Improving Ebola Surveillance

Ebola surveillance in Guinea, Liberia, and Sierra Leone had two primary components: 1) case investigation and reporting

and 2) contact tracing. Although other components of Ebola surveillance, such as community event-based surveillance, were important in these countries, case reporting and contact tracing made up the core of Ebola surveillance and are the focus of this report. Effective case reporting requires timely collection, reporting, and integration of epidemiologic, clinical, laboratory, and outcome data on all suspected, probable, and confirmed Ebola cases. These data help response staff understand the current impact and distribution of Ebola in the country and provide insight into whether the response is succeeding and where future response efforts should be targeted. Meanwhile, contact tracing promotes rapid identification of new cases and referral of those case-patients to isolation units, thereby improving clinical outcomes and reducing opportunities for transmission. Contact tracing requires individual tracking of each contact for 21 days after exposure and constant, effective community engagement (*1*).

By the end of the epidemic, the overall components of Ebola surveillance were similar in all three countries. Cases initially were identified through contact tracing; case-finding; or additional surveillance mechanisms, such as calls to the national alert system (*2*) and walk-ins to Ebola treatment units (ETUs), holding centers, and hospitals (Figure 1). Once a possible case was identified, surveillance staff gathered additional information about the possible case-patient and his or her contacts (Figure 1). Case data were then compiled at the prefecture, county, or district level in a local database or line list and transmitted to ministry of health staff working at the national level. Meanwhile, local staff initiated contact tracing to observe each contact's health for 21 days after exposure. Contact lists were sometimes shared with the national level, but detailed contact tracing information usually was retained and used only locally. However, despite these broad similarities, surveillance system structure and information flow varied widely among areas.

Challenges to obtaining case-level information in Guinea, Liberia, and Sierra Leone included reluctance of some communities to report cases; few and often inadequately trained outbreak response staff to collect, enter, synthesize, and analyze surveillance data; and difficulties in coordinating the many groups involved with surveillance and the response. Compounding these difficulties, particularly in Liberia and Sierra Leone, was the exponential increase in the number of cases reported during summer and fall 2014, which made timely collection and compilation of case information by surveillance staff increasingly difficult.

Despite these issues, Ebola surveillance was continuously maintained in each of the three countries heavily affected by Ebola. Data gathered through these surveillance systems are not complete or perfectly accurate, but they enabled analyses of case characteristics, risk factors for infection, and changes in case distribution over time (*3*–*5*). The data also were used to inform the indicators by which specific components of the Ebola response in the three countries were assessed. CDC's process indicators (Box) enabled identification of gaps in surveillance data and communicated progress toward ending the epidemic to U.S. government leaders.

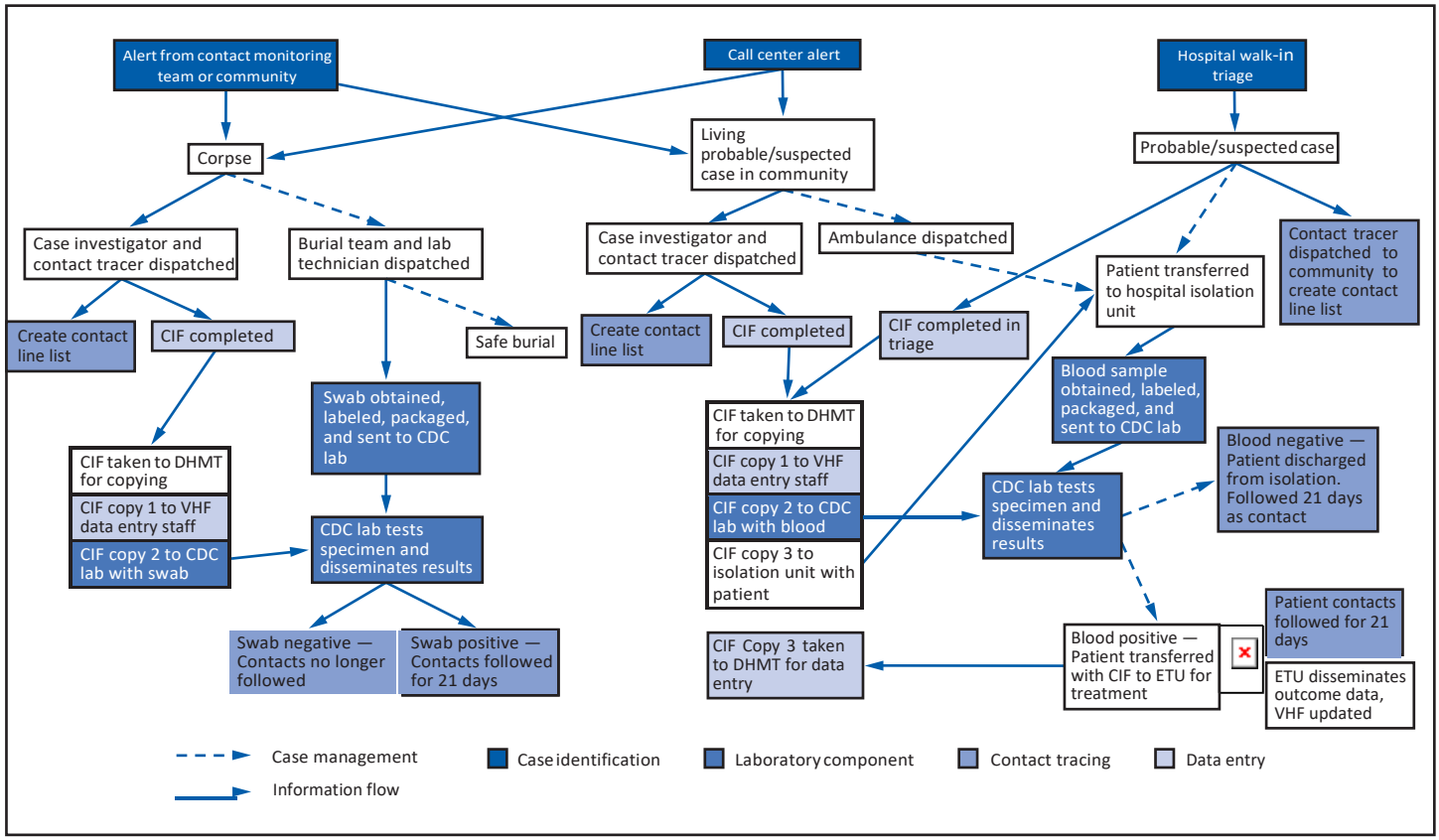
Guinea

The first CDC team deployed to Guinea soon after the outbreak was identified in March 2014. This team, along with the Guinean Ministry of Health and Public Hygiene (MoH) and the World Health Organization (WHO), immediately began work on an Ebola surveillance system. The CDC team set up a national database using CDC's Epi Info Viral Hemorrhagic Fever (VHF) application (http://epiinfovhf.codeplex.com/releases/), development of which began in early 2013. CDC provided on-site programming assistance to continue development and modify the application to suit local needs and trained partner organization staff to use this database. Within 2 weeks after outbreak identification, the database was being used daily to compile up-to-date case information from the initially affected prefectures (Gueckedou, Macenta, and Kissidougou and the capital city of Conakry) and to produce national situation reports. These data were also shared with WHO, which produced international situation reports that were then shared with CDC and other partners. WHO and the MoH continued to use this database throughout the emergency response.

Along with the MoH, Médecins Sans Frontières, and numerous other partners, CDC facilitated development and implementation of case identification and contact tracing procedures in Conakry and Gueckedou. The CDC team played a particularly critical role in starting contact tracing in Conakry by training contact tracers, organizing the contact tracing system, and implementing an initial system for contact data management using the Epi Info VHF application (transitioned to Microsoft Excel in August 2014). In rural areas, CDC staff supported contact tracing through data management, training, and quality control through direct supervision of local contact tracers. The CDC team also introduced a standardized case investigation form and trained partners to use the form. Finally, CDC staff helped coordinate transfer of Ebola case information from ETUs to data entry staff and helped verify and clean data entered into the national database.

Beginning in September 2014, the growing number of CDC response staff in Guinea enabled CDC to expand its support to the MoH and WHO through more intense field-based case finding, contact listing and tracing, and case and contact investigations. CDC staff focused on improving rigor

FIGURE 1. Ebola surveillance network — Bo District, Sierra Leone, late November 2014



Abbreviations: CIF = case investigation form; DHMT = District Health Management team; Ebola = Ebola virus disease; ETU = Ebola treatment unit; VHF = Epi Info Viral Hemorrhagic Fever application.

BOX. Process indicators of CDC's response to the 2014–2016 Ebola virus disease epidemic — West Africa, 2015*

- National emergency management program established, functional, and intraconnected (yes/no)
- Percentage of affected subnational units with access to adequate bed capacity
- Percentage of new laboratory tests that are positive for Ebola
- Percentage of suspected community deaths of persons testing positive for Ebola
- Percentage of calls to burial teams responded to within 24 hours after request
- Percentage of cases that occur among known and monitored contacts
- Percentage of new infections among health care workers
- Percentage of respondents who report willingness to visit a health care facility if symptoms appear

*Indicators were updated periodically during the epidemic to reflect current information needs.

and oversight of these activities with the goal of improving documentation of each chain of transmission, which in turn improved investigation of cross-prefecture and cross-border movement of contacts.

Still, full implementation of strong case identification and contact tracing procedures sometimes lagged substantially behind the appearance of cases in affected prefectures (e.g., *6*), in part because of limited numbers of trained staff and reliance on insufficiently supervised community agents (community members who each day check on contacts within their own or neighboring villages). To overcome this difficulty, CDC worked with the MoH and other partners to strengthen case investigations and contact tracing and to supplement passive case reporting with active case finding, including house-to-house visits in affected areas (*6*,*7*). However, some persons and communities resisted surveillance efforts by not disclosing the status of contacts or cases or refusing to allow outbreak response staff into villages, which resulted in missed cases and increased transmission (*8*) (CDC, unpublished data, 2014–2015). Nevertheless, as of May 13, 2016, Guinea had not reported any Ebola cases since the last Ebola patient twice tested negative on April 19, 2016.

Liberia

Liberia's Ministry of Health and Social Welfare (renamed Ministry of Health [MoH] in October 2014) began surveillance when the first Ebola cases appeared in Liberia in March 2014 (*9*); however, when no new cases were reported during late April–early June, surveillance was discontinued. When Ebola resurged in mid-June 2014, the MoH reestablished surveillance and began obtaining aggregate case counts from each county daily by telephone or e-mail. The CDC team that arrived in July 2014 immediately began collaborating with the MoH, WHO, and other partners on a case-based surveillance system, in which detailed information about each case is reported individually, to obtain more comprehensive and accurate information about the epidemic.

Initially, case-based surveillance data from throughout the country were transmitted by Excel line lists and paper forms to the MoH in Monrovia, where they were entered into an Epi Info VHF database. Lofa County started a second database in mid-August 2014 to compile data for that county; this database was then transmitted to the MoH (daily when possible) to maintain a complete national database. During this period, however, Ebola incidence in Liberia increased much faster than data management capacity. The rapid increase in cases led to a quickly growing backlog of information to enter into the case-based surveillance database. To address this backlog, CDC staff performed data entry, trained new data entry and management staff, and fixed numerous software and hardware issues that hindered data entry.

CDC staff also initiated key improvements to the case-based surveillance system. In late August 2014, CDC and MoH staff implemented preprinted unique identification (ID) stickers that could be used on, for example, case report forms and laboratory samples to facilitate linking of multiple pieces of information pertaining to the same case-patient. In early September, CDC staff collaborated with the MoH to introduce a shorter case report form to make form completion and data entry easier. CDC staff also helped organize the surveillance and laboratory data flow, which faced logistical obstacles because of the outbreak's broad geographic scale and the large number of partners involved in surveillance (Figure 2). Finally, CDC helped the MoH design and run surveillance training sessions for county public health staff to improve case finding, contact tracing, and case reporting throughout the country.

As the case-based surveillance system developed, comparisons with the aggregate case data received from telephone calls and e-mails demonstrated that the latter were inaccurate. Therefore, in October 2014 Liberia's national situation reports transitioned reporting from aggregate case data to case-based data from laboratory and ETU line lists. This change resulted in an increase of 1,870 reported* cases during October 25–29, 2014 (Figure 3).

* Suspected, probable, or confirmed cases reported to the MoH.

Meanwhile, each county began to manage and enter data into its own case database rather than sending case identification forms to the MoH for entry. The initial plan was for each county to send an updated Epi Info VHF database to the MoH daily to maintain the national database. However, limited Internet connectivity, lags in data entry, and problems combining databases made this system unsustainable. Liberia switched to the District Health Information Software system (https://www.dhis2.org) (Health Information Systems Programme) for data transmission and management beginning in December 2014; even after this change, however, substantial lags in data entry meant that these detailed data were inaccurate for current case counts and difficult to directly apply to outbreak control.

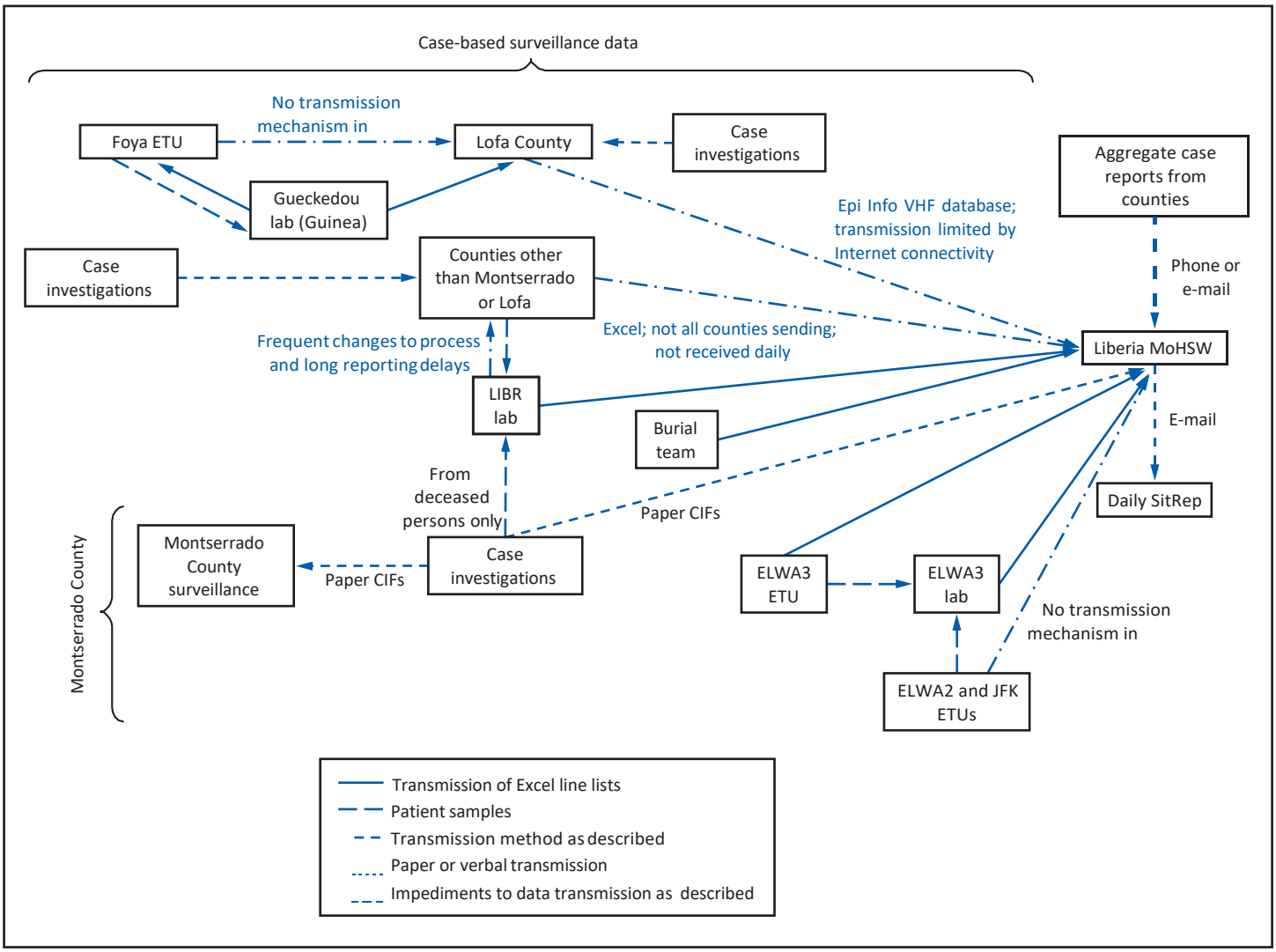
As the incidence rate of Ebola in Liberia declined in October–December 2014, renewed emphasis was placed on controlling outbreaks in remote communities through active case finding, contact tracing, and community education (*10*,*11*). The MoH, CDC, and numerous partners conducted rapid response investigations in outlying areas of Liberia during October–November 2014 to establish patient care strategies and enhance contact tracing, active surveillance, and other response activities (*12*). In Montserrado County, CDC worked with county staff and partner agencies, especially Action Contre la Faim, to implement decentralized, sector-based contact tracing in January 2015; this approach resulted in more complete contact tracing and helped eliminate transmission in this area (*13*). Cases in Liberia subsequently dropped to zero from late May until early July 2015 and have remained at zero except for small clusters of illness in July and November 2015 and March–April 2016.

After initially reaching zero cases, Liberia maintained surveillance through Ebola testing of dead bodies and health facility patients with symptoms consistent with suspected Ebola; community event–based surveillance to trigger alerts for events (e.g., suspicious deaths) associated with Ebola transmission in communities bordering neighboring countries; and establishment of isolation, infection control, and triage protocols at health facilities nationwide. Along with strengthening integrated disease surveillance and response for hemorrhagic fevers and priority diseases with symptoms that overlap with those of Ebola, these measures promoted rapid detection and control of new Ebola clusters.

Sierra Leone

When the CDC team arrived in Sierra Leone in early August 2014, the country already had reported approximately 550 Ebola cases. The team found that, because of Sierra Leone's decentralized health system, districts were taking different approaches to control the epidemic, including using differing

FIGURE 2. National surveillance data flow for reporting Ebola — Liberia, late August 2014



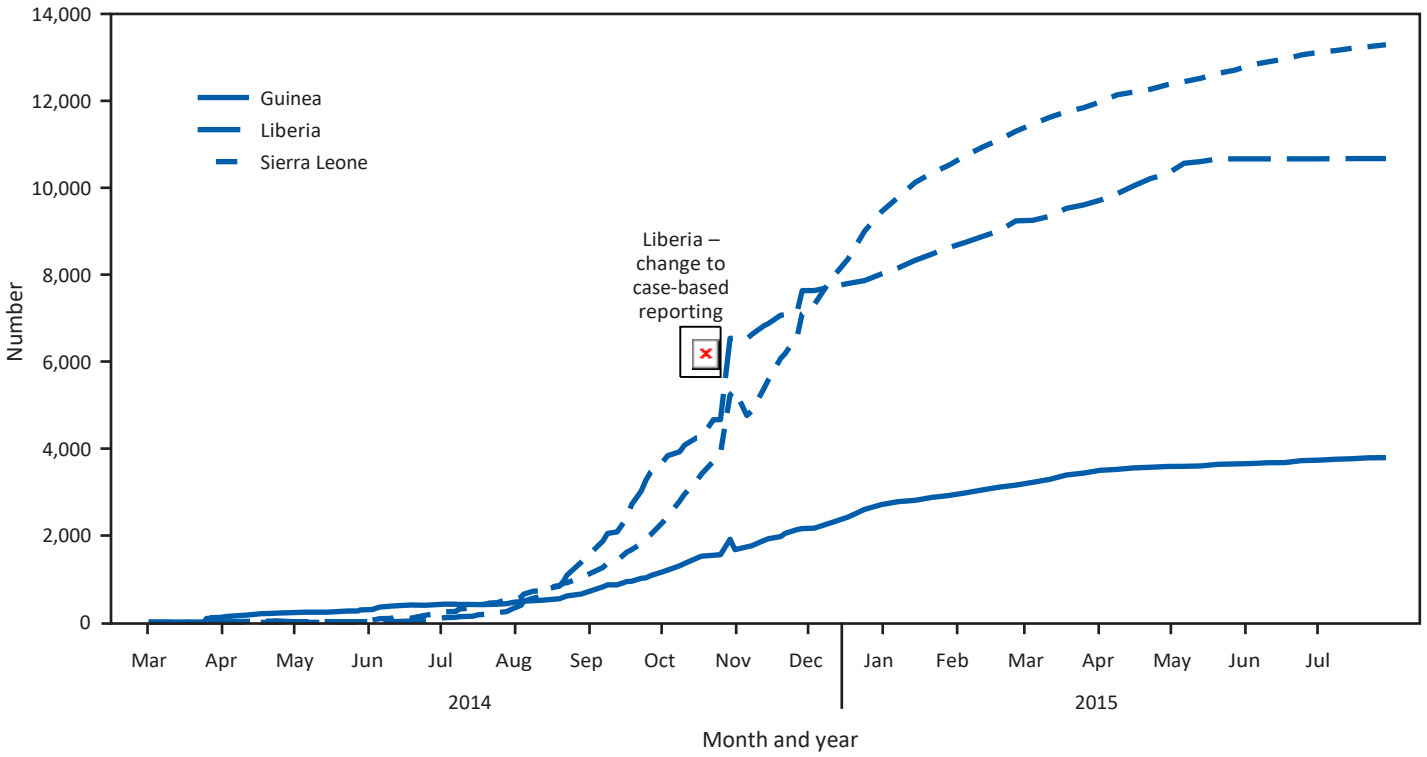
Abbreviations: CIF = case investigation form; Ebola = Ebola virus disease; ELWA = Eternal Love Winning Africa; ETU = Ebola treatment unit; Excel = Microsoft Excel; JFK = John F. Kennedy; LIBR = Liberia Institute for Biomedical Research; MoHSW = Ministry of Health and Social Welfare; SitRep = situation report; VHF = Viral Hemorrhagic Fever application.

case definitions. CDC, WHO, the Sierra Leone Ministry of Health and Sanitation (MoHS), and other partners quickly began creation of a consistent national surveillance system. The CDC team helped develop and train local staff on standardized procedures for case notification, investigation, and reporting, as well as on standardized definitions of Ebola infection, transmission, and control, leading to standardization of case investigation protocols throughout the country.

Although Sierra Leone's surveillance system is similar in many ways to those in Guinea and Liberia, it has several unique features. For example, beginning in October 2014, Sierra Leone's policy was that all deaths, not just those of persons whose illness met the Ebola case definition, would be tested for Ebola, a unique approach that enabled Ebola laboratory result records to double as a short-term death registry. Sierra Leone also used multidisciplinary field teams to conduct periodic "surges" of house-to-house active case finding beginning with Western Area (Freetown and surrounding region) in December 2014.

The initial CDC teams also implemented Epi Info VHF databases that could be controlled and maintained at the district level but combined and analyzed nationally. The national Epi Info VHF database was maintained through the end of the epidemic and is often used for national-level and international-level data analyses because it provides the most comprehensive epidemiologic and laboratory data on Ebola cases available in Sierra Leone. However, a major challenge to Sierra Leone's surveillance early in the epidemic was difficulty getting information from ETUs to district surveillance officers.

FIGURE 3. Total number of reported* suspected, probable, and confirmed cases of Ebola as reported through World Health Organization situation reports — Guinea, Liberia, and Sierra Leone, March 2014–July 29, 2015†



Abbreviation: Ebola = Ebola virus disease.
* Suspected, probable, or confirmed cases reported to ministries of health.
† Figure highlights increase in reported cases from Liberia due to transition from aggregate to case-based reporting in October 2014. Reported case counts temporarily increased in Guinea and Sierra Leone during the same period. Shortly thereafter, reported case counts for Guinea decreased again as several hundred cases initially reported as suspected were reclassified. Meanwhile, reported case counts from Sierra Leone also decreased because the World Health Organization shifted data sources from a combination of patient databases and country situation reports to national reports only.

As a result, patients' families often lacked information about the status or location of their loved ones, and patient outcome data collected in the surveillance system were highly incomplete. An analysis conducted in September 2014 demonstrated that although Sierra Leone's Ebola case-fatality rate appeared to be 31.6% when all reported confirmed and probable cases were included, the rate actually was 69.0% when only those with definitive outcome data available were included (*5*).

Throughout the epidemic,† CDC helped strengthen Ebola surveillance and contact tracing in Sierra Leone. CDC staff provided daily contact tracing support to the district surveillance officers and helped develop consistent messaging to counteract the fear and mistrust that lead to community resistance to case investigation and contact tracing. In October 2014, CDC worked with the International Rescue Committee and the Bo District Health Management Team to develop and implement community event–based surveillance to supplement case finding and contact tracing, an initiative piloted in Bo and then adopted as part of the national surveillance strategy (*14*). CDC helped train local contact tracing staff beginning with Bo district in November 2014 and January 2015; CDC also helped support the "Western Area surge" strategy (*15*) implemented in December 2014, in which many additional district surveillance officers, contact tracers, and community mobilizers were recruited and trained across Western Area. The surge greatly improved contact tracing capacity in this region.

In January 2015, CDC staff helped distribute and train local and partner staff to use an updated case identification form with water-resistant unique ID stickers that enabled use of a universal ID by the laboratory, ETU, and district surveillance officers. CDC staff also were pivotal in identifying laboratory performance and coordination issues and, for some districts, distributing laboratory results to surveillance staff to help with contact tracing and patient management.

† As of May 13, 2016, Sierra Leone had not identified any Ebola cases since the last Ebola patient was discharged on February 5, 2016.

Key Challenges to Ebola Surveillance

Case Definitions

Lack of a consistent Ebola case definition was an early impediment in the response. In Guinea and Liberia, involvement of CDC teams and their partners early in the response led to rapid adoption of a case definition similar to the one used by WHO and CDC (*16*). In contrast, in Sierra Leone, many districts initially adopted a narrower case definition requiring fever, vomiting, diarrhea, and one additional symptom. Use of this narrower case definition probably resulted in many missed cases early in the epidemic. After the CDC team arrived in Sierra Leone, CDC and Sierra Leone MoHS staff aligned the case definition with those in the neighboring countries, resulting in adoption of a broader case definition in mid-August 2014. However, even after central adoption of the new case definition, ensuring nationwide application of this definition was difficult. Only after several months did all the rural districts adopt the new version. Earlier nationwide standardization would have improved and unified the response in Sierra Leone.

Case Data Collection

Throughout the epidemic, missing case data and underreporting of cases were serious obstacles to obtaining accurate surveillance data. Many factors contributed to the often substantial amount of missing data on each reported case, including insufficient training of case investigation staff, logistical difficulties in getting case investigation forms to all parties who identified cases, and inadequate time to find and complete the initial case investigation form, which proved too long given the often overwhelming number of cases identified. CDC staff helped resolve these issues by training case investigation staff at the national and local levels and developing a shorter case investigation form. Meanwhile, underreporting of cases also was substantial; published estimates suggest that the true number of cases in some areas might have been 17%–250% higher than the number reported (*17*,*18*). Underreporting and missing data substantially impaired the ability of surveillance staff to understand the true magnitude and distribution of the epidemic and highlighted the need for streamlined, standardized, and flexible case reporting tools that could be easily adapted to accommodate infectious disease outbreaks, especially outbreaks of new or uncommon diseases.

Laboratory Testing

When the number of infected persons dramatically increased in Liberia and Sierra Leone in July 2014, few laboratories in-country were equipped to test samples from Ebola patients, resulting in substantial delays in sample transport, testing, and reporting. Difficulties linking laboratory results with epidemiologic data exacerbated reporting delays. In some instances, sample testing and reporting were delayed a week or longer, which hindered use of test results for patient management. To improve in-country laboratory capacity, CDC and the National Institutes of Health established an additional laboratory in Monrovia, Liberia, in August 2014; CDC also established a laboratory in Kenema, Sierra Leone (later moved to Bo), that tested up to 180 samples each day at the peak of the epidemic. Expanding laboratory capacity improved patient management and the overall function of the surveillance system and resulted in a shift toward reporting primarily confirmed cases (rather than suspected or probable cases) from all three countries by December 2014. The difficulties encountered in providing timely laboratory testing during this epidemic highlight the need to expand public health laboratory capacity in these countries.

Contact Tracing

Contact tracing teams in Guinea, Liberia, and Sierra Leone often were hindered by inadequate staffing to follow the sometimes enormous number of contacts, difficulties reaching remote villages, inadequate pay, and insufficient training. However, one of the greatest difficulties in contact tracing was community mistrust of contact tracers and other outbreak response staff. For example, this mistrust motivated individual contacts to deny their exposures and/or hide or flee from contact tracers and communities to bar outbreak response staff from entering or even erupt into violence (*7*,*8*,*19*) (CDC, unpublished data, 2014–2015). CDC staff in many areas of Guinea, Liberia, and Sierra Leone were physically threatened by local communities and forced to evacuate; other outbreak staff were injured and even killed by angry community members (*7*). Creating a strong network of trusted local health care workers to provide information and assistance during a public health crisis is critical to preventing such resistance during future public health emergencies.

Information Technology

Information technology (IT) is essential during a public health emergency for data to be rapidly collected, synthesized, and used to provide information for the response. Guinea, Liberia, and Sierra Leone had limited IT and communications infrastructure. Internet and cell phone service are inadequate in many areas, especially in rural areas; power outages occur frequently; and availability of servers, routers, and other IT equipment is limited. In addition, in-country IT expertise

is limited: only a tiny proportion of the population has the basic computer skills needed for data entry tasks, let alone the training to set up or troubleshoot IT systems.

To support Ebola surveillance, CDC has, by necessity, supported IT needs in the three countries through both on-site and remote assistance. This support included assistance setting up servers and other equipment, technical support and development of the Epi Info VHF application, and IT and computer training for local staff. In Sierra Leone, for instance, beginning in November 2014, CDC and WHO trained MoHS staff on data management, Microsoft Excel, the Epi Info VHF application, and computer security. Development of improved IT and communications infrastructure (especially increasing Internet access nationwide) and extensive IT training for local staff is needed to resolve the limitations in IT capacity in these and other countries before the next public health emergency.

Case Data Management

In Guinea, Liberia, and Sierra Leone, CDC staff were key to establishing and maintaining data management systems for case-based surveillance. Staff working on these systems faced numerous obstacles, including limited communications infrastructure, software and hardware issues, limited computer expertise among local staff, insufficient funding to pay local data entry and management staff, and often systemic problems with the surveillance system (Figure 2) that resulted in low-quality incoming data. In addition, the huge volume of cases during summer and fall 2014 made obtaining, entering, cleaning, and verifying data on all cases particularly difficult and led to a high frequency of missing or erroneous data. These problems made using case-based surveillance strategies for timely case reporting difficult and highlight the need for robust surveillance and data management systems and extensive training and support to in-country users on the use of these systems before a public health emergency occurs.

Contact Data Management

Managing contact tracing data is complex and time-consuming at the best of times because of the difficulty of maintaining an accurate contact list and the need to record each contact's follow-up information daily. Because of the complexity of contact data management and limited numbers of local data management staff, CDC frequently assisted with contact data management in the countries heavily affected by Ebola, especially in rural areas.

Software for contact data management was limited. Excel was often used for this purpose in the three countries, but it lacks automated functions suitable for managing contact data. The frequent manipulations needed to update contact lists often resulted in substantial errors in the data. Paper-based systems have similar flaws and make analyzing contact data or sharing data among partners more difficult. Other software systems were implemented only occasionally. For instance, the mobile Sense Follow-up application (https://play.google.com/store/apps/details?id=com.ehealthafrica.lrsenseebola) was used in Montserrado and Margibi counties in Liberia to manage contact tracing around a small cluster of cases in mid-2015. CDC developed the Epi Info VHF application specifically to facilitate and link case and contact tracing data management for outbreaks of Ebola and other viral hemorrhagic fevers; however, limited flexibility in the application, difficulties changing contact tracing systems, limited familiarity with the contact tracing features of the application, and ongoing application development during the epidemic led to use of this tool as the primary contact data management tool in only a few areas, notably Kambia District, Sierra Leone. To prepare for future viral hemorrhagic fever outbreaks, it would be beneficial for CDC, WHO, and their partners to agree on and pilot a single contact data management software tool that can be quickly and easily implemented when needed.

Conclusion

Developing Ebola surveillance in Guinea, Liberia, and Sierra Leone was difficult because of the need to implement timely, accurate surveillance under emergency conditions over a wide area. The Ebola responders conducted impressive and meaningful work supporting Ebola surveillance in these three countries; however, the many challenges faced during surveillance implementation highlight the need to be prepared for public health emergencies before they occur. CDC and its partners can facilitate the public health response by developing and agreeing on standardized response systems with clear protocols and objectives before outbreaks occur and rapidly implementing these systems during an outbreak. In addition, CDC and other public health partners need to continue to support development of strong, sustainable public health surveillance, data management, and IT infrastructure and training in developing countries, as described in the Global Health Security Agenda (*20*), to frame the response to future public health emergencies. With the establishment of CDC offices in Guinea, Liberia, and Sierra Leone, CDC is well-positioned to continue supporting the expansion of public health and surveillance capacity infrastructure to improve the response to future epidemics.

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Laboratory Response to Ebola — West Africa and United States

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Summary

The 2014–2016 Ebola virus disease (Ebola) epidemic in West Africa highlighted the need to maintain organized laboratory systems or networks that can be effectively reorganized to implement new diagnostic strategies and laboratory services in response to large-scale events. Although previous Ebola outbreaks enabled establishment of critical laboratory practice safeguards and diagnostic procedures, this Ebola outbreak in West Africa highlighted the need for planning and preparedness activities that are better adapted to emerging pathogens or to pathogens that have attracted little commercial interest. The crisis underscored the need for better mechanisms to streamline development and evaluation of new diagnostic assays, transfer of material and specimens between countries and organizations, and improved processes for rapidly deploying health workers with specific laboratory expertise. The challenges and events of the outbreak forced laboratorians to examine not only the comprehensive capacities of existing national laboratory systems to recognize and respond to events, but also their sustainability over time and the mechanisms that need to be pre-established to ensure effective response. Critical to this assessment was the recognition of how response activities (i.e., infrastructure support, logistics, and workforce supplementation) can be used or repurposed to support the strengthening of national laboratory systems during the postevent transition to capacity building and recovery. This report compares CDC's domestic and international laboratory response engagements and lessons learned that can improve future responses in support of the International Health Regulations and Global Health Security Agenda initiatives.

The activities summarized in this report would not have been possible without collaboration with many U.S. and international partners (http://www.cdc.gov/vhf/ebola/outbreaks/2014-west-africa/partners.html).

Introduction

The 2014–2016 Ebola virus disease (Ebola) epidemic in West Africa presented an unprecedented challenge for CDC and its partners, not only because of the complexity of responding to an Ebola outbreak of such proportion, duration, and intensity internationally, but also because of the exceptional situation created for U.S. clinical and public health laboratory systems. CDC's role in health emergencies is complex; multilayered interactions range from state and local health care institutions and care providers to the national-level U.S. agencies and ministries of health internationally.

As with many other viral hemorrhagic fevers, Ebola can be difficult to differentiate clinically from other common infectious diseases and requires laboratory diagnostics to confirm or rule out Ebola virus (EBOV) infection when the level of suspicion is heightened. Rapid and reliable laboratory testing for diagnosis of suspected Ebola cases or of EBOV-infected persons is central to controlling the disease and serves multiple purposes, including differential diagnosis of cases and triage of patients into care, initiation of contact tracing, and safe discharge of EBOV-negative patients to their home communities.

The increase in cases during March–October 2014 led to an influx of international support to the three most affected countries (Guinea, Liberia, and Sierra Leone) as well as to Mali and Nigeria. The World Health Organization initially organized laboratory response activities as part of the Emerging and Dangerous Pathogens Laboratory Network and Global Outbreak Alert and Response Network (*1*).

These early activities were hampered by several factors. These included the lack of approved diagnostic tools adapted to such a large-scale outbreak; a shortage of skilled personnel; limited biosafety knowledge by local staff; inadequate supply chain management to provide for universal use of personal protective equipment; and weak national laboratory systems that could not support the rollout of standardized methods and mechanisms for safe collection, transport, and testing of specimens from persons suspected to have Ebola.

Laboratory Environment

International Response

Historically, the remote locations of Ebola outbreaks have required rapid, highly mobile, and transient responses. This changed with the recent Ebola epidemic in West Africa. From the early serology studies that retrospectively mapped the extent of the 1995 Ebola outbreak in Kikwit (*2*), recognition of the need to establish field laboratory capacities grew. By 2000, CDC's Viral Special Pathogens Branch field laboratory in Gulu, Uganda, was able to provide next-day serology and reverse transcription-polymerase chain reaction (RT-PCR) diagnostics on specimens for acute and convalescent case identification (*3*). This represented a transition for field laboratories from retrospectively mapping the extent of an outbreak to providing near real-time diagnostic service. These field techniques continued to be polished during later responses and ecologic studies that sought an animal reservoir for the virus. By 2005, the concept of a high-throughput field laboratory using semiautomated systems was firmly established (*4*,*5*). These field laboratories had become highly sophisticated but still could be broken down into a series of trunks that could be transported readily by one or two persons and set up in local structures (e.g., health care unit, house, or tent).

The greatest challenge to robust field operations was not the selection and arrangement of diagnostic equipment but rather the ability to ensure biosecurity and safety for staff during operations. These concerns were satisfied by physically separating sample processing of infectious materials from the remainder of the testing procedure and having the staff operate in complete personal protective equipment, including a powered air-purifying respirator or an N95 respirator to guard against unexpected exposures to infectious materials (*6*). This was the standard of operations in the earliest international laboratories responding to the Ebola outbreak in summer 2014, and many laboratories continued to operate in this manner. The CDC laboratory originally established under the Global Outbreak Alert and Response Network in Kenema District and later moved to Bo District, Sierra Leone, is one such example. Located in a small house, this laboratory provided rapid results for approximately 26,000 specimens, with a peak of 180 specimens in a single day. Diagnostic operations were maintained continuously from August 2014 until the facility closed in late October 2015, even during the 70-km transition from Kenema to Bo (*7*). These earlier lessons would help countries affected by Ebola develop recovery and capacity plans for both sustainable fixed laboratory structures and rapid response strategies in their national laboratory systems.

Domestic Response

During the domestic response to Ebola, the U.S. clinical laboratory environment presented a different set of challenges from those in West Africa. In the United States, many years of preparation for such an event, including coordinated preparedness activities, produced robust and adaptable laboratory systems capable of rapidly deploying new assays and technologies. This preparedness enabled ready adaptation of existing clinical and public health laboratory networks to respond to the need to scale up diagnostic testing for Ebola. However, many clinical laboratories had migrated to large-scale high-volume laboratory structures that rely heavily on rapid specimen transport and reporting systems, often across multiple states. Regional facilities and laboratories in larger hospitals have open working spaces, high-throughput automated systems, robotic equipment, and multiple parallel testing of samples. This environment is not readily conducive to the introduction of isolated specimen-specific management and safeguard measures for samples from persons with suspected EBOV infection, and the multiple-barrier protective practices employed in field laboratories are not readily adaptable to these large open-floor–plan environments. These considerations increased concerns about and difficulties in standardizing biocontainment and safety procedures for routine clinical testing in open laboratory environments. Manufacturers could not guarantee the decontamination procedures for their products and announced they would void warranties on products used in Ebola care and treatment. The costs and liability concerns led many large referral laboratories to announce they would not accept routine clinical test specimens from persons suspected to have Ebola. These concerns within the health care facilities and referral laboratories initially led

to delays in routine diagnostic services to patients in whom Ebola was a concern (*8*,*9*).

CDC and public health partners worked closely with the public and private clinical laboratory sectors to establish guidance for managing and testing routine clinical specimens in situations where concern existed about EBOV infection (*10*). In addition, a tiered service model was established for clinical institutions and their laboratories that assess and provide care for patients exhibiting symptoms of possible Ebola or who were known to be infected with EBOV (*11*). State public health agencies identified and designated these geographically distributed facilities. Adjustments to the laboratory environment resulted from the collaborative engagement of multiple individuals and organizations, through peer-reviewed reports, national conference calls, webinars, electronic messaging and listserves, consults through professional associations, and other communications media. This collaboration was one of the greatest strengths of the response, particularly as it pertains to the laboratory.

CDC collaborated with the U.S. Department of Defense (DoD), the Association of Public Health Laboratories, and state and local public health agencies to meet the need for enhanced domestic diagnostic capacity by rapidly expanding EBOV testing within the Laboratory Response Network (LRN) (*12*). This network enabled quick distribution of testing capacity to well-equipped laboratories serving the entire United States, with staff trained to manage dangerous pathogens and operate under uniform practices, and established processes of communications with public health institutions.

The initial deployment of the DoD Ebola Zaire quantitative real-time polymerase chain reaction (EZ1 rRT-PCR) began in early August 2014 with 13 LRN laboratories. CDC selected these laboratories based on the known population of West African citizens in the area and their proximity to major airports. During August 2014–September 2015, a total of 59 laboratories were approved to test for EBOV. This enhanced network consisted of state, large city, and metropolitan county public health laboratories (*10*). The ability to incorporate EBOV testing into existing processes and networks readily, as is the case with the LRN, is further evidence of past lessons learned and the value of strong national laboratory systems. Commercial availability of Food and Drug Administration (FDA)–authorized EBOV diagnostic tests is expanding these diagnostic services in facilities prepared to assess patients with suspected Ebola. Because of the consequences of a positive Ebola diagnosis and to ensure informed public health decision-making, the CDC reference laboratory must continue to confirm any presumptive positive Ebola diagnosis in these facilities.

Diagnostic Testing Strategies and New Assay Developments

Until this outbreak, few assays existed to detect, differentiate, and diagnose Ebola. The design and appropriate selection of diagnostic assays in Ebola evaluations depend on the patient's disease state. When the index of suspicion for Ebola is low but not negligible, ruling it out becomes a biosafety requirement because the presence of EBOV will lead to changes in the type of patient care needed, such as heightened precautions and limited laboratory testing to reduce exposure risks to medical and laboratory personnel.

During the acute viremic phase of illness, RT-PCR–based techniques are the most sensitive diagnostic method. They are frequently used with serology (IgM and IgG) to track virus-negative but antibody-positive survivors or for surveillance activities in geographic regions previously affected (*2*,*3*). The timing of specimen collection in regard to symptom onset is key to evaluating any person suspected to have Ebola. During symptom onset, blood specimens are usually PCR positive; however, in a small number of patients, circulating virus titers might not reach detectable levels in peripheral blood for 72 hours, enabling potential false-negative results. For this reason, if symptoms have been present for <3 days, a second specimen might be required 72 hours after symptom onset to definitively rule out Ebola. Critically ill patients are highly viremic, and virus is readily detectable in oral swabs from deceased persons. In survivors, the humoral immune response begins to manifest toward the end of the second week of disease with transient IgM and rising IgG titers as circulating virus titers decrease (*2*).

The most frequently implemented diagnostic tests are based on quantitative RT-PCR (qRT-PCR) targeting conserved domains within genes for the viral polymerase (L) and structural elements (NP, VP40, and GP) of EBOV (species: *Zaire ebolavirus*). In October 2014, FDA issued emergency use authorizations (EUAs) for several EBOV RNA detection assays, including the DoD EZ1 Realtime RT-PCR, CDC's qRT-PCRs for the viral NP and VP40, and the bioMerieux BioFire Film array assay (BioFire Defense, LLC, Salt Lake City, Utah). In November 2014, Altona Diagnostics' RealStar Ebola Virus RT-PCR (Altona Diagnostics GmbH, Hamburg, Germany) followed, and in March 2015, Cepheid's Xpert Ebola Assay (Cepheid, Sunnyvale, California) was authorized for use on its GeneXpert platform. Details about these authorizations, the products, and their approved uses are available on the FDA website (*13*). Within the United States, these products are designated for use with patients demonstrating signs and symptoms of Ebola and require confirmatory testing. All are authorized for use in Clinical Laboratory Improvement Amendments (CLIA)–designated moderate-to-high–complexity

laboratories with specific instrumentation. CDC's combined NP and VP40 assays typify the normal testing algorithm and incorporate an endogenous human housekeeping gene control for extraction and amplification controls. The presence of viral RNA is confirmed when both targets and the housekeeping gene are amplified and detected. This algorithm remains the confirmatory strategy for U.S. cases and for samples referred to CDC as a World Health Organization Collaborating Center for Viral Hemorrhagic Fevers.

These key molecular diagnostic assays are available for both domestic and international use by U.S. agencies, but they require staff qualified to perform moderate-to-high–complexity tests as well as modified biosafety protocols and complex workflows. The need for low-complexity, screening point-of-care assays to improve differential diagnosis and triage of suspected cases became evident early during the 2014–2016 Ebola epidemic. CDC worked closely with various partners and organizations to promote development of innovative assays able to support this requirement. A full array of diagnostic tests is under development in the public and private sectors.

In March 2015, FDA issued the first EUA for a lateral-flow antigen-capture assay to Corgenix, Inc. (Broomfield, Colorado) for the ReEBOV Antigen Capture Rapid Test. In July 2015, the OraQuick Ebola Rapid Antigen Test from OraSure Technologies, Inc. (Bethlehem, Pennsylvania) also was issued an EUA. These simple robust tests are based on the capture of circulating viral antigens by polyclonal or monoclonal antibodies bound to a filter strip and are driven by the wicking of the specimen (generally body fluids such as whole blood, plasma, or oral fluids) and reagents across the strip. The tests require no complex equipment; can be read in 30 minutes; and are individually packaged, stable, and disposable. Thus, these tests can be distributed widely as point-of-care assays in alternative testing sites (e.g., primary care and triage centers) that lack laboratory capacity. This technology also lends itself to multipathogen detection because several pathogens possibly can be captured on a single strip, which might provide differential diagnosis for confounding agents (e.g., malaria parasites, Marburg virus, and Lassa fever virus). Implementation of point-of-care testing brings challenges in training clinical staff in its use as well as in waste management, quality assurance, and development of alternative testing algorithms. The tests are approved for use on patients with symptoms consistent with Ebola and require further confirmation.

As further antiviral therapeutics or vaccines are deployed, particular attention must be given to selecting diagnostic assays and testing algorithms that can distinguish persons receiving these therapeutics from persons with natural virus infection. In West Africa, this difficulty is already recognized; however, with careful planning, appropriate reagents can be selected to avoid confusion and provide robust and reliable laboratory diagnostic services.

Overcoming Challenges

The 2014–2016 Ebola epidemic provided an opportunity to test years of preparedness that required extensive support from public and private health sectors, associations, and multiple federal entities, ranging from the point of service up to the national level. The epidemic highlighted numerous difficulties common during the initial phases of laboratory responses to high-consequence pathogens, such as viral hemorrhagic fevers. Among these were timely and appropriate transport of specimens, limited availability of experienced staff, integration of testing for public health and case management needs, assurance of continuity of laboratory services for routine patient care, inadequate standard operating procedures in institutions, and need for sustainable diagnostic testing and differential testing strategies. The need to detect and respond to a pathogen for which no commercially available assays were readily available further complicated these efforts.

Domestically, CDC was able to rely heavily on the administrative structures and processes in place with the LRN and state and local public health agencies while operational practices and safeguards were addressed in the health care setting. In the United States, rapid implementation of heightened biosafety practices and distribution of specialized testing capabilities and guidance were required to support the laboratory systems of both clinical and public health laboratories. Fortunately, the existing framework of a robust and adaptable laboratory system enabled effective deployment of assays and response. Challenges were mostly caused by biosafety concerns from the use of high-throughput instrumentation rather than by an inability of the laboratory system to absorb and adapt to change.

Internationally, the need for capacity building and lack of overall laboratory system capacity were pronounced and were addressed in parallel as the response was implemented. Most often the question was not what had to be done but rather how it should be accomplished on a scale appropriate to the needs of the response. There were additional challenges in coordinating a multinational laboratory response; supplementing the limited infrastructure resources to support laboratories; and communicating among all partners, including established ministry of health structures and nascent emergency operations centers in each country.

The need to expand timely testing to support informed patient management and public health decision-making was an ongoing concern. That resource-poor communities lacked

supplies for safe collection and proper transport of specimens was recognized early by responders. This deficiency slowed specimen processing times because care was needed to avoid broken glass, needles, and other dangerous conditions. CDC and its partners supplied each country with hundreds of International Air Transport Association–compliant plastic specimen-transport containers and developed a pictogram illustrating proper packaging (*14*,*15*). However, one underlying difficulty in fully addressing these needs was the lack of overall appreciation for the workflow processes common to all diagnostic testing: the preanalytical (e.g., sample collection, documentation, and transport), analytical, and postanalytical paths of work. A common consequence of this was use of the time from sample collection to aggregate data reporting as a measure of laboratory performance. This misunderstanding greatly hindered the process of identifying and rectifying preanalytical root causes, which are independent of the laboratory testing processes. Chief among these were inadequate documentation of time of symptom onset, patient clinical information, and time of sample transport to the laboratory. Failure to properly document symptom onset meant requests for retesting patients within the 72-hour window were not followed up, and the inconsistent use of patient identifiers made linking repeat testing to patient monitoring and epidemiologic data difficult. In many instances, test results did not follow the patient, who might have moved into treatment away from local clinics or holding centers. This problem was of particular concern if patients were moved before results were reported through official channels and the laboratory had no direct contact with the care center or patient.

As the epidemic progressed, communications and transportation networks expanded, with varying degrees of success, to meet these needs. The most notable examples included rapid specimen transport by helicopters, where available, and national electronic reporting databases with ever-increasing fidelity of patient information. However, the overall number of tests done never approached the available testing capacity in the most-affected countries and was directly linked to low overall specimen collection activities and specimen transport.

Conclusion

West Africa's ability to develop long-term, sustainable laboratory capacity to recognize and respond to future threats to health security depends on improvements in the laboratory system. These improvements involve infrastructure reforms and organizational changes in laboratory networks, standardization of processes and procedures for rapid deployment of testing strategies, mechanisms to develop and adapt laboratory tools, and critical expansion of skilled workforce development as identified in the Global Health Security Agenda initiative (*16*).

Domestically, the U.S. public health laboratory infrastructure demonstrated its robust and flexible capacity to respond to a potential high-impact health emergency. However, further examination and refinement of biosafety and laboratory practices are needed to safely manage potentially hazardous patient specimens in today's complex laboratory environment. The integrated and close cooperation of the U.S. national, state, and local agencies and professional advisory groups during this response was a tremendous asset. Nevertheless, these interactions should be strengthened further to guard against the next high-consequence health threat.

Establishment of emergency operations centers in both domestic and international settings during the response substantially benefited laboratories. These coordinating centers provided feedback mechanisms to enable recognition of core issues and provide for process improvements that would be difficult to achieve in the rigid administrative structures under which laboratories often operate in resource-poor settings. The growing role of laboratory technical working groups within ministries of health and engagement with the African Society for Laboratory Medicine indicate the successful transitioning of these efforts into established structures. Nevertheless, these nascent efforts must be refined into more effective and efficient entities for coordinating and assisting emergency laboratory responses. Recognition by the affected countries that residual structures, such as mobile laboratories and diagnostic equipment donated in the response, must migrate into defined functional roles within the established national laboratory network is essential to capitalize on the advances implemented during this health emergency. Close cooperation between the many international agencies and partners involved with a focus on long-term development strategies will help prevent a repeat of the West Africa Ebola tragedy and provide for sustainable public health capacities throughout West Africa and beyond.

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Infection Prevention and Control for Ebola in Health Care Settings — West Africa and United States

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Summary

The 2014–2016 Ebola virus disease (Ebola) epidemic in West Africa underscores the need for health care infection prevention and control (IPC) practices to be implemented properly and consistently to interrupt transmission of pathogens in health care settings to patients and health care workers. Training and assessing IPC practices in general health care facilities not designated as Ebola treatment units or centers became a priority for CDC as the number of Ebola virus transmissions among health care workers in West Africa began to affect the West African health care system and increasingly more persons became infected. CDC and partners developed policies, procedures, and training materials tailored to the affected countries. Safety training courses were also provided to U.S. health care workers intending to work with Ebola patients in West Africa. As the Ebola epidemic continued in West Africa, the possibility that patients with Ebola could be identified and treated in the United States became more realistic. In response, CDC, other federal components (e.g., Office of the Assistant Secretary for Preparedness and Response) and public health partners focused on health care worker training and preparedness for U.S. health care facilities. CDC used the input from these partners to develop guidelines on IPC for hospitalized patients with known or suspected Ebola, which was updated based on feedback from partners who provided care for Ebola patients in the United States. Strengthening and sustaining IPC helps health care systems be better prepared to prevent and respond to current and future infectious disease threats.

The activities summarized in this report would not have been possible without collaboration with many U.S. and international partners (http://www.cdc.gov/vhf/ebola/outbreaks/2014-west-africa/partners.html).

Background

Infection prevention and control (IPC) is an essential, ongoing requirement to protect patients and health care workers (HCWs) from the spread of infectious diseases in health care settings. The 2014–2016 Ebola virus disease (Ebola) epidemic in West Africa underscored how actions in health care settings can contain or amplify an infectious disease threat in a community. Failure to effectively and consistently implement IPC practices can lead to outbreaks among HCWs and patients. A smaller workforce after an outbreak might require the closing of facilities, as occurred during the 2014–2016 Ebola epidemic. Closing of a facility not only affects outbreak control but can jeopardize the delivery of care (e.g., routine, trauma, cardiac emergency, and obstetric care).

During outbreaks of new and emerging infectious diseases, CDC provides guidance on IPC for U.S. health care settings to prevent spread of infections within health care facilities; coordinates and engages experts throughout CDC and federal and state partners for activities, such as developing additional guidance or tools; and communicates with and engages stakeholders to reach the broadest audience. During the Ebola epidemic, CDC expanded its domestic role and provided guidance and leadership internationally to train and educate HCWs in affected countries in West Africa and in the United States.

CDC Contributions and Impact

International Infection Prevention and Control

Early in the Ebola epidemic, Ebola transmission to HCWs occurred in health care facilities that were not Ebola treatment units (ETUs) (*1–3*). Health care facility assessments conducted by CDC and partners in 2014 documented substantial gaps in IPC. These gaps (i.e., a lack of IPC oversight, poor waste management procedures, a lack of triage and isolation protocols, frequent lack or misuse of personal protective equipment [PPE], and inadequate standard infection control precautions) increased the risk for Ebola transmission in non-ETU health care settings (*4,5*).

Beginning in August 2014, CDC developed partnerships with ministries of health, the World Health Organization (WHO), and others to improve IPC rapidly at non-ETU health care facilities and to decrease the risk for Ebola transmission to HCWs. A critical first step was to establish national IPC task forces to coordinate infection control efforts within Guinea, Sierra Leone, and Liberia. Before these task forces were established, numerous organizations working to improve IPC within the affected countries had developed training materials that sometimes gave conflicting technical details and led to confusion among HCWs. The establishment of ministry of health–supported national IPC task forces within each country improved communication among partners and coordinated the development of technically sound and consistent standard operating procedures relevant for resource-limited clinical settings. These standard operating procedures listed procurement of PPE and other IPC supplies for health care facilities.

Along with the establishment of national IPC task forces, CDC and partners developed and trained local and facility-level IPC leadership, also called IPC specialists or focal persons. IPC specialists oversaw IPC at facilities and led ongoing facility IPC improvements, including providing HCW training and ensuring availability of supplies. In addition to conducting IPC training, CDC and partners provided onsite mentorship and supportive supervision to rapidly implement IPC improvements. In Liberia, the first cadre of IPC specialists included medical residents and physicians from hospitals that closed because of the epidemic. These specialists supported 10–15 hospitals, health centers, and clinics in 14 of 15 counties in the country. In Guinea, IPC specialists, trained and funded by partner organizations, were overseeing triage and IPC at large hospitals in the short term. In Sierra Leone, the Ministry of Health and Sanitation appointed permanent IPC specialists for the 25 Government hospitals in February 2015.

In addition to helping establish IPC policies and procedures, CDC also worked with partners to develop standard IPC training materials specific for available resource levels that were then tailored (e.g., translated into different languages) for use in the affected countries. These outlined the IPC practices that needed to be implemented in health care facilities, community care centers, patient transport systems, and communities (*6*). After CDC technical review of materials, IPC partners launched efforts intended to train HCWs in each of the three countries on proper screening, isolation, and notification procedures for patients arriving at non-ETU facilities. CDC staff participated in the trainings using a train-the-trainers framework, resulting in at least 765 master trainers delivering training to approximately 24,000 HCWs in Liberia, Guinea, and Sierra Leone.

To supplement efforts to strengthen IPC practices system-wide, a new strategy known as Ring IPC was introduced in which rapid, intensive, and short-term IPC support is delivered to health care facilities in areas of active Ebola transmission to help break the chain of transmission (*7*). Once high-risk facilities were identified, IPC assessments were conducted to guide technical assistance, medical supply distribution, and daily supportive supervision to ensure HCWs were trained to triage, isolate, and refer suspected and probable Ebola patients rapidly to ETUs.

Ring IPC impacted several places. For example, in Liberia, three febrile HCWs were identified when screened for work; all were properly isolated and transferred to an ETU for testing (*7*). Sierra Leone integrated Ring IPC around clusters of Ebola patients in three districts. Guinea focused on minimizing transmission by rapidly investigating infected HCWs and remediating IPC lapses.

Training U.S. Health Care Workers Traveling to West Africa

The large number of infected HCWs caused workforce shortages in the three countries that were most heavily affected. Clinical staff from countries around the world, including the United States, volunteered to care for Ebola patients in ETUs. Although training courses, such as those offered by Médecins Sans Frontières (MSF) and WHO, had been developed to prepare ETU workers, requests for enrollment in available training courses exceeded capacity. In addition, no similar courses in the United States met the need for training U.S. clinicians on providing safe care for patients in West Africa.

To address the safety of U.S. medical volunteers, CDC formed a task force that developed a 3-day safety training course for U.S. HCWs intending to work in West Africa ETUs (*8*). Task force members traveled to Belgium in August 2014 to participate in the MSF course. With the full collaboration and participation of MSF and WHO, the team used the two organizations' Ebola materials as the foundation for the CDC course curriculum.

CDC conducted the course, called Preparing Healthcare Workers to Work in Ebola Treatment Units (ETUs) in Africa, at the U.S. Federal Emergency Management Agency's Center for Domestic Preparedness in Anniston, Alabama. The team trained approximately 600 HCWs representing 42 nongovernment organizations and 21 institutions, organizations, and agencies of the U.S. government. Of the HCWs trained, 276 were Commissioned Officers of the U.S. Public Health Service who staffed the Monrovia Medical Unit in Liberia during 2014–2015 (*9*) and provided care to infected HCWs. The training team also produced a tool kit of the training curriculum so that other organizations could replicate the course (*10*).

Developing Ebola IPC Guidance for U.S. Health Care Facilities

CDC is the lead federal agency for developing infection control guidance that U.S. health care facilities can use when implementing local protocols and procedures. This guidance is based on evidence found in published literature or gained from field experience. In situations where intervention is required for new or emerging infections and there is a paucity of data available, CDC develops guidance based on the best information available (e.g., existing CDC guidance for similar diseases, current epidemiologic and laboratory information, peer-reviewed evidence, and expert opinion). These documents typically are written to provide flexibility in implementation to account for differences in facility-specific characteristics (e.g., facility design and types of supplies available) across health care settings (e.g., hospitals compared with outpatient settings).

In August 2014, anticipating the possibility that Ebola could be diagnosed and treated in the United States and knowing that no U.S. health care facility had experience treating Ebola, CDC infection control, occupational safety and health, and Ebola experts developed and disseminated *Infection Prevention and Control Recommendations for Hospitalized Patients with Known or Suspected EVD in U.S. Hospitals* (*11*). These recommendations included guidance on patient placement, PPE use, aerosol-generating procedures, environmental infection control, monitoring and management of potentially exposed HCWs, and other critical aspects of prevention of Ebola transmission in hospitals. At the time, the recommended PPE for Ebola patient care was a gown, gloves, eye protection, and facemask; additional PPE (e.g., shoe covers, leg covers, double gloving, and respirator) for HCWs was recommended if the HCW anticipated contact with copious body fluids or would be performing aerosol-generating procedures. In September 2014, CDC and the Office of the Assistant Secretary for Preparedness and Response (ASPR) advised that all hospitals should prepare for the possibility that persons in West Africa with Ebola could travel to the United States and distributed a checklist to guide hospitals' preparedness (*12*).

The importation of an Ebola case to a Dallas, Texas, health care facility and the subsequent spread of Ebola to two nurses who provided care demonstrated that HCW PPE recommendations needed to be more directive (e.g., only two recommended PPE ensemble options) and be standardized to facilitate training efforts as well as to ensure the proper supply distribution of the recommended PPE. In addition, CDC received feedback from partners, including those who had provided care for the Ebola patients in the United States, regarding invasive procedures or changes to routine processes (e.g., patient care staff remained in patient's room for extended periods). As a result of these experiences, CDC updated the Ebola PPE guidance for HCWs in October 2014, emphasizing that facilities should choose a single standardized PPE approach for patient care, provide training and document competency in PPE use, and use a trained observer during donning and doffing. The observer would help to ensure that PPE was donned correctly and would alert the HCW to

possible contact with body fluids during doffing of used PPE (*13*). CDC received input from other federal agencies with regulatory oversight of health care and occupational safety and health issues, including the Food and Drug Administration, the Occupational Safety and Health Administration, and the National Institutes of Health. Feedback was also received from nongovernment professional medical societies and organizations and public health authorities with expertise in Ebola, IPC, and occupational safety and health. Other sources of feedback were hospital staff who had safely cared for Ebola patients in the United States (Emory University Hospital in Atlanta, Georgia, and Nebraska Medical Center in Omaha, Nebraska) and in Africa (MSF).

Training and Educating HCWs in U.S. Health Care Facilities

Updating the infection control guidance was an important step to provide additional specificity; however, the delivery of information and the requirements for implementation needed to be strengthened. Challenges included the differing levels of preparedness among U.S. health care facilities, variations in HCWs' roles and their baseline levels of infection control knowledge and training, and differences in the amount and types of infection control supplies (e.g., PPE) available to HCWs. To address these challenges, CDC developed partnerships with a diverse group of organizations to develop educational resources applicable to various settings and HCW types. CDC deployed teams to assess infection control readiness at facilities being designated by state authorities to care for and assess Ebola patients, with the goal of creating training and educational resources based on CDC guidance that are action-oriented, modular, accessible on mobile devices for on-demand use, available in multiple formats, and endorsed by key stakeholders. These tools also took into account best practices related to adult learning, risk communication, and clear communication. CDC training was delivered by using a multifaceted approach: onsite technical assistance, Web-based tools, video training and resources, webinars and conference calls, and in-person training.

Onsite Technical Assistance

CDC and ASPR collaborated with state health departments to improve facility readiness by assessing facilities that can safely care for a patient with Ebola and develop guidance to prepare U.S. health care facilities for Ebola. Facilities were designated in three tiers (*14*): Ebola treatment centers (ETCs) (*14*,*15*), assessment hospitals (*14*,*16*), and frontline health care facilities (*14*,*17*). Fifty-five state-designated ETCs were designated by state health authorities by February 2015, of which nine serve as regional treatment centers. ETCs are staffed, equipped, and have been assessed for their ability to provide care for an Ebola patient for the complete duration of illness. CDC teams assessed infection control readiness by visiting 81 facilities in 21 states and the District of Columbia that were being considered to serve as ETCs by January 2015.

CDC and ASPR worked with state and local public health officials to identify Ebola assessment hospitals through Ebola readiness assessment teams. These hospitals are intended to have the capability to evaluate and care for persons suspected of having Ebola for up to 96 hours, initiate or coordinate Ebola testing, and test for alternative illnesses. These hospitals can transfer patients to an ETC as needed. Ebola readiness assessment teams assess facilities for key capacities, including staff training, infection control, and PPE use. Through December 2015, Ebola readiness assessment teams assessed approximately 40 facilities.

Web-Based Tools

CDC's Ebola HCW Web pages, which feature training videos and materials (e.g., job aids such as algorithms and checklists), were successively tailored during the fall of 2014 to accommodate the growing needs of the response (*18*). Usability testing was conducted with stakeholders before the third redesign in December 2014 to ensure that users could easily access CDC's guidelines and training information. The Ebola HCW Web pages were viewed approximately 7.5 million times in fall of 2014.

Web-Based Video Training

Effectively donning and doffing PPE are two of the most complex actions for HCWs caring for an Ebola patient. On October 31, 2014, within 11 days after releasing updated PPE guidance, CDC and Johns Hopkins Armstrong Institute for Patient Safety used human factors engineering methods to develop and launch an interactive Web-based video learning program detailing procedures for four main PPE combinations (*19*). To support facility preparedness, four Web-based video training modules were included for emergency department personnel in ETCs and Ebola assessment hospitals, providing detailed instructions on safely assessing and caring for patients with Ebola and other infectious diseases (*20*). By July 31, 2015, the PPE video modules had been viewed 576,410 times, with an estimated 518,682 minutes (8,644 hours) watched. The emergency department training modules were viewed a total of 15,675 times, with an estimated 1,405 hours watched.

Webinars and Conference Calls

CDC conducted approximately 160 webinars and conference calls, reaching approximately 160,000 U.S. health

care providers. Most of these calls were conducted during July 2014–January 2015 in collaboration with clinical professional partners (e.g., American Hospital Association).

Resources on Clinician-Specific Websites

During the fall of 2014, online clinical communities (e.g., Medscape) provided substantial additional outreach to U.S. health care providers. The public–private partnership between CDC and WebMD/Medscape enables rapid dissemination of urgent training and information to clinicians during public health crises. Medscape produced eight video expert commentaries and a short how-to video on donning and doffing PPE when caring for Ebola patients and collaborated with CDC to address questions from health care professionals (*21*). The Ebola commentaries on Medscape were viewed approximately 386,000 times and have been promoted and used for HCW training throughout the United States and internationally.

In-Person Training

CDC linked with Partnership for Quality Care and numerous health care organizations and unions to conduct live training events in New York, New York; Los Angeles, California; and Philadelphia, Pennsylvania; these events reached approximately 6,500 individuals in person and approximately 20,000 through live webcast (*22*,*23*). In addition, CDC, Emory University Hospital, and Nebraska Medical Center trained approximately 1,000 HCWs from designated ETCs, Ebola assessment hospitals, and state health departments on all aspects of infection control and patient care for Ebola patients. On July 1, 2015, CDC and ASPR announced the launch of the National Ebola Training and Education Center, led by three institutions (Emory University Hospital, Nebraska Medical Center, and Bellevue Hospital in New York, New York) to continue and expand on efforts to ensure health care facilities and biocontainment centers maintain readiness to care for patients with Ebola in the United States (*24*).

Conclusion

Even after Ebola cases in West Africa have declined to zero, the infection control safety net must be sustained to prevent reemergence of the epidemic, and the lessons learned from this response augmented to improve infection control in U.S. health care facilities and globally. Emerging infectious diseases such as Ebola will inevitably occur, possibly without warning. Hospitals and other health care facilities must remain vigilant and prepared to implement prompt triage of potentially infectious patients and maintain recommended infection control practices during all patient care activities, regardless of patients' known infection status.

As of March 2016, a total of 261 CDC or other U.S. government staff had deployed to West Africa to support IPC efforts. These IPC efforts have resulted in numerous improvements in safety and most likely have prevented infection in many patients and HCWs. Triage procedures were established at nearly all non-ETU key health care facilities, with trained staff to screen for suspected cases at entry points. HCWs, now trained on the use of PPE for standard and Ebola-specific precautions, routinely provide care using appropriate PPE. IPC specialists in Guinea, Sierra Leone, and Liberia have overseen numerous IPC improvements in waste management, hand hygiene, environmental decontamination, and other critical facility safety components. One of the last cases in Liberia, a symptomatic person with no known contact with an Ebola patient, was identified by a triage nurse before entry to the hospital; subsequent isolation resulted in no health care–associated cases or exposures (*25*). Overall, the number of HCW infections has declined dramatically, as has the proportion of cases occurring among HCWs (*1*). Taken together, IPC efforts have greatly reduced the likelihood of transmission in a health care setting, one of the major settings for Ebola transmission during this epidemic (*1*).

In West Africa, strengthening and sustaining IPC in health care systems established for the epidemic will help prevent future disease transmission. Equipment, supplies, and infrastructure are all essential elements of IPC, and access to them will need to be ensured. International partners will need to ensure that, at a minimum, HCWs always have access to gloves, especially at primary care points, such as hospitals, clinics, and other facilities where the risk for transmission is high. Reliable water, electricity, and waste disposal at health care facilities are critical, and such infrastructure improvements would further contribute to decreasing disease transmission in West Africa. In addition, effective, sustainable, and scalable lower-cost solutions, such as local production of alcohol-based hand rub, are needed.

In the United States, sustaining the education, training, and competency of HCWs on IPC practices is needed not only to prepare for emerging threats but also to prevent transmission of endemic disease in U.S. health care facilities. Common health-care–associated infections alone are responsible for substantial numbers of illnesses and even deaths among patients; in 2011, an estimated 722,000 U.S. patients acquired health-care–associated infections, and 75,000 died (*26*). Emphasis on microbiology and IPC principles for all HCWs that begins during medical, nursing, and other clinical education programs can help provide a foundation for safe care.

The Ebola response also highlighted the need for research and evaluation of new infection control practices and technologies to ensure that the safety of care keeps pace with

the ever-evolving health care system. Opportunities for health care innovations include ways to:

- improve the detection, triage, and isolation process for potentially infectious patients seeking care; ensure HCW and patient safety; and prevent spread within health care systems;
- upgrade the design and construction of health care facilities to make infection control as effective as possible (e.g., by eliminating crowded waiting rooms and providing pathways for patient triage and transport of infectious material);
- adopt innovative technologies for environmental cleaning and disinfection; and
- improve the design of PPE for health care so that it meets the needs of the personnel caring for patients (e.g., PPE designed to allow effective patient care interactions and facilitate removal without risk of contaminating the environment or the wearer).

In addition to training HCWs, implementing IPC across health care systems requires improving accountability and incentives to support sustained change, providing evidence-based interventions and solutions to support facility improvements, and using public health data to track progress. As these processes are implemented, health care systems will be better prepared to prevent and respond to current and future infectious disease threats.

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Travel and Border Health Measures to Prevent the International Spread of Ebola

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Summary

During the 2014–2016 Ebola virus disease (Ebola) epidemic in West Africa, CDC implemented travel and border health measures to prevent international spread of the disease, educate and protect travelers and communities, and minimize disruption of international travel and trade. CDC staff provided in-country technical assistance for exit screening in countries in West Africa with Ebola outbreaks, implemented an enhanced entry risk assessment and management program for travelers at U.S. ports of entry, and disseminated information and guidance for specific groups of travelers and relevant organizations. New and existing partnerships were crucial to the success of this response, including partnerships with international organizations, such as the World Health Organization, the International Organization for Migration, and nongovernment organizations, as well as domestic partnerships with the U.S. Department of Homeland Security and state and local health departments. Although difficult to assess, travel and border health measures might have helped control the epidemic's spread in West Africa by deterring or preventing travel by symptomatic or exposed persons and by educating travelers about protecting themselves. Enhanced entry risk assessment at U.S. airports facilitated management of travelers after arrival, including the recommended active monitoring. These measures also reassured airlines, shipping companies, port partners, and travelers that travel was safe and might have helped maintain continued flow of passenger traffic and resources needed for the response to the affected region. Travel and border health measures implemented in the countries with Ebola outbreaks laid the foundation for future reconstruction efforts related to borders and travel, including development of regional surveillance systems, cross-border coordination, and implementation of core capacities at designated official points of entry in accordance with the International Health Regulations (2005). New mechanisms developed during this response to target risk assessment and management of travelers arriving in the United States may enhance future public health responses.

The activities summarized in this report would not have been possible without collaboration with many U.S. and international partners (http://www.cdc.gov/vhf/ebola/outbreaks/2014-west-africa/partners.html).

Background

Before the 2014–2016 Ebola virus disease (Ebola) epidemic in West Africa, reports of Ebola virus exportation to other countries were rare, a fact partially attributed to the remote, rural locations of previous outbreaks of Ebola. When Ebola spread in 2014 to the capital cities of Guinea, Liberia, and Sierra Leone, where infected persons and their contacts had greater access to international airports, concerns arose about the potential for further international spread. These concerns were heightened in July 2014, after a Liberian-American businessman with symptomatic Ebola traveled from Monrovia, Liberia, via Togo to Lagos, Nigeria. This event triggered an outbreak in Nigeria that spread to a second city by air travel, infected 20 persons (confirmed and probable cases), resulted in the deaths of eight persons, and exposed almost 900 persons (*1*).

On August 8, 2014, an emergency committee convened by the Director-General of the World Health Organization (WHO) under the International Health Regulations (2005) declared the Ebola epidemic in West Africa a Public Health Emergency of International Concern (*2*). Among the recommendations of the emergency committee were that countries with Ebola transmission should conduct exit screening at international airports, seaports, and major land crossings and that other countries should not generally ban travel or trade.

CDC's initial response to the Ebola epidemic in West Africa included communication to travelers (e.g., travel notices on CDC's website, messaging displayed in airports) and enhancement of existing mechanisms to detect sick travelers entering the United States. Recognizing the importance of preventing further isolation of, and economic impact to, the countries with Ebola outbreaks and maintaining the essential flow of humanitarian aid workers and supplies, CDC sent teams to these countries in August 2014 to provide technical assistance with border health measures. The teams initially focused on training and capacity building to rapidly implement effective exit screening (i.e., screening of departing travelers for acute illness or possible exposures) at international airports (*3*). Although not routinely recommended, exit screening might be considered an important mechanism of source containment during an infectious disease outbreak to prevent international spread. Because the primary benefit of exit screening is protection of the international community, assisting in its effective implementation is a shared international responsibility.

In late 2014, two imported cases of Ebola were identified in the United States, one of which resulted in two domestic cases and extensive contact investigations in the community and for travelers on two domestic flights (*4–7*). Demands increased from some political leaders and members of the public to strengthen the domestic response, including banning air travel between the United States and the three countries with widespread transmission (*8*). Many public health professionals cautioned that such a ban would cause greater harm than good to the public health response by hampering travel of responders and delivery of supplies into the region and paradoxically could increase the risk for spread via covert and circuitous travel routes (*9,10*). To build on the exit screening already in place, CDC collaborated with the U.S. Department of Homeland Security (DHS) to initiate an enhanced entry risk assessment and management program for travelers from countries with Ebola outbreaks. This unprecedented operation required coordination across multiple U.S. government agencies, as well as with airport authorities and health departments in all U.S. states and territories (*3*).

CDC's travel and border health–related response to the Ebola epidemic comprised three goals: 1) prevent international spread of disease, 2) educate and protect travelers and communities, and 3) minimize disruption of international travel and trade. This report discusses specific measures, considerations for their implementation, and their potential use in response to future outbreaks of international public health concern (Table).

CDC's Role: Working with Partners

International Response

Airports

In August 2014, after Ebola spread from Liberia to Nigeria by air travel, concerned airlines canceled flights to Guinea, Liberia, and Sierra Leone, and multiple countries closed their borders to travelers from these countries (*11*); the shortage of commercial flights caused delays to the provision of humanitarian aid, resulting in shortages of medical supplies, personal protective equipment, and food (*12*). The few airlines that continued to fly to the countries with Ebola outbreaks insisted that departing travelers be screened before boarding (*11*). CDC Border Health teams in Guinea, Liberia, Nigeria, and Sierra Leone, and later Mali and Senegal, helped airport and health authorities implement airport exit screening measures that included administering an exposure-and-symptom questionnaire and at least one temperature check with a handheld noncontact thermometer to all departing passengers. Health screeners were trained to conduct secondary assessments of travelers who reported possible exposures or who had symptoms compatible with Ebola. Symptomatic or exposed travelers were denied boarding and referred for further medical and public health assessment. As national databases of known contacts became more robust, they were matched against passenger manifests for departing flights. These measures helped countries with Ebola outbreaks meet WHO recommendations and ensured that some commercial air carriers continued to fly to these countries, serving as vital conduits for supplies and response personnel.

During August 2014–January 2016, approximately 300,000 travelers were screened in Guinea, Liberia, and Sierra Leone. Only four cases of Ebola were exported through air travel to other countries (United States [two cases], United Kingdom [one case], Italy [one case]) after exit screening was implemented; none of the infected travelers were overtly symptomatic at the time of travel (*4,7,13,14*). No Ebola cases were reported to have been detected during exit screening.

To support the international response, CDC developed Ebola communications tools, job aids for airline and airport staff, and messages specific to different organizations and populations. Information also was provided through webcasts and trainings, and some materials were made available on the CDC website as templates to assist other countries in developing their own communications resources.

TABLE. Timeline of key travel-related events and CDC border health measures during the 2014–2016 Ebola epidemic in West Africa

Date	Event/CDC action or recommendation
2014	
March 23	WHO announces Ebola outbreak in Guinea.
March 26	CDC posts Level 2 travel notice* for Guinea.
March 30	First cases of Ebola confirmed in Liberia.
April 10	CDC posts Level 2 travel notice for Liberia.
May 27	First cases of Ebola confirmed in Sierra Leone.
June 4	CDC posts Level 2 travel notice for Sierra Leone.
July 9	CDC EOC is activated to support Ebola response.
July 20	Symptomatic infected traveler flies from Liberia to Nigeria, triggers outbreak in Nigeria.
July 31	CDC elevates travel notices for Guinea, Liberia, and Sierra Leone to Level 3, recommending against nonessential travel to these countries.
August 4–11	CDC deploys border health teams to Guinea (August 4), Liberia (August 4), Sierra Leone (August 9), and Nigeria (August 11); CDC posts Level 2 travel notice for Nigeria (August 5).
August 7	First publication of CDC's Interim U.S. Guidance for Monitoring and Movement of Persons with Potential Ebola Virus Exposure with recommendations for self-monitoring.
August 8	WHO declares Ebola in West Africa a Public Health Emergency of International Concern.
September 25	CDC downgrades Nigeria travel notice to Level 1.
September 30	First imported U.S. case identified in Texas.
October 6	Transmission of Ebola to a HCW reported in Spain.
October 11–16	Two domestic cases of Ebola diagnosed in Dallas, Texas, HCWs; one infected HCW travels domestically by commercial airline (October 10 and 13).
October 11–16	CDC and CBP begin enhanced entry risk assessment and management for travelers from Guinea, Liberia, and Sierra Leone: October 11 at JFK and October 16 at four other airports (EWR, IAD, ORD, and ATL).
October 20	CDC removes travel notice for Nigeria.
October 21	CBP announces that travelers from Guinea, Liberia, and Sierra Leone will be redirected to the five airports participating in enhanced entry risk assessment.
October 23	Second imported U.S. case identified in New York.
October 27	CDC updates Interim U.S. Guidance for Monitoring and Movement of Persons with Potential Ebola Virus Exposure with recommendations for active and direct active monitoring.
October 27	Traveler from Guinea dies of Ebola in Mali, triggers outbreak in Mali.
November 13	CDC posts Level 2 travel notice for Mali.
November 17	Enhanced entry risk assessment and management begins for travelers from Mali.
December 29	Imported case of Ebola identified in the United Kingdom.
2015	
January 6	Enhanced entry risk assessment and management discontinued for travelers from Mali.
January 7	CDC removes travel notice for Mali.
May 4	CDC downgrades Liberia travel notice to Level 2.
May 9	Liberia first declared free of Ebola transmission by WHO.
May 11	Imported case of Ebola identified in Italy.
June 17	Recommendation for monitoring changed to self-observation for travelers from Liberia.
September 3	CDC downgrades Liberia travel notice to Level 1.
September 21	Enhanced entry risk assessment and management discontinued for travelers from Liberia.
November 2	CDC downgrades Sierra Leone travel notice to Level 2.
November 7	Sierra Leone declared free of Ebola transmission by WHO.
November 10	Recommendation for monitoring changed to self-observation for travelers from Sierra Leone.
November 25	CDC downgrades Sierra Leone travel notice to Level 1 and Guinea travel notice to Level 2.
December 22	Enhanced entry risk assessment and management discontinued for travelers from Sierra Leone.
December 29	Guinea declared free of Ebola transmission by WHO; recommendation for monitoring changed to self-observation for travelers from Guinea; CDC downgrades Guinea travel notice to Level 1.
2016	
February 19	Enhanced entry risk assessment and management discontinued for travelers from Guinea; CDC removes all Ebola travel notices.
March 29	WHO declares end of the Public Health Emergency of International Concern.

Abbreviations: ATL = Hartsfield–Jackson Atlanta International Airport; CBP = Customs and Border Protection, U.S. Department of Homeland Security; Ebola = Ebola virus disease; EOC = Emergency Operations Center; EWR = Newark Liberty International Airport; HCW = health care worker; IAD = Washington Dulles International Airport; JFK = John F. Kennedy International Airport (New York City); ORD = Chicago O'Hare International Airport; WHO = World Health Organization.

* CDC travel notice definitions are available at http://wwwnc.cdc.gov/travel/yellowbook/2016/introduction/planning-for-healthy-travel-cdc-travelers-health-website-and-mobile-applications.

Seaports

Countries in West Africa, including Guinea, Liberia, and Sierra Leone, rely heavily on commercial maritime transport to deliver food and other critical commodities and to export supplies that sustain national economies (*15*). Keeping these supplies moving was critical to avoiding further strain on the countries' already fragile systems. CDC assisted national seaport and maritime authorities by evaluating health security measures at major seaports and training staff how to recognize and respond to Ebola. Port authorities established temperature

checkpoints for port access; reviewed and practiced emergency medical response procedures; established onsite isolation facilities; implemented personal protective equipment requirements for staff required to board vessels; and restricted access to vessels in port and disembarkation of seafarers, including cancellation of shore passes and crew transfers.

Land Borders

Ebola initially spread at the land borders of Guinea, Liberia, and Sierra Leone, and frontiers between these countries and their neighbors posed the most difficulties for the border health component of the response. Movement across land borders also resulted in the introduction of Ebola into neighboring Senegal and Mali causing an outbreak in Mali that resulted in eight cases and six deaths; international sharing of information about contacts led to interventions that prevented transmission and contributed to successful containment in Senegal without further spread (*16*).

The origin of the epidemic highlighted weaknesses in routine and cross-border disease surveillance. In the border regions of West Africa, tribal and ethnic kinship affiliations rather than geopolitical boundaries define village communities. Official border points of entry (those where travelers are inspected by border officials) are sparse, understaffed, and underresourced; dozens of informal border crossings exist for every official point of entry; and travel volumes are high. For all of these reasons, land borders are porous and applying screening procedures at official land border crossings similar to those used at airports is impractical and probably ineffective. CDC, together with ministries of health, WHO, the International Organization for Migration, nongovernment organizations, and other international partners, strengthened disease surveillance in border communities and sharing of information across borders; implemented simple, sustainable measures (e.g., visual screening for illness at designated official border crossings); and developed clearly articulated plans for isolation, communication, assessment, referral, and transportation on the basis of existing and nearby resources. These organizations also coordinated improved mapping of geopositional landmarks, including official and informal border crossings, villages, and markets and other areas of congregation, as well as mapping of population movement patterns. This approach aimed to improve cross-border operations and situational awareness and engage community members in the public health response.

Domestic Response

Travel and border health measures within the United States evolved over time in response to changing needs, newly identified risks, and public concern. At the start of the epidemic, CDC strengthened coordination with U.S. port-of-entry and community partners to identify and assess risks for symptomatic or potentially exposed travelers. Communications materials supported a strategy that relied on educating travelers to self-monitor and seek health care if they developed symptoms.

In August 2014, CDC issued interim guidance that provided a standard for public health measures in the United States on the basis of clinical criteria and exposure risk (*17*). Measures ranged from monitoring (primarily self-monitoring) to controlled movement (e.g., preclusion from long-distance travel on commercial conveyances such as aircraft, ships, buses, or trains) and aimed to apply the least restrictive measures necessary to protect communities and travelers.

CDC issued revised interim guidance in October 2014 (*17*) after the first imported case of Ebola in the United States was identified (and initially diagnosed as presumed sinusitis) in Dallas, Texas (*4*); an infected U.S. health care worker (HCW) flew on two domestic commercial flights, causing panic among U.S. travelers and disrupting the travel industry (*6*,*18*,*19*); and an infected humanitarian aid worker was reported to have been in public areas, including the New York City subway, during the early stages of his illness (*7*,*20*). CDC's guidance was revised in response to assertions that self-monitoring was insufficient; growing concerns about infected HCWs in Spain, the United States, and the West African countries with Ebola outbreaks (*4*,*7*,*21*,*22*); and renewed calls for travel bans (*8*). Demands to restrict movement of HCWs caring for patients with Ebola were countered by predictions that stringent restrictions would discourage HCWs from supporting the response in West Africa or taking care of patients with Ebola at designated facilities in the United States (*23*,*24*). The revised guidance recommended that state or local public health authorities assume responsibility for monitoring all potentially exposed persons for the duration of the 21-day incubation period (active monitoring); established a higher standard of monitoring (direct active monitoring that included daily direct observation by public health officials) for persons with greater potential risk for exposure, including HCWs; and provided guidance for possible application of movement restrictions within communities. Although CDC's guidance represented a minimum standard, states could, and in many cases did, apply more restrictive measures (e.g., temporarily quarantining HCWs returning from West Africa) (*25*). Many of these measures were enacted before CDC issued the updated guidance.

To facilitate postarrival management of travelers, in October 2014, CDC and DHS's Customs and Border Protection (CBP) began an enhanced entry risk assessment and management program for travelers arriving in the United States from

countries with Ebola outbreaks (3). To implement this program with maximum efficiency and minimal disruption to travel, CBP limited entry of air travelers from Guinea, Liberia, and Sierra Leone (and for several weeks from Mali, during the outbreak in that country) to five airports: Hartsfield–Jackson Atlanta International Airport, Newark Liberty International Airport, Washington Dulles International Airport, John F. Kennedy International Airport (New York City), and Chicago O'Hare International Airport.

Enhanced entry risk assessment at U.S. airports included processes to identify travelers from countries with Ebola outbreaks, either through scheduled flight itineraries or during customs and immigration inspections. CBP officers and other U.S. Department of Homeland Security staff collected contact and locating information, administered an exposure-and-symptom questionnaire, checked travelers' temperatures with noncontact thermometers, and observed travelers for signs of illness. Data were entered electronically through an online interface and transmitted securely to CDC's database and then to states. Travelers who were symptomatic or who reported possible exposures were referred to CDC for an in-depth public health risk assessment. Symptomatic travelers who met predefined criteria were referred for medical evaluation to designated assessment hospitals, in consultation with the health department with jurisdiction for the airport.

The enhanced entry risk assessment and management program enabled CDC to educate travelers individually about Ebola and the postarrival monitoring process. Screened travelers received a CDC CARE (Check and Report Ebola) kit containing information and tools (including a thermometer and prepaid cell phone) to facilitate monitoring and reporting to health departments (Figure 1).

Enhanced entry risk assessment was discontinued for travelers from Liberia on September 21, 2015; for travelers from Sierra Leone on December 22, 2015; and for travelers from Guinea on February 19, 2016. Of the approximately 38,000 travelers assessed at U.S. ports of entry during October 11, 2014–February 18, 2016, only one was subsequently determined to have Ebola. The infected humanitarian aid worker arrived during the brief period between initiation of enhanced entry risk assessment and implementation of postarrival monitoring. He was asymptomatic upon arrival, and his illness was detected through self-monitoring and reporting to the local health department as recommended at the time (7).

To help enforce recommendations that travelers with certain exposures to Ebola should not travel on commercial conveyances and to further reduce the risk for Ebola spread through air travel, in March 2015 CDC revised criteria for use of federal travel restrictions to prevent travel by persons possibly exposed to Ebola or other communicable diseases but not yet considered contagious (26). The updated criteria gave CDC greater flexibility to control the movement of persons who might pose a public health threat during travel and to apply federal travel restrictions in support of outbreak control.

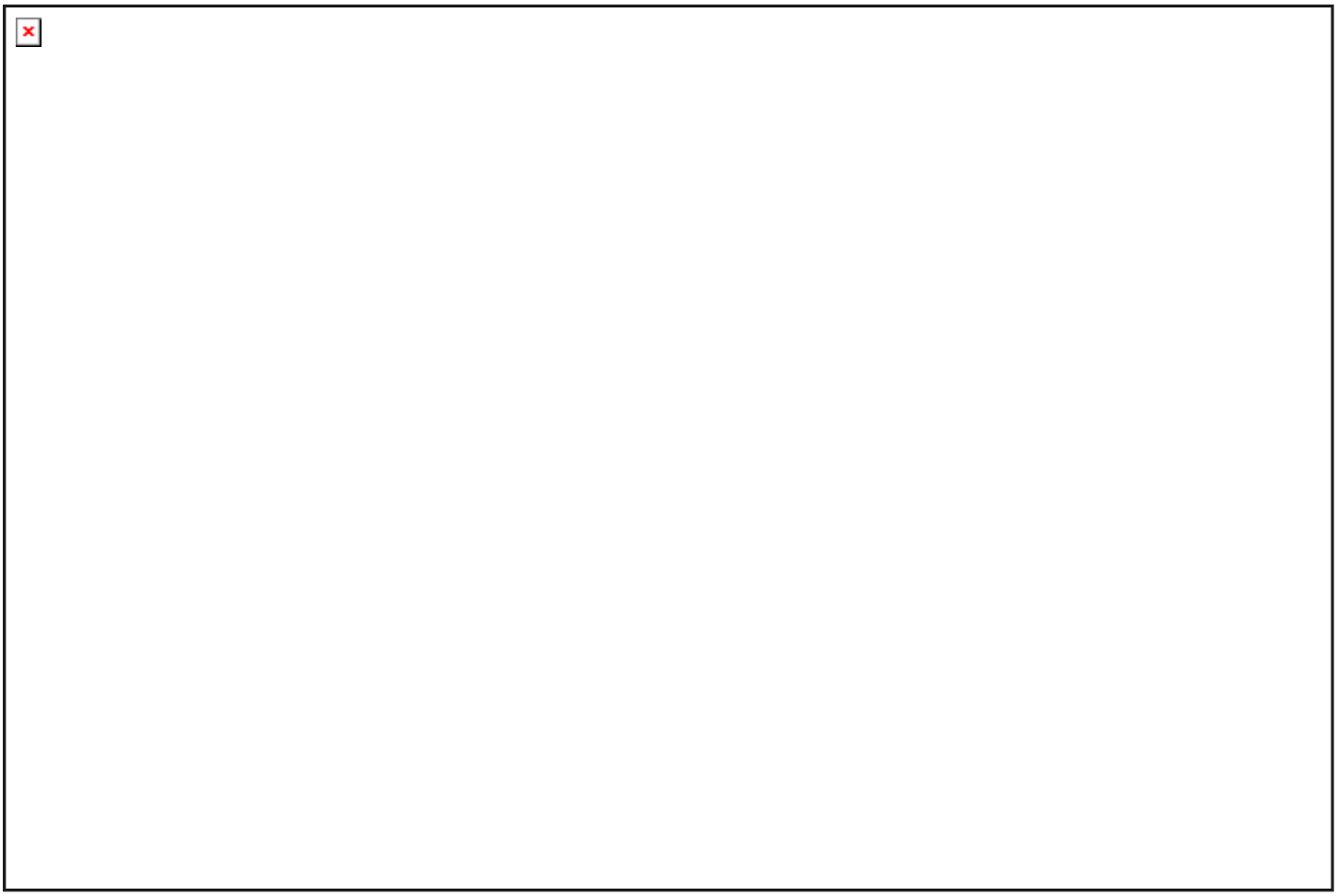
Communication

Throughout the response, CDC disseminated messages to inbound and outbound travelers through the CDC website, traditional and social media, partner outreach, and printed materials. Messages displayed in U.S. airports and in airports in countries with Ebola outbreaks reminded travelers to avoid travel while symptomatic, monitor themselves for illness, and seek health care should symptoms develop (Figure 2) (Figure 3) (Figure 4).

To provide international travelers with information to protect their health and, ultimately, the health of their communities, CDC regularly posts travel notices about disease outbreaks and international events. Notices are assigned a risk level (27) on the basis of the situation and available health recommendations and are escalated or deescalated as the analysis of risk to travelers changes (e.g., status of the outbreak or ability to access health care facilities). The highest risk level is Level 3 (i.e., warning), used only for situations in which the risk is so great that CDC recommends against nonessential travel to a destination. When considering issuance of Level 3 travel notices, CDC takes into account the health risk and impact to travelers and the potential for economic harm to the destination country and the travel industry.

During the 2014–2016 Ebola epidemic in West Africa, CDC initially posted Level 2 (i.e., alert) notices, which recommended enhanced precautions for travelers to Guinea (March 2014), Liberia (April 2014), and Sierra Leone (June 2014); later, Level 2 notices were added for Nigeria (August 2014) and Mali (November 2014) when Ebola outbreaks occurred in those countries. The notices for Guinea, Liberia, and Sierra Leone were subsequently elevated to Level 3 in July 2014 to advise U.S. residents to avoid nonessential travel to these countries and enable their governments to respond most effectively to the epidemic by reducing the potential for difficulties posed by nonessential travelers. As the situation improved in Liberia and extensive control measures were put into place, CDC downgraded the notice for this country to Level 2 in May 2015, then to Level 1 (i.e., watch) in September 2015. Similarly, CDC downgraded the notices for Sierra Leone to Level 1 and Guinea to Level 2 in November 2015, and the notice for Guinea was downgraded to Level 1 in December 2015. CDC removed all three notices on February 19, 2016, coinciding with the discontinuation of enhanced entry risk assessment at U.S. ports of entry.

FIGURE 1. CDC CARE kit distributed to travelers to facilitate monitoring and reporting to health departments during the 2014–2016 Ebola epidemic in West Africa



Abbreviations: CARE = Check and Report Ebola; Ebola = Ebola virus disease.

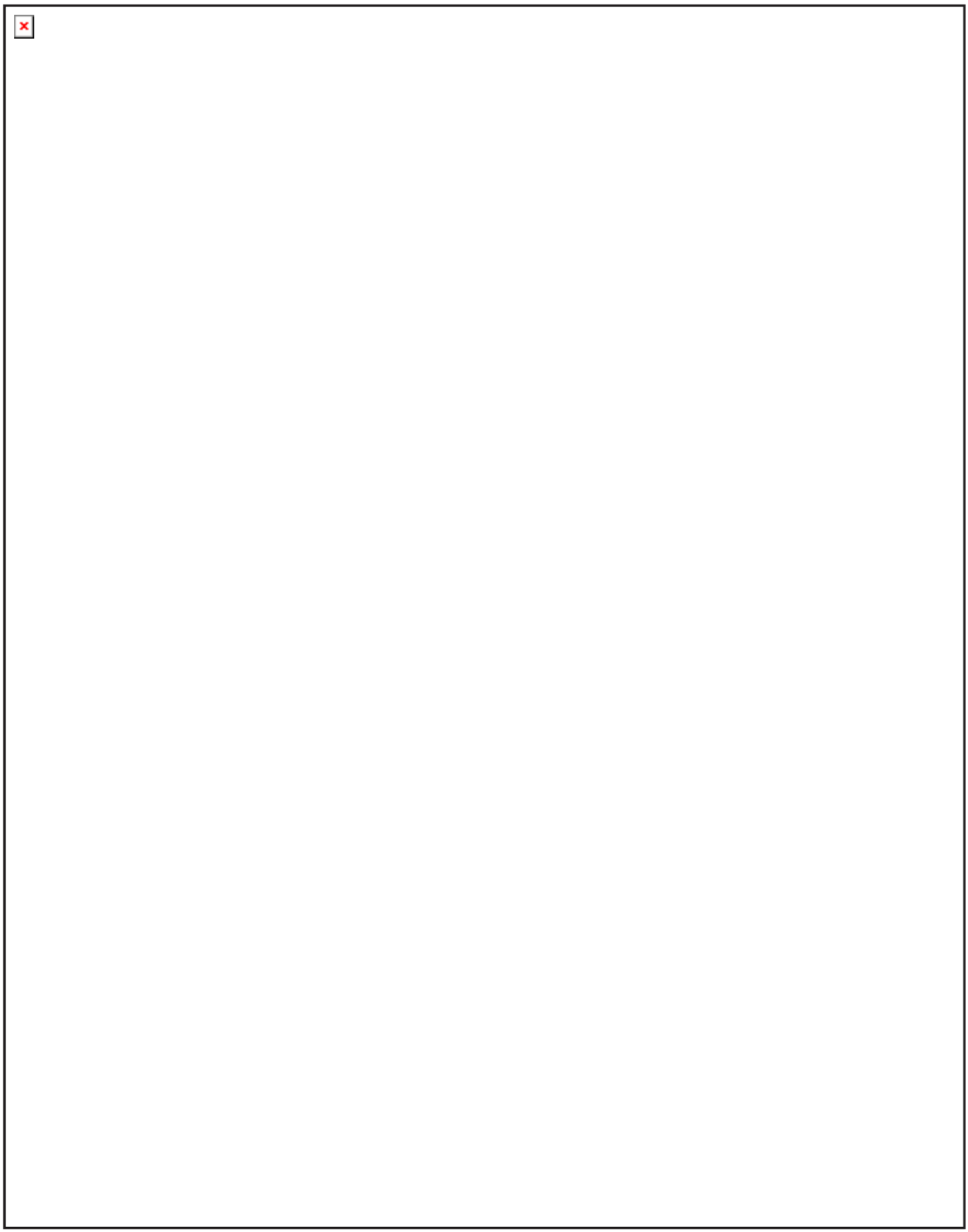
CDC also issued guidance for specific groups of travelers most at risk. Because humanitarian aid was essential to managing the epidemic, CDC posted guidance for aid workers and organizations to help ensure safe travel to and from the region. In contrast, CDC considered education-related travel to be nonessential and advised postponing travel in its guidance for colleges, universities, and students. CDC also published guidance for airlines, cruise ships, and cargo ships to help crew members manage sick travelers onboard when Ebola was suspected.

CDC Contributions and Impact

As CDC's response to the Ebola epidemic ends, travel and border health measures can be reviewed to assess whether they met the stated goals: 1) prevent international spread of disease, 2) educate and protect travelers and communities, and 3) minimize disruption of international travel and trade. These measures fall into four broad categories: 1) risk determination and characterization, 2) risk communication, 3) risk assessment of persons, and 4) risk management on the basis of individual assessment. Although spread of Ebola through air travel is an inherently low-probability event, the consequences of such spread would be high, including potential for disruption of travel and trade to a highly vulnerable region. Thus, any consideration of travel and border health measures must balance public health risk against the perception of such risk by travelers, the travel industry, and government decision makers. These measures demand constant assessment and refinement to adjust to changing epidemic characteristics. When recommending and implementing such measures, CDC aims to protect civil liberties through the use of least restrictive means.

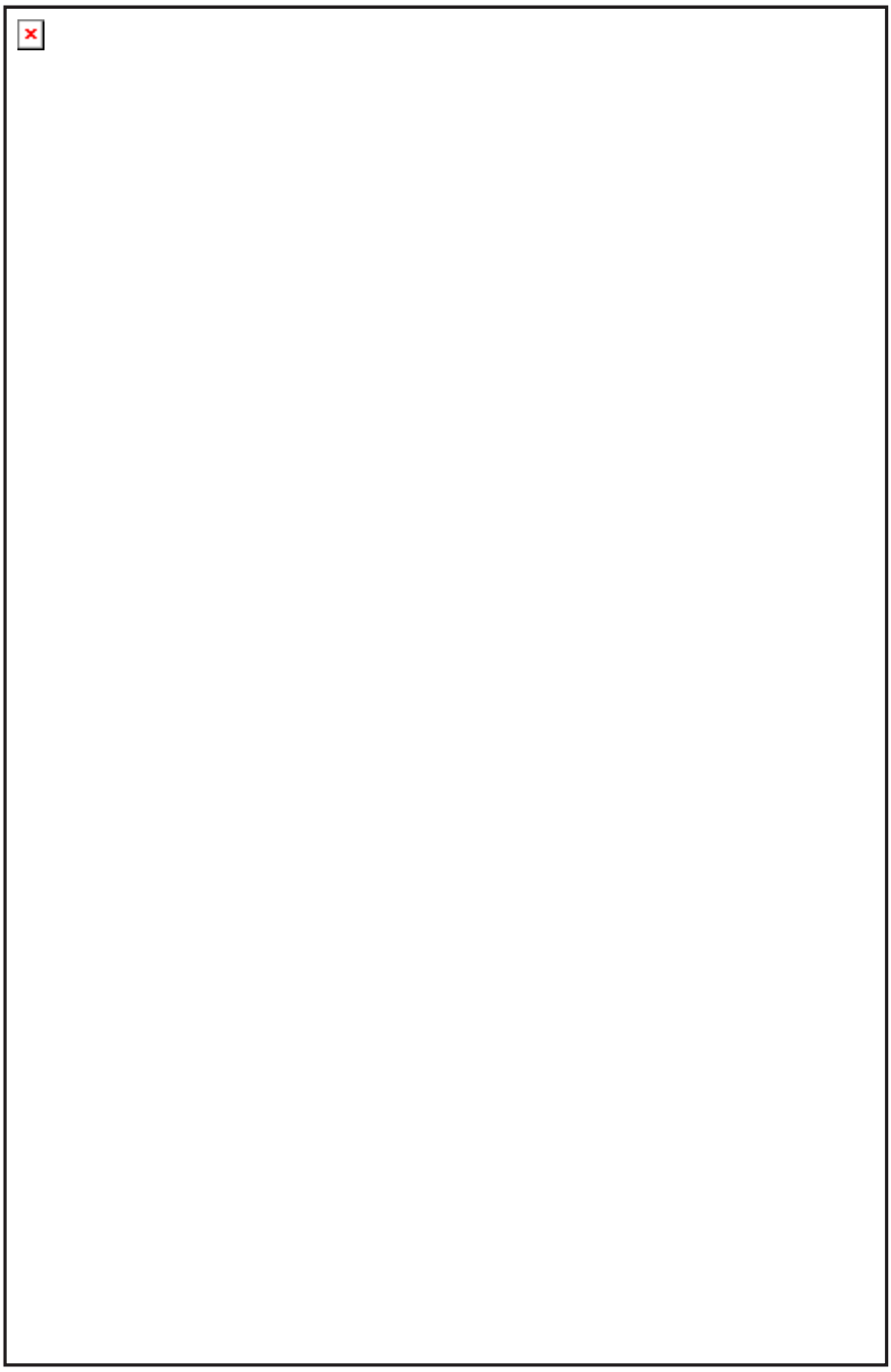
Although WHO declared the end of the Public Health Emergency of International Concern and recommended

FIGURE 2. Example of CDC messages displayed on posters at U.S. airports for travelers going to West Africa during the 2014–2016 Ebola epidemic



Abbreviation: Ebola = Ebola virus disease.

FIGURE 3. Example of CDC messages displayed on posters at airports in Sierra Leone* for departing travelers during the 2014–2016 Ebola epidemic in West Africa



Abbreviation: Ebola = Ebola virus disease.
* Similar posters were displayed in airports in Guinea, Liberia, Mali, Nigeria, and Senegal.

FIGURE 4. Example of information displayed on electronic message boards at U.S. airports for travelers arriving from West Africa during the 2014–2016 Ebola epidemic

Abbreviation: Ebola = Ebola virus disease.

discontinuation of exit screening on March 29, 2016 (*28*), exit screening continued in Guinea, Liberia, and Sierra Leone in response to a cluster of cases in Guinea with limited spread to Liberia. As of June 6, 2016, when this report went to press, no new cases had been reported and exit screening was expected to end shortly. Exit screening successfully addressed vulnerabilities that enabled exportation of Ebola to Nigeria by an actively symptomatic traveler, minimizing the number of exported cases and preventing travel by overtly symptomatic persons (*29*). Separating the effectiveness of exit screening at airports from other public health measures (e.g., identifying and managing cases and exposed persons at the community level or educating travelers) or the deterrent effect of the screening process is difficult. However, these collaborations contributed meaningfully to controlling the epidemic. Exit screening was challenging for the affected countries because resources and staffing needs for these activities competed with other priorities. These difficulties most likely were offset by intangible benefits, including reassurance of airlines and travelers of the continued safety of air travel that no doubt contributed to the willingness of some airlines to maintain flight schedules within the region throughout the epidemic (*11*).

Operationally, the U.S. enhanced entry risk assessment and management program succeeded as a mechanism to assess individual risk, educate travelers, and facilitate postarrival management of travelers including active or direct active monitoring by public health authorities. Funneling of travelers from countries with Ebola outbreaks to selected airports rather than diverting airplanes was substantially less disruptive to the travel industry. The ability to track and monitor travelers in any U.S. state or territory, including their movement among states, resulted in rapid identification and evaluation of approximately 1,400 symptomatic travelers, none of whom had Ebola diagnosed. However, the operation was not without costs (e.g., high resource demands), much of which have been borne by the federal government, as well as the subsequent burden to health departments in the United States and inconvenience to airlines and travelers. The opportunity costs of diverted public health resources must also be taken into account.

The more difficult task of preventing, detecting, and responding to the spread of Ebola across highly porous land borders in West Africa resulted in a multisector collaboration, greater awareness of population movement, enhanced procedures and resources to manage sick travelers in remote border locations, and improved binational and multinational communication and cooperation. Border officials and residents of border communities were trained to recognize sick travelers as sentinel events, contributing to more integrated surveillance and response systems that could help prevent unrecognized cross-border spread during future epidemics. However, much work remains to build and maintain these nascent border health systems as part of the broader public health infrastructure.

Travel and border health measures applied in the countries with Ebola outbreaks, domestically in the United States, and through various communications mechanisms might have averted a breakdown of global interconnectedness that would have damaged the Ebola response and severely disrupted international travel and trade to a highly vulnerable region. A new model was developed that replaced single-point screening at borders with a continuum of measures that started with pretravel information for travelers and ended with monitoring through the end of the potential incubation period. These measures provided an alternative to more stringent options (e.g., travel bans or widespread use of quarantine) and calmed the concerns of political leaders and the public. This experience managing a public health threat from a relatively remote area elevated interagency cooperation at the federal, state, local, and international levels and led to development, revision, and validation of new and old tools that were effective and might prove invaluable in the future.

Conclusion

The Ebola epidemic devastated Guinea, Liberia, and Sierra Leone. However, the reconstruction process presents a unique opportunity to build sustainable public health infrastructure by leveraging resources and systems put in place to combat the epidemic, including helping countries comply with core capacities at designated official points of entry in accordance with the International Health Regulations (2005) (*30*) and developing systematic cross-border communication as part of plans to establish a West African surveillance network. Moving forward, the Global Health Security Agenda (*31*) presents an opportunity to reduce the risk for global spread of disease through migration and travel and to meet the crucial need for enhanced border health security in vulnerable regions of the world. In the United States, new mechanisms for targeted risk assessment and management of travelers can improve the efficiency of border health measures aimed at preventing the introduction and spread of high-consequence communicable diseases into the United States and enhance the public health response to future outbreaks involving travelers.

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Lessons of Risk Communication and Health Promotion — West Africa and United States

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Summary

During the response to the 2014–2016 Ebola virus disease (Ebola) epidemic in West Africa, CDC addressed the disease on two fronts: in the epidemic epicenter of West Africa and at home in the United States. Different needs drove the demand for information in these two regions. The severity of the epidemic was reflected not only in lives lost but also in the amount of fear, misinformation, and stigma that it generated worldwide. CDC helped increase awareness, promoted actions to stop the spread of Ebola, and coordinated CDC communication efforts with multiple international and domestic partners. CDC, with input from partners, vastly increased the number of Ebola communication materials for groups with different needs, levels of health literacy, and cultural preferences. CDC deployed health communicators to West Africa to support ministries of health in developing and disseminating clear, science-based messages and promoting science-based behavioral interventions. Partnerships in West Africa with local radio, television, and cell phone businesses made possible the dissemination of messages appropriate for maximum effect. CDC and its partners communicated evolving science and risk in a culturally appropriate way to motivate persons to adapt their behavior and prevent infection with and spread of Ebola virus. Acknowledging what is and is not known is key to effective risk communication, and CDC worked with partners to integrate health promotion and behavioral and cultural knowledge into the response to increase awareness of the actual risk for Ebola and to promote protective actions and specific steps to stop its spread.

The activities summarized in this report would not have been possible without collaboration with many U.S. and international partners (http://www.cdc.gov/vhf/ebola/outbreaks/2014-west-africa/partners.html).

Background

During an emergency response, communication is often the first activity as responders mobilize (*1*). During the 2014–2016 Ebola virus disease (Ebola) epidemic in West Africa, CDC's response focused on two fronts, the epidemic epicenter in West Africa and at home in the United States. Media coverage and public opinion drove the demand for information in the United States, whereas in West Africa, the need for life-saving information was crucial. The numbers of persons infected and

lives lost, as well as the amount of fear, misinformation, and stigma that Ebola generated worldwide, reflected the severity of the epidemic.

Although CDC has worked with partners to develop and implement communication messages and products for international groups of intended recipients during many other public health emergencies and responses, some difficulties faced in the Ebola response in West Africa were different from those faced during previous, smaller occurrences (e.g., responding to fear of Ebola as it spread for the first time in densely populated urban settings in a region unfamiliar with the disease) (*2*). CDC supported the domestic and international responses by providing timely, customized messages for groups of recipients in West Africa and in the United States so communities could understand how to protect themselves and journalists could report accurate information quickly. CDC needed to depict information differently for each group: more abstractly for those in the United States and more literally for those in West Africa. For example, symptoms of Ebola were illustrated differently for each group (*3*). CDC's communicators worked closely with counterparts in West Africa and in the United States to develop core messages that could be customized for different countries and groups during different phases of the response. Experts in communication, education, anthropology, and behavioral science helped support the ministries of health (MoHs) in the countries in West Africa most affected by Ebola, as well as partners to ensure that communities could obtain the information they needed to protect themselves through multiple channels (e.g., radio, cell phone text messages, posters and billboards, and face-to-face visits).

CDC has supported successful responses to Ebola for almost 40 years, since the first recognized outbreak of Ebola in Zaire in 1976, but those outbreaks occurred in remote areas of East and Central Africa, were small, and usually were contained quickly (*4*). The size and scope of the West African epidemic were unprecedented (*5*). At the start of the response, CDC's communication products were complex and text-based and did not contain much information that persons could act on to protect themselves from getting Ebola (*6*). As media coverage of Ebola, and the spread of the disease itself, expanded, the public's need for information outpaced the ability of public health officials to respond (*7*). When the first case of Ebola was diagnosed in the United States in Dallas, Texas, the U.S. public's resulting fear was disproportionate to the actual risk (*8*). In contrast, in West Africa, lack of understanding that germs spread disease led to belief that Ebola had causes other than a virus (e.g., witchcraft); this lack of understanding initially hindered public health efforts and contributed to the spread of the disease (*9*,*10*). MoHs, CDC, and their partners needed to launch and sustain coordinated communication efforts to address community needs in West Africa; CDC and state and local departments of health and their partners needed a communication approach to address needs in the United States. These efforts involved parallel, but different, approaches on the basis of the different cultures, available communications technologies, and circumstances in West Africa and the United States.

Communicating in West Africa

Before the 2014–2016 Ebola epidemic, Guinea, Liberia, and Sierra Leone did not have the public health infrastructure and corresponding risk communication experience needed for this epidemic. These countries had never experienced a case of Ebola, and the world had never seen an epidemic of this magnitude; collectively, the global public health community lacked experience in how to address this epidemic (*11*,*12*). Differences in governments, cultures, religions, languages, and tribes made having a single communication approach nearly impossible. Adding to these difficulties was a strong tradition of oral communication and a need for clear and literal illustrations that were also culturally appropriate. To be useful, communication materials had to be customized to accommodate different literacy levels, languages and dialects, and beliefs.

The number of languages and dialects spoken in the three countries that were most heavily affected demonstrates one impediment to communicating with West Africa's diverse populations. Guineans speak an estimated 36 languages comprising 59 dialects; Liberians an estimated 31 languages comprising 100 dialects; and Sierra Leoneans an estimated 25 languages comprising 76 dialects (*13*). Each country has an official language that was used for nationwide messaging (English for Liberia and Sierra Leone, French for Guinea), but many West Africans speak the official language as their second or third language (*14*), and literacy levels are among the lowest in the world. Literacy levels among persons aged ≥15 years for Guinea (30.4%), Liberia (47.6%), and Sierra Leone (48.1%) are much lower than the global average (84.0%) and that of the United States (99.0%) (*15*,*16*). Women in the three countries, who are often caregivers for the sick, have much lower literacy rates than men (Guinea: 22.8% for women, 38.1% for men; Liberia: 32.8% for women, 62.4% for men; Sierra Leone: 37.7% for women, 58.7% for men) (*15*). Thus, health communication teams created predominately pictorial communication materials (*3*) and needed to engage with knowledgeable in-country partners to develop appropriate communication messages and materials with little existing communication research about the barriers persons faced,

information on how they were interpreting messages, or the types of attitudes and values that needed to be activated to support behavior change (*17*).

Before this epidemic, Ebola was unknown in West Africa and so did not seem real for many persons until their family members and neighbors died of the disease (*18*). CDC and partners had to address beliefs that Ebola was caused by witchcraft or by something other than a virus; mistrust of outsiders; and cultural practices that contributed to the spread of the virus before responders could effectively implement public health interventions that are known to stop an outbreak (*18*). Instances of disbelief in Ebola, coupled with strong cultural traditions (e.g., caring for the sick at home, seeking care from traditional healers, washing and burying the dead) increased the risk for Ebola transmission (*19*–*21*). Fear, stigma, and superstition also complicated implementation of standard public health practices. Residents hid the sick and fled communities, breaking quarantine, because of social stigma surrounding Ebola; this stigma even extended to survivors who were no longer contagious but were still shunned by their communities. In addition, ill persons avoided Ebola treatment units and ambulances because they feared dying of Ebola, turned to traditional healers to counter what they believed to be witchcraft, and at times defied recommendations from public health authorities because of fear that those authorities were responsible for spreading Ebola through apparent cause and effect (*2*,*22*).

Lack of effective dialogue with communities and lack of public health resources early in the response inflamed public distrust of authorities (*23*) and outsiders. For example, the government of Liberia advised persons with symptoms of Ebola to seek immediate care at hospitals and clinics, but these facilities lacked sufficient numbers of beds and trained staff to care for the rapidly growing number of sick persons (*24*). CDC medical anthropologists supported response teams with rapid field assessments of community perceptions to guide message development and culturally appropriate information delivery (CDC, unpublished data, 2015).

Changing the behaviors that fueled the epidemic required each country to develop its own approach for adapting traditions and promoting protective actions that often ran counter to fundamental beliefs and day-to-day practices. In one example from Liberia, President Ellen Johnson Sirleaf expressed a national goal to have no new cases of Ebola by Christmas 2014. In just 8 days after this announcement, CDC and partners worked with the Liberian Ministry of Health and Social Welfare to rapidly launch a national communication campaign, *Ebola Must GO*, based on specific interventions demonstrated to stop Ebola (*25*). By that time in the response, adequate Ebola treatment unit beds, ambulances, and rapid response teams were available in Liberia, so the campaign focused on protective actions that persons could take until help arrived. The campaign included the message "Stopping Ebola is Everybody's Business" (*25*), which was a twist on a Liberian taboo: *Che-che-polay* (i.e., being a busybody). To address this taboo, this message in the campaign was designed to encourage persons to connect with their neighbors to show caring and to strengthen their community.

In another example from Sierra Leone, in mid-2014 the public was initially inundated with complex information about Ebola transmission (CDC, unpublished data, 2015). Recognizing the need to simplify and coordinate messaging, CDC and partners worked with the Sierra Leone National Ebola Response Centre to launch the *Ebola Big Idea of the Week* campaign on November 10, 2014. Approximately 80 radio, television, and print journalists from across the country were trained by experts on critical communication topics from CDC and other partner organizations. The campaign focused on one culturally sensitive message each week (e.g., practicing safe burials, getting early treatment, supporting survivors to defuse stigma), engaged official and unofficial spokespersons, and used a wide range of available communication channels. This media campaign was extended through October 2015 and complemented numerous social mobilization and community engagement efforts.

In Guinea, coordinated communication strategies addressed cultural differences and focused on identifying trusted local spokespersons and Ebola survivors who could relate to diverse communities. These spokespersons were paired with French-speaking staff members from CDC and partner organizations to convey messages about protective behaviors and the need for changes in established traditions to avoid further spread of disease. Messages were adjusted for a specific community and were provided to trusted community members who in turn conveyed the messages to ensure greater attention and adherence to recommendations (*26*).

All of these activities were conducted in the context of a coordinated global communication effort that included CDC working with in-country partners, such as MoHs, humanitarian aid organizations, and other international partners. This response spanned many countries and numerous stakeholders, each with its own culture, allegiances, way of offering support, and experience in West Africa. Central to the response was collaboration with these partners to deliver coordinated messages and avoid duplication of effort while respecting individuals and communities.

Communicating in the United States

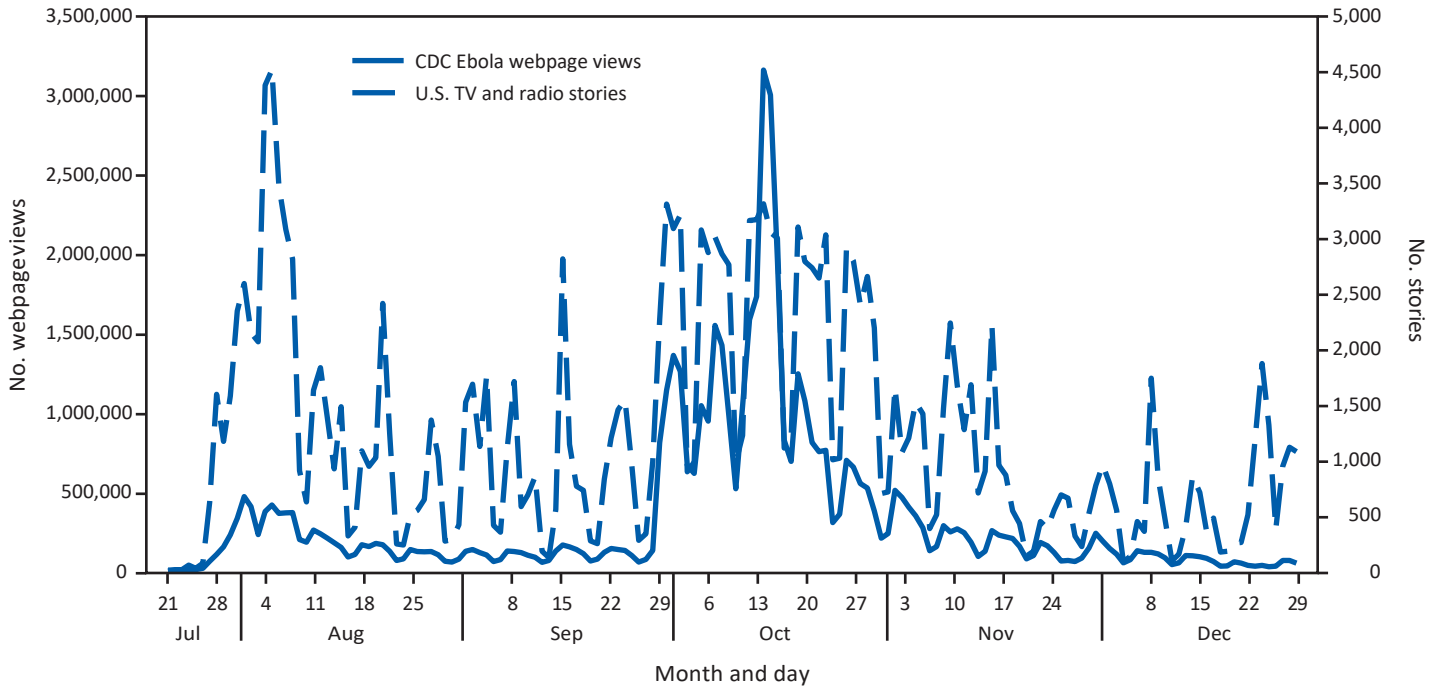
Before the West Africa epidemic, Ebola was perceived in the United States as a distant threat that the media and entertainment industries had dramatized (*27*,*28*). When two infected U.S. clinicians who had worked in Liberia were brought to the United States for treatment in August 2014, some Americans questioned the wisdom of bringing patients with Ebola to the United States; they believed themselves to be at risk for the illness from those patients (*29*), and media reports and traffic to the CDC Ebola website soared (Figure). Around-the-clock news coverage of the escalating Ebola crisis reinforced and heightened public concern to the point of alarm when patients came to the United States (*30*,*31*).

Although the risk for Ebola transmission in the United States was low, the U.S. public began to view the disease as a serious threat to the nation's health and security (*32*). The fear of a U.S. epidemic required a massive communication effort by CDC, larger than for any previous emergency response. To address this fear, messages intended to reassure (e.g., U.S. hospital capacity to manage a case of Ebola) and reduce anxiety increased confusion and mistrust when Ebola developed in two U.S. hospital workers (*33*).

As news of the epidemic in West Africa spread and aid workers returned to the United States, so did fear, and the rumors and stigma that arose from it affected both returning aid workers and persons from Africa living in or visiting the United States (*34*). Many Ebola responders faced hostility upon their return from West Africa; were ostracized by friends, families, and communities; and felt the effects of stigma at work or elsewhere (CDC, unpublished data, October 2015). For example, when some states indicated they would impose mandatory 21-day quarantines for health care workers returning from West Africa, the American Nurses Association urged "authorities to refrain from imposing more restrictive conditions than indicated in CDC guidelines, which will only raise the level of fear and misinformation" (*35*).

An assistant principal was asked to stay home from school for 21 days because she visited South Africa, approximately 5,000 miles away from the epidemic (*36*). In one state, parents would not allow their children to go to school because the principal had attended a funeral in Africa, even though that part of Africa did not have Ebola cases (*37*). In response to fear of Ebola that extended to CDC staff returning from West Africa, CDC and the Georgia Department of Public Health

FIGURE. U.S. news media stories* and CDC Ebola webpage† views, by day — July 21–December 31, 2014§



Sources: National Center for Emerging and Zoonotic Infectious Diseases, CDC (webpage views); MetroMonitor (news media stories).
Abbreviations: Ebola = Ebola virus disease; TV = television.
* TV and radio news that mentioned Ebola.
† Daily number of visits to all CDC webpages related to Ebola.
§ August 4: Second U.S. aid worker with Ebola arrives in United States for treatment. October 1–2: First case of Ebola diagnosed in the United States, in Dallas, Texas; CDC webpage views spike. October 13–15: Ebola diagnosed in two nurses in Dallas; at a news conference, CDC asks airline passengers who flew with one of the nurses to contact CDC; contact tracing begins in Ohio; President Barack Obama vows more aggressive Ebola response.

jointly wrote a guidance letter to Georgia educators (*38*). This letter explained Ebola transmission and reassured Georgia educators about the measures being taken to protect their safety. The letter encouraged Georgia schools to allow children of asymptomatic travelers returning from countries affected by Ebola to continue attending class and encouraged the return to school of faculty or other school workers who had traveled to West Africa and were asymptomatic.

Universities canceled speaking engagements for persons who had recently visited West Africa (*39*). ABC News' chief medical correspondent and former CDC Acting Director Richard Besser, MD, was asked to conduct a talk through Skype, rather than speak in person, at a conference after he returned from Liberia. Dr. Besser said, "The level of risk posed by my appearance was vanishingly small, but fear won anyway. I turned them down. I did not want to feed the idea that anyone who has been to West Africa, even if not sick, poses a risk. You cannot catch Ebola in a lecture hall hearing about the power of communication during a public health crisis. What we need to do is communicate, as strongly and as often as we can, what the real risks are and aren't" (*40*).

During the Ebola response, the media and the public challenged simple health risk messages. The lack of relevant messages about actions the public could take to protect itself led to speculation that resulted in rumors and seeking of cures or other protective measures. For example, in November 2014, news media erroneously reported that CDC quarantined a Texas turkey farm because the turkeys were infected with Ebola (*41*). Other rumors capitalized on the public's fear by promoting cures (e.g., vitamin C) (*42–44*) and selling products marketed as Ebola prevention (e.g., Ebola virus protection kits) (*43,45*). Calls and e-mails flooded CDC; for example, during October 2014, CDC-INFO received 24,827 calls and e-mails compared with 1,801 during September 2014. These inquiries asked whether mosquitoes could spread Ebola; expressed concerns about Ebola virus in products from Africa (e.g., soap, food); and suggested remedies for Ebola (e.g., soda, herbal teas and garlic) (CDC, unpublished data, 2014). CDC continually addressed these rumors with additional communication products and messages that sought to counter fears of Ebola spreading through handshakes, pets, or mosquitoes, for instance, with facts about transmission (*46*).

To outpace the fear-based messages on the news and social media sites and in communities in the United States, CDC and partners worked to educate a wide range of specific groups, including clinicians, school administrators, airport staff, businesses and their employees, West Africans in the United States, and community organizations. The challenge was to balance the communication needs of persons most likely to contact a person with Ebola (health care workers, travelers to outbreak countries) and the anxiety Ebola caused for persons at little or no risk. CDC held Twitter and Facebook chats; produced infographics, fact sheets, videos, public service announcements, podcasts, and guidelines at an unprecedented pace; and handled many interactive public events (e.g., press briefings), interviews, and telephone and e-mail inquiries from the media and the public. CDC engaged with persons and organizations representing West Africans living in the United States through regular conference calls on health protection messages that they were then encouraged to share with family and friends in their home countries. These activities, along with the containment of Ebola cases in Dallas and New York City, corresponded with a decrease in information seeking, as shown by webpage views decreasing despite high media interest (Figure). The response in the United States required intense focus to ease public concern at the same time CDC's human resources were stretched as health communicators, educators, and others deployed to West Africa, sometimes multiple times.

Lessons Learned

For almost 40 years, since the 1976 Ebola outbreak in Zaire, CDC has responded to Ebola outbreaks. However, the 2014–2016 epidemic in West Africa pushed the limits of CDC's knowledge and ability to communicate necessary information, not only in West Africa but also in the United States and globally. Working partnerships with MoHs and other local counterparts in West Africa were essential, as were collaborations with numerous U.S. partners, including many federal, state, and local agencies.

In societies where news outlets need to fill 24 hours every day and social media channels make reporting almost instantaneous, new strategies may be needed in the application of risk communication principles to avoid an information void that, in the absence of a constant flow of clear, science-based messages, becomes filled with speculation (*47*).

Response to this epidemic also required integration of health promotion and anthropology with more traditional public health functions. Anthropologists are experts in cultural knowledge; their role as cultural translators benefitted this public health crisis. Earlier inclusion of anthropologists into the 2014–2016 Ebola response might have facilitated earlier community involvement and insight into factors contributing to resistance to public health interventions (e.g., the need to formally engage traditional leaders and community volunteer groups).

Some of CDC's more memorable campaigns during the response involved engaging groups (e.g., journalists and local leaders in affected communities) as part of the life-saving message development and delivery effort, rather than simply

as receivers of information. Understanding these audiences' perspectives and actively engaging them in finding solutions was critical. Likewise, establishing strong partnerships with other organizations (e.g., those serving West African communities living in the United States) ultimately expanded the reach of public health messaging when broad reach was essential to slowing disease transmission (*19*).

During this response, information about Ebola constantly evolved, and health communication messages and products needed to keep pace. For example, as the response unfolded, new developments in vaccines and therapeutic drugs (*48*) and increasing evidence of viral persistence in body fluids of survivors and of possible sexual transmission (*49*,*50*) required new messages. Responding agencies, such as CDC, need to recognize and acknowledge publicly that a key component of accurate messaging (i.e., scientific knowledge) will evolve during any response.

CDC had to balance rushing critical communication resources to Guinea, Liberia, Mali, Nigeria, and Sierra Leone to help spread life-saving health protection messages with maintaining the resources needed domestically to assuage fears when Ebola was diagnosed in this country. The agency learned that it had to devote sufficient attention and resources to each front, a lesson it must apply in future global epidemic responses. For CDC to adequately support MoHs and partners during large outbreaks, it needs a large enough pool of health communication specialists, health educators, and behavioral scientists who have the training (in incident management systems, plain language communication, risk communication, and cultural competency) and readiness (fluency in local languages, predeployment training, and vaccinations) required to deploy.

Finally, CDC and other response partners must continue to adhere to plain language and clear communication standards, including revising materials to meet the needs of each group of intended recipients. To address the difficulties presented by the specific needs of local populations, CDC must collaborate with partners to build and share a coordinated body of communication-based research, demographic data, and information about how communities in different countries understand and process information.

Conclusion

Communication is an essential part of sustainable preparedness and long-term global health security. The Ebola epidemic demonstrated that tailored, culturally appropriate communication is one of the first activities responders use as new threats emerge, especially when public fear outpaces information that persons can use to protect themselves (*51*). Behavioral and communication sciences also are essential to persuade the public to suspend traditions, entrust their sick family and friends to strangers, and remain in isolation to protect themselves and others, even during critical times such as harvests.

This epidemic increased global knowledge about Ebola and resulted in the need for communication about newly discovered information, particularly related to survivors. New messaging about the possibility of sexual transmission from survivors, family planning, and maternal health is continuously being developed and updated to reflect the latest scientific data and needs to be balanced with reducing stigmatization of survivors. CDC communication developed for this response will continue to provide information for global health security capacity building long after the end of the West Africa Ebola epidemic; going forward, culturally appropriate risk communication and health promotion need to be central to this work.

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Early Identification and Prevention of the Spread of Ebola — United States

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Summary

In response to the 2014–2016 Ebola virus disease (Ebola) epidemic in West Africa, CDC prepared for the potential introduction of Ebola into the United States. The immediate goals were to rapidly identify and isolate any cases of Ebola, prevent transmission, and promote timely treatment of affected patients. CDC's technical expertise and the collaboration of multiple partners in state, local, and municipal public health departments; health care facilities; emergency medical services; and U.S. government agencies were essential to the domestic preparedness and response to the Ebola epidemic and relied on longstanding partnerships. CDC established a comprehensive response that included two new strategies: 1) active monitoring of travelers arriving from countries affected by Ebola and other persons at risk for Ebola and 2) a tiered system of hospital facility preparedness that enabled prioritization of training. CDC rapidly deployed a diagnostic assay for Ebola virus (EBOV) to public health laboratories. Guidance was developed to assist in evaluation of patients possibly infected with EBOV, for appropriate infection control, to support emergency responders, and for handling of infectious waste. CDC rapid response teams were formed to provide assistance within 24 hours to a health care facility managing a patient with Ebola. As a result of the collaborations to rapidly identify, isolate, and manage Ebola patients and the extensive preparations to prevent spread of EBOV, the United States is now better prepared to address the next global infectious disease threat.

The activities summarized in this report would not have been possible without collaboration with many U.S. and international partners (http://www.cdc.gov/vhf/ebola/outbreaks/2014-west-africa/partners.html).

Background

As the epidemic of Ebola virus disease (Ebola) unfolded in West Africa in 2014, CDC prepared for the possible introduction of Ebola into the United States. The immediate objectives were to rapidly identify and isolate any cases of Ebola, prevent transmission of Ebola virus (EBOV), and ensure timely treatment of affected patients within the United States. CDC also sought to inform and prepare partners in the U.S. health care and public health systems.

In summer 2014, the lack of easy access to a diagnostic assay for EBOV complicated preparations for management of a patient with Ebola seeking care at any of the approximately 6,500 urgent-care clinics and 5,000 acute-care hospitals in the 50 states and the U.S. territories. Preparing the U.S. health care

system to handle a rare but often fatal illness for which most clinicians and public health providers had no experience was daunting, particularly given the public's expectation that there should be zero risk that a person who has Ebola could enter the country. Furthermore, providers needed to be educated on how to identify and isolate patients with suspected Ebola in a way that minimized the delay of appropriate medical care for more common and often serious illnesses (e.g., malaria) in travelers from West Africa.

Achieving readiness for the possibility that a person with Ebola could enter the United States required extensive collaboration with state and local public health officials, doctors and nurses in health care settings ranging from small clinics to large hospitals, hospital administrators, emergency responders, federal agencies, and transportation officials. This report describes the U.S. approach to achieving domestic Ebola readiness and response capacity and highlights key successes and unique challenges of the multiple facets of this process.

U.S. Preparations for Possible Importation of Ebola and the Impact of the First Confirmed Case

During summer 2014, while the Ebola epidemic raged approximately 5,000 miles away, CDC used health advisories and conference calls with public health partners and health care professionals to educate providers about Ebola and to encourage vigilance for imported cases of Ebola in the United States. On July 9, 2014, CDC activated its Emergency Operations Center (EOC), enabling a coordinated domestic and international response. Recognizing the need to diagnose Ebola quickly, CDC identified and distributed to state and local public health laboratories a laboratory assay that could reliably detect infection with the EBOV strain circulating in West Africa. CDC contacted the U.S. Department of Defense, which had an assay prepared for Emergency Use Authorization by the Food and Drug Administration, and worked with the Department of Defense and the Association of Public Health Laboratories to rapidly introduce and validate the assay in public health laboratories through the Laboratory Response Network (*1*).

In the early months of the EOC's activation, CDC updated and posted prevention guidance developed for multiple audiences, including hospitals where travelers with suspected exposures to EBOV could seek care, emergency medical service providers, air medical transport operators, aircraft crew and airport personnel, laboratorians handling specimens from patients with suspected Ebola, and mortuary workers (Table 1). U.S. hospitals were considered to be capable of safely managing patients with Ebola (i.e., similar to the domestic experience treating patients with other viral hemorrhagic fevers, such as Marburg and Lassa) if recommendations for isolation of patients, appropriate use of personal protective equipment (PPE), and environmental cleaning and disinfection were followed.

On September 25, 2014, a man who had recently traveled to the United States from Liberia became symptomatic (i.e., fever, headache, and abdominal pain) and sought care at a hospital in Dallas, Texas. His illness was diagnosed as presumed sinusitis (*2*); he was treated and discharged to home (Table 2). On September 28, he was transported by ambulance to the hospital because of persistent fever and progressive symptoms and was hospitalized; on September 30, he became the first patient to have laboratory-confirmed EBOV infection diagnosed in the United States. Health officials from CDC and Texas subsequently identified 48 persons who had contact with him before his isolation at the hospital and began monitoring them for early signs of infection (*3*).

Within 7 days after the patient's death, on October 8, Ebola symptoms developed in two nurses directly involved in his care, and they were confirmed to have Ebola (secondary cases) (*2*). Neither nurse reported an unprotected exposure to infectious blood or body fluids. A total of 147 health care workers who were involved in the care of the index patient or the two secondary cases (regardless of PPE used) were therefore closely monitored for 21 days after their last exposure to an Ebola patient (*3*). Ebola did not develop in any community or health care–related contacts of the three Ebola patients, including the family members with whom the index patient was living before hospitalization. Both nurses subsequently recovered (*2*).

Assisting the U.S. Clinical Community

After diagnosis of the three Ebola cases in Texas, requests for clinical consultation and general guidance from CDC increased, peaking at 227 calls per week in mid-October. The most frequent requests were for assistance in determining whether a patient fit the criteria for a person under investigation,* therefore warranting evaluation for Ebola. In most (75%) situations, the patients had no identifiable risk factors for Ebola (*4*). For these inquiries, CDC typically offered reassurance, confirming that the patient was actually not at risk for Ebola, and encouraged providers to provide timely routine medical care.

* 1) Fever (subjective or temperature ≥100.4°F or ≥38.0°C) or symptoms, including severe headache, fatigue, muscle pain, vomiting, diarrhea, abdominal pain, or unexplained hemorrhage AND 2) epidemiologic risk factors including contact with an Ebola patient or patient's body fluids or travel to a country affected by Ebola within 21 days of symptom onset (http://www.cdc.gov/vhf/ebola/healthcare-us/evaluating-patients/case-definition.html).

TABLE 1. Key CDC guidance documents for use in domestic preparedness and response to the Ebola epidemic in West Africa — United States, 2014–2016

Category	Document
Public health preparedness and response	Case Definition for Ebola Virus Disease (EVD): http://www.cdc.gov/vhf/ebola/healthcare-us/evaluating-patients/case-definition.html
	Interim U.S. Guidance for Monitoring and Movement of Persons with Potential Ebola Virus Exposure: http://www.cdc.gov/vhf/ebola/exposure/monitoring-and-movement-of-persons-with-exposure.html
Hospital preparedness	Preparing for Ebola—a Tiered Approach (includes Preparing Frontline Healthcare Facilities; Preparing Ebola Assessment Hospitals; Preparedness Checklists): http://www.cdc.gov/vhf/ebola/healthcare-us/preparing/index.html
	Infection Prevention and Control Recommendations for Hospitalized Patients Under Investigation (PUIs) for Ebola Virus Disease (EVD) in U.S. Hospitals: http://www.cdc.gov/vhf/ebola/healthcare-us/hospitals/infection-control.html
Clinical guidance	Guidance for U.S. Laboratories for Managing and Testing Routine Clinical Specimens When There Is a Concern About Ebola Virus Disease: http://www.cdc.gov/vhf/ebola/healthcare-us/laboratories/safe-specimen-management.html
	Ebola Virus Disease (EVD) Information for Clinicians in U.S. Healthcare Settings: http://www.cdc.gov/vhf/ebola/healthcare-us/preparing/clinicians.html
	Guidance on Personal Protective Equipment (PPE) to Be Used by Healthcare Workers During Management of Patients with Confirmed Ebola or Persons Under Investigation (PUIs) for Ebola Who Are Clinically Unstable or Have Bleeding, Vomiting, or Diarrhea in U.S. Hospitals, Including Procedures for Donning and Doffing PPE: http://www.cdc.gov/vhf/ebola/healthcare-us/ppe/guidance.html
	For U.S. Healthcare Settings: Donning and Doffing Personal Protective Equipment (PPE) for Evaluating Persons Under Investigation (PUIs) for Ebola Who Are Clinically Stable and Do Not Have Bleeding, Vomiting, or Diarrhea: http://www.cdc.gov/vhf/ebola/healthcare-us/ppe/guidance-clinically-stable-puis.html
	Interim Guidance for Management of Survivors of Ebola Virus Disease in U.S. Healthcare Settings: http://www.cdc.gov/vhf/ebola/healthcare-us/evaluating-patients/guidance-for-management-of-survivors-ebola.html
Laboratory guidance	Guidance for U.S. Laboratories for Managing and Testing Routine Clinical Specimens When There Is a Concern About Ebola Virus Disease: http://www.cdc.gov/vhf/ebola/healthcare-us/laboratories/safe-specimen-management.html
	Collection, Transport, and Submission of Specimens for Ebola Virus Testing: http://www.cdc.gov/vhf/ebola/healthcare-us/laboratories/specimens.html
Infection control and waste management	Interim Guidance for Environmental Infection Control in Hospitals for Ebola Virus: http://www.cdc.gov/vhf/ebola/healthcare-us/cleaning/hospitals.html
	Ebola Waste Management: http://www.cdc.gov/vhf/ebola/healthcare-us/cleaning/waste-management.html
	Procedures for Safe Handling and Management of Ebola-Associated Waste: http://www.cdc.gov/vhf/ebola/healthcare-us/cleaning/handling-waste.html
	Interim Guidance for U.S. Residence Decontamination for Ebola and Removal of Contaminated Waste: http://www.cdc.gov/vhf/ebola/prevention/cleaning-us-homes.html
	Interim Guidance for Ebola Virus Cleaning, Disinfection, and Waste Disposal in Commercial Passenger Aircraft: http://www.cdc.gov/vhf/ebola/prevention/cleaning-commercial-passenger-aircraft.html
	Interim Guidance for Managers and Workers Handling Untreated Sewage from Individuals with Ebola in the United States: http://www.cdc.gov/vhf/ebola/prevention/handling-sewage.html
	Guidance for Safe Handling of Human Remains of Ebola Patients in U.S. Hospitals and Mortuaries: http://www.cdc.gov/vhf/ebola/healthcare-us/hospitals/handling-human-remains.html
	Guidance on Air Medical Transport for Patients with Ebola Virus Disease: http://www.cdc.gov/vhf/ebola/healthcare-us/emergency-services/air-medical-transport.html
	Interim Guidance for Emergency Medical Services Systems and 9-1-1 Public Safety Answering Points for Management of Patients Under Investigation for Ebola Virus Disease in the United States: http://www.cdc.gov/vhf/ebola/healthcare-us/emergency-services/ems-systems.html
Patient transportation	Guidance on Air Medical Transport for Patients with Ebola Virus Disease: http://www.cdc.gov/vhf/ebola/healthcare-us/emergency-services/air-medical-transport.html
	Interim Guidance for Emergency Medical Services Systems and 9-1-1 Public Safety Answering Points for Management of Patients Under Investigation for Ebola Virus Disease in the United States: http://www.cdc.gov/vhf/ebola/healthcare-us/emergency-services/ems-systems.html
	Guidance for Developing a Plan for Interfacility Transport of Persons Under Investigation or Confirmed Patients with Ebola Virus Disease in the United States: http://www.cdc.gov/vhf/ebola/healthcare-us/emergency-services/interfacility-transport.html

Abbreviation: Ebola = Ebola virus disease.

Patients who were isolated and evaluated for suspected Ebola were likely to experience delays in evaluation for and treatment of common but often serious (non-Ebola) illnesses. Basic diagnostic laboratory tests (e.g., complete blood counts, serum chemistries, malaria smears) and radiologic studies were often delayed for >2–3 days while patients were tested for EBOV (*4*). Although rapid identification and isolation (or transfer) of persons with suspected Ebola were important, so was the need to complete diagnostic testing quickly to enable proper management of other potentially life-threatening conditions (e.g., malaria, malignant hypertension, ectopic pregnancy) among persons arriving in the United States from West Africa (*4*).

Several reasons existed for this reluctance — or in some cases, refusal — to run basic diagnostic tests. The most recent (2009) U.S. Department of Health and Human Services (HHS) manual of biosafety (*5*) states that clinical specimens from persons with suspected Ebola should be manipulated only in a biosafety level (BSL)-4 facility, but most clinical laboratories are BSL-2. During the 2014–2016 Ebola epidemic, CDC updated its guidance for handling clinical specimens outside

TABLE 2. Abbreviated timeline of the domestic response to the Ebola epidemic in West Africa — United States, 2014–2016

Date	Event
2014	
July 9	CDC EOC is activated to support Ebola response.
August 2	HCW with Ebola diagnosed in West Africa is admitted to Emory University Hospital in Atlanta, Georgia.
August 7	First version of CDC Interim U.S. Guidance for Monitoring and Movement of Persons with Potential Ebola Virus Exposure posted.
September 20	Businessman from Liberia arrives in Dallas, Texas, after negative fever screening on departure from Liberia and entry into United States.
September 25	After 1 day of symptoms, Liberian businessman seeks care at Texas Health Presbyterian Hospital in Dallas, is treated for presumed sinusitis and discharged.
September 28	Liberian businessman remains ill, is admitted to hospital.
September 30	Ebola diagnosed in Liberian businessman; he becomes first person with Ebola diagnosed in the United States. CDC and Texas health officials begin contact tracing and identify 48 total possible or confirmed contacts of the U.S. index patient before his isolation at the hospital; active monitoring of these contacts begins.
October 8	First person with Ebola diagnosed in the United States dies.
October 11–16	CDC and CBP begin enhanced entry risk assessment and management at five U.S. airports (JFK: October 11; EWR, IAD, ORD, and ATL: October 16) that receive approximately 94% of travelers from Guinea, Liberia, and Sierra Leone.
October 11	A nurse (nurse 1) who provided care for the Ebola patient in Dallas develops fever, seeks care in an emergency department; Ebola is diagnosed.
October 12	CDC and Texas health officials begin active monitoring of household contact of nurse 1. CDC begins active monitoring of 76 hospital workers who treated first patient with Ebola diagnosed in the United States. Active monitoring begins for all 147 HCW contacts of any of the Ebola patients, irrespective of PPE use; monitoring continues until 21 days from their last exposure.
October 14	A second nurse (nurse 2) who provided care for the Ebola patient in Dallas develops fever and is hospitalized. CDC, Texas, and Ohio health officials begin contact tracing of contacts of nurse 2 and active monitoring of three household contacts.
October 15	Ebola is diagnosed in nurse 2, who is transferred to Emory University Hospital in Atlanta. CDC notifies a domestic airline that a passenger (nurse 2) who traveled from Cleveland, Ohio, to Dallas on October 13 tested positive for EBOV.
October 16	Nurse 1 is transferred from Texas Health Presbyterian Hospital to the National Institutes of Health hospital in Bethesda, Maryland.
October 19	CDC REP teams begin visits to U.S. hospitals to provide technical assistance.
October 20	CDC revises guidance on PPE for U.S. HCWs caring for Ebola patients.
October 21	CBP announces that all travelers from Guinea, Liberia, and Sierra Leone will be routed to one of five participating U.S. airports for enhanced entry risk assessment and management.
October 23	New York City Department of Health and Mental Hygiene diagnoses Ebola in an HCW (HCW 1) who had returned to New York City from Guinea; patient is isolated at Bellevue Hospital.
October 24	CDC and New York City health officials begin contact tracing of HCW 1's contacts before isolation at the hospital. An asymptomatic HCW (HCW 2) who returned to the United States after treating patients in Sierra Leone is isolated by New Jersey officials at a nearby hospital.
October 27	CDC issues revised Interim U.S. Guidance for Monitoring and Movement of Persons with Potential Ebola Virus Exposure. Active postarrival monitoring begins for travelers from Guinea, Liberia, and Sierra Leone. HCW 2 is released from quarantine and drives from New Jersey to Maine.
October 28	Nurse 2 is discharged from Emory hospital after being declared Ebola virus free.
October 29	Monitoring is completed for 47 of 48 initial contacts of Dallas index patient.
October 30	Maine judge issues a 1-day court-ordered restriction of HCW 2's movements.
October 31	Active monitoring is completed for passengers and crew on October 10 airline flight (Dallas to Cleveland) on which nurse 2 traveled.
November 3	HCW 2 agrees to daily monitoring by Maine state health department. Active monitoring is completed for passengers and crew on October 13 airline flight (Cleveland to Dallas) on which nurse 2 traveled.
November 7	Active monitoring is completed for all 177 contacts of Ebola patient in Dallas and nurses 1 and 2 (some persons were contacts of more than one patient) after completing 21 days of monitoring; Ebola did not develop in any contacts.
November 10	Active monitoring of HCW 2 is discontinued.
November 11	HCW 1 is discharged from Bellevue Hospital in New York City.
November 17	Travelers from Mali are routed to one of five U.S. airports for enhanced entry risk assessment and management.
December 2	Guidance is released for tiered approach to health care facility preparedness.
2015	
May 9	WHO declares end of the Ebola epidemic in Liberia.
June 29	New cases of Ebola are reported in Liberia.
September 3	WHO declares Liberia free of EBOV transmission for the second time.
November 7	WHO declares Sierra Leone free of EBOV transmission.
November 19	New cases of Ebola are reported in Liberia.
December 29	WHO declares Guinea free of EBOV transmission.
2016	
January 14	WHO declares Liberia free of EBOV transmission for the third time.
February 19	U.S. government discontinues enhanced entry screening procedures and airline routing for Ebola. CDC retires the Interim U.S. Guidance for Monitoring and Movement of Persons with Potential Ebola Virus Exposure.
March 17	New cases of Ebola are reported in Guinea.
April 1–4	New cases of Ebola are reported in Liberia.

Abbreviations: ATL = Hartsfield–Jackson Atlanta International Airport; CBP = Customs and Border Protection, U.S. Department of Homeland Security; Ebola = Ebola virus disease; EBOV = Ebola virus; EOC = Emergency Operations Center; EWR = Newark Liberty International Airport; HCW = health care worker; IAD = Washington Dulles International Airport; JFK = John F. Kennedy International Airport (New York City); ORD = Chicago O'Hare International Airport; PPE = personal protective equipment; REP = Rapid Ebola Preparedness; WHO = World Health Organization.

of a BSL-4 facility, but many laboratories considered the longstanding BSL-4 recommendation more appropriate. Also, clinical laboratories were concerned about the risk for aerosolization from instruments in highly automated clinical laboratories. Although CDC, and later other laboratories, provided guidance on conducting routine clinical laboratory tests using biosafety cabinets and point-of-care instruments (Table 1), many laboratories were not able to put these specialized systems in place.

CDC collaborated with other U.S. government partners, researchers, and manufacturers of medical countermeasures to assist health care providers with clinical management of Ebola patients in the United States. In early August 2014, Emory University Hospital (Atlanta, Georgia) hospitalized and treated the first Ebola patient medically evacuated to the United States (Table 2). During August 2014–March 2015, seven persons (six health care personnel and one journalist) who had Ebola diagnosed in West Africa were transported to the United States for clinical management; one died. These were in addition to two cases of Ebola diagnosed among persons traveling to the United States from countries affected by Ebola (the Dallas traveler and a health care worker who returned to New York City after working in Guinea) and the secondary EBOV infections in two nurses in Dallas (*2*,*6*). Extensive information sharing among clinicians managing these patients at the three specialized U.S. treatment centers,[†] Bellevue Hospital in New York City, Texas Health Presbyterian Hospital in Dallas, and hospitals in Europe contributed to substantial progress in understanding the clinical spectrum, complications, virology, and clinical management of Ebola, as well as the use of postexposure prophylaxis and medical countermeasures (*2*,*7*–*11*).

CDC's outreach to clinicians included 1) directly assisting clinicians managing Ebola patients and Ebola survivors in the United States and sharing updated information with the general clinical community, including U.S. personnel deployed to the Monrovia Medical Unit in Liberia (*12*–*15*); 2) assisting with coordination of medical evacuations of Ebola patients who were U.S. citizens or legal permanent residents from West Africa to the specialized U.S. treatment centers (*7*–*9*); 3) working with clinical and federal partners to further the development of investigational therapeutic drugs for Ebola patients; and 4) coordinating information sharing among clinicians managing Ebola patients in the United States and Europe (*16*).

[†] Specialized treatment centers: Emory University Serious Communicable Diseases Unit, Atlanta, Georgia; the National Institutes of Health Clinical Center, Bethesda, Maryland; and the University of Nebraska Biocontainment Unit, Omaha, Nebraska.

Ensuring Early Identification by Tracking Travelers and Tracking Contacts of Persons with Confirmed Ebola

During October 11–16, 2014, shortly after the patient from Liberia died, staff with CDC and the U.S. Department of Homeland Security's Customs and Border Protection (CBP) began enhanced entry risk assessment and management at five U.S. airports that received approximately 94% of travelers from Guinea, Liberia, and Sierra Leone (*17*). This enhanced assessment followed growing concern that traveler self-monitoring might be insufficient to rapidly identify potential cases of Ebola (*6*). After travelers from countries affected by Ebola were screened for symptoms of Ebola and assigned an assessment of their personal risk, the responsibility for monitoring asymptomatic travelers for whom exposure to EBOV could not be ruled out and who were still in the 21-day incubation period was transferred from CDC to state and local public health partners. On October 21, 2014, CBP announced that all travelers from countries affected by Ebola were to be routed to one of five participating U.S. airports, enabling a standard approach to enhanced entry risk assessment of travelers and rendering the program more manageable.

CDC's *Interim U.S. Guidance for Monitoring and Movement of Persons with Potential Ebola Virus Exposure*, initially issued in August 2014 and revised October 27,[§] recommended that state, local, and territorial health agencies actively contact persons with specific risk factors for Ebola daily for the 21-day incubation period to assess them for symptoms and fever (*18*). Persons at low risk for Ebola (e.g., travelers from countries affected by Ebola without a known exposure) were asked to monitor their temperature twice a day, self-evaluate symptoms, and report daily to the designated health agency (active monitoring). Persons at high risk for exposure to EBOV (e.g., persons in contact with blood or other body fluids of known Ebola patients without proper PPE; health care workers who cared for patients even while using appropriate PPE) were to be under direct active monitoring; public health agencies conducted direct active monitoring for fever and symptoms twice daily, including direct observation by a public health official at least once a day. Each state and territory developed a plan to 1) monitor persons with possible EBOV exposure and locate those lost to follow-up and manage those who were noncompliant; 2) establish a 24/7 telephone number

[§] Initial movement and monitoring guidance was posted on August 22, 2014; the guidance was reviewed and revised as needed throughout the response; the most recent guidance is available at http://www.cdc.gov/vhf/ebola/exposure/monitoring-and-movement-of-persons-with-exposure.html.

for persons with symptoms to call; 3) establish and practice systems (e.g., emergency medical services [EMS]) to ensure the safe transport of ill persons to a health care facility; and 4) identify the hospital to which a person would be referred should he or she become ill and ensure that the receiving health care facility was prepared at minimum to evaluate, isolate, and test (including collecting and shipping specimens) for Ebola.

Active monitoring of returning travelers and of health care providers and contacts of Ebola patients managed in the United States was a novel strategy introduced to facilitate early detection of new cases in the setting of no or minimal U.S. domestic transmission. Within 7 days after issuance of the revised CDC guidance in October 2014, all 50 states and two local jurisdictions were effectively monitoring travelers arriving from countries affected by Ebola and health care workers caring for Ebola patients in the United States (*19*). Approximately 29,000 persons were monitored from October 2014 through December 2015.

Nationwide implementation of this active monitoring system brought many challenges. Additional resources were needed to rapidly establish and staff 24/7 call numbers and to develop plans for effective daily observation of each person under direct active monitoring (including those living in remote places) (*17*). CDC awarded $145 million of supplemental Ebola funds to support the resulting substantial increase in staffing needs. Monitoring travelers moving across state lines required coordination among state health departments. Health departments and CDC were expected to achieve 100% accountability for all travelers; several health departments creatively used social media and police missing person units to find persons lost to follow-up. Also, a number of states elected to implement much more restrictive policies than recommended by CDC, resulting in inconsistencies among state-specific policies (*6*). Several states used existing laws requiring monitoring, with legal penalties for those not in compliance. For example, a nurse returning from treating patients in Sierra Leone (and asymptomatic) was quarantined in a New Jersey hospital for nearly 3 days (Table 2). Although the average rate of successful active monitoring reached approximately 99% by early March 2015 (*19*), this approach detected no new confirmed Ebola cases. Throughout this process, CDC maintained regular and frequent contact with partners to build a closer and better integrated response among federal, state, and local public health officials. During the height of the response, some federal public health partners embedded staff within CDC and the EOC.

On February 19, 2016, when more than 45 days had passed since Guinea was declared free of EBOV transmission and widespread human-to-human transmission was at an end, the interim guidance was retired. CDC will consider the need for similar guidance during future outbreaks on the basis of the situation, taking into account the extent of the outbreak and the risk of importation and spread of disease into the United States (*18*).

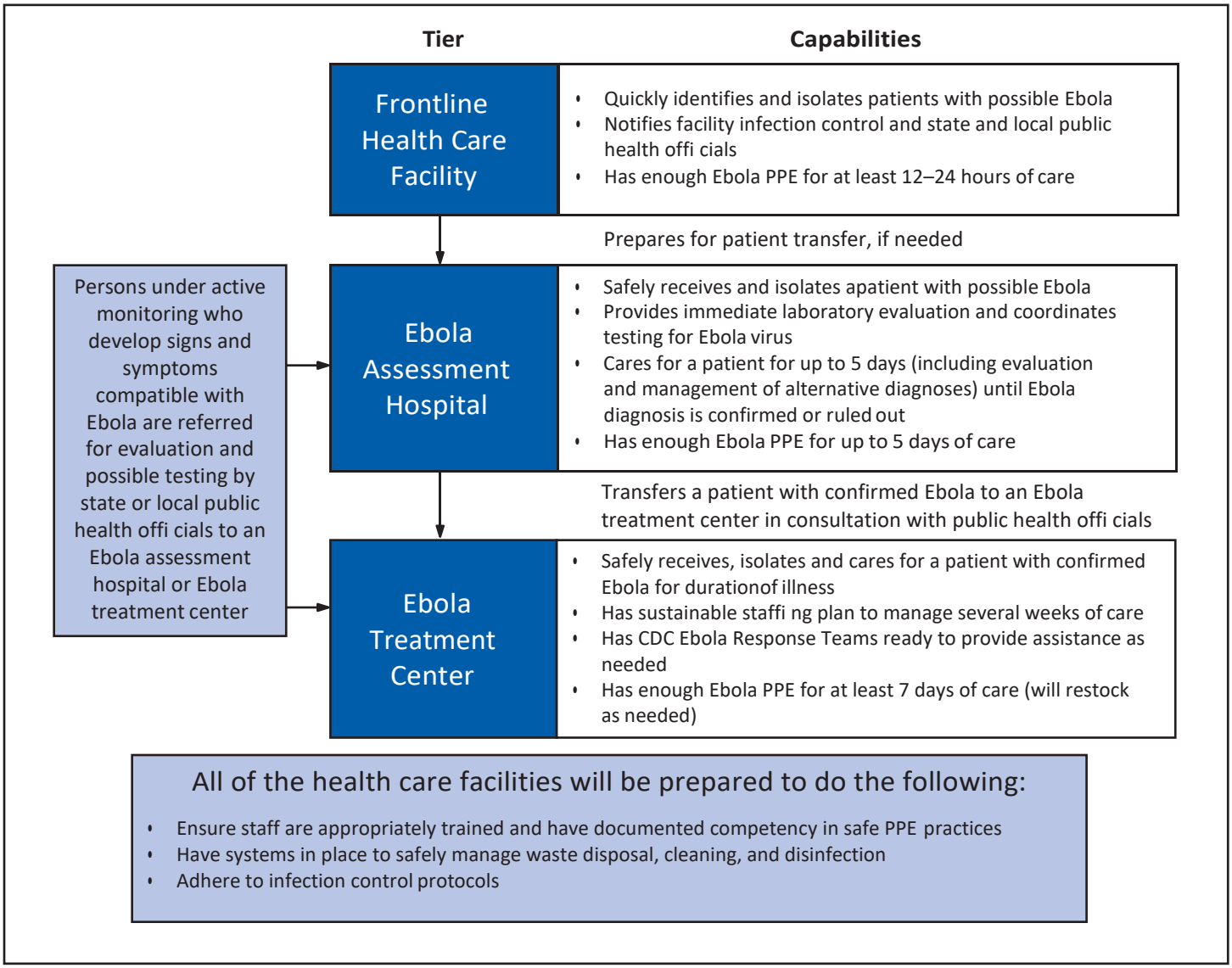
A Tiered Approach to Hospital Readiness

During the early phase of the epidemic in West Africa, any U.S. facility with trained staff, isolation room capacity, and appropriate supplies and equipment was considered capable of caring for a patient with Ebola. However, because of the complexity of care and strict attention to infection control (*20*) required for safe treatment of Ebola patients, highlighted by secondary EBOV transmission to the two nurses in Texas, CDC determined that ensuring adequately trained staff, availability of designated space, and adequate specialized PPE might not be possible in all inpatient facilities throughout the entire U.S. health care system. This level of preparation was critical for facilities most likely to receive patients for evaluation of Ebola. Also, the likelihood of a person with possible Ebola seeking care in an emergency department or hospital was not equally distributed among all hospitals in the United States for several reasons. Many travelers from West Africa lived in or visited specific regions of the country, travelers who were symptomatic on arrival to the United States were directed to specific hospitals near one of the five airports, and all persons under active monitoring by state public health officials could be directed to a particular hospital for evaluation if they developed symptoms during their monitoring period.

CDC and the HHS Office of the Assistant Secretary for Preparedness and Response (ASPR) developed a three-tiered approach to prepare U.S. acute health care facilities to safely and rapidly identify, isolate, evaluate, manage, and transfer (if needed) persons under investigation or patients with confirmed Ebola (*21*). The three tiers were frontline health care facilities, Ebola assessment hospitals, and Ebola treatment centers (Figure). CDC aimed to establish a limited number of Ebola treatment centers strategically in regions of the United States most likely to identify a person with Ebola.

Difficulties initially encountered included the few facilities with personnel trained to provide the complex care needed by Ebola patients, the limited number of facilities capable of managing children with Ebola, and a hesitancy of some facilities capable of providing care to Ebola patients to be identified publicly or to accept patients from other states. In addition, not all health care workers were trained in or familiar with using the specialized PPE recommended for care of Ebola patients. Some facilities struggled to identify dedicated space that was appropriately configured for Ebola management, and many

FIGURE. Tiered approach for U.S. hospital and health care facility* preparedness for Ebola



Source: CDC; available at http://www.cdc.gov/vhf/ebola/healthcare-us/preparing/hospitals.html.
Abbreviations: Ebola = Ebola virus disease; PPE = personal protective equipment.
* Ebola treatment center includes regional treatment centers for Ebola and other special pathogens.

facilities had substantial problems acquiring sufficient quantities and types of PPE (e.g., an Ebola treatment center should have a 5-day supply of PPE for a team of six nurses, three doctors, two laboratory technicians, two observers, and one environmental specialist for one to three shifts per day, depending on the health care worker's role). Initially, PPE was ordered by facilities in high volumes with little strategic guidance, resulting in substantial delays in filling of orders and national shortages for some items. Manufacturers and distributors struggled to determine how much to increase production and how to prioritize orders and allocate limited resources.

CDC and ASPR, in collaboration with state and local public health authorities, produced detailed guidance for outpatient and inpatient facilities about managing persons under investigation and persons with confirmed Ebola (Table 1). Hospital Preparedness Program funding (22) was provided to states and eligible municipalities to improve surge capacity, including building needed infrastructure within health care systems, retrofitting hospitals to establish safe places to treat patients with Ebola, and reimbursement of care costs for confirmed Ebola patients. CDC also assembled Rapid Ebola Preparedness (REP) teams to assess infection control readiness

of facilities interested in serving as Ebola treatment centers and provided on-site technical assistance regarding staffing, improvement in infection control, worker safety, laboratory processes, diagnostics, waste management, and other key areas. Initially, the REP teams provided direct technical assistance to hospitals near airports with a large number of persons traveling from countries that had widespread EBOV transmission and in communities where these travelers or large numbers of persons from West African countries reside. Beginning in October 2014, REP teams traveled to approximately 80 U.S. hospitals to provide technical support.

During October–December 2014, after extensive preparations, 55 hospital facilities were designated Ebola treatment centers by state health officers in collaboration with hospital administrators. These facilities received direct CDC and HHS technical assistance and formulated comprehensive plans outlining policies and procedures for managing patients with confirmed Ebola, which included training staff and instituting infection control measures, acquiring equipment and PPE, creating plans for managing waste, and designating appropriate space to treat Ebola patients. By August 2015, 92% of persons being monitored were within 200 miles of an Ebola treatment center and within 50 miles of an assessment hospital.

CDC's Ebola Response Teams

To improve the response capacity to EBOV infections in the United States, CDC established teams capable of rapidly providing on-site assistance to any health care facility treating a confirmed or probable case of Ebola. These CDC Ebola response teams could be immediately deployed to provide technical assistance for infection control procedures, clinical care, logistics of managing a patient with Ebola, contact tracing, and media relations (*23*).

Emergency Medical Services

Success of the three-tiered health care system plan rested on safe and rapid transport of a person under investigation or patient with confirmed Ebola to a designated facility to be evaluated or treated. EMS responders faced multiple challenges, such as the potential to enter uncontrolled environments including homes and public areas with little or no information about the patient's risk factors and the need to transport patients over long distances during which the patient's condition could worsen. Lack of experience with Ebola and limited access to appropriate PPE encountered early in the U.S. response compounded these challenges.

CDC collaborated with federal partners to rapidly develop guidance for EMS systems and 9-1-1 public safety answering points for managing persons under investigation or patients with confirmed Ebola (Table 1). CDC also hosted conference calls to provide a forum for EMS providers from Emory University Hospital and the University of Nebraska Medical Center to share their experiences transporting Ebola patients. Further guidance addressing the complexities of interfacility and interstate transport of persons under investigation and patients with confirmed Ebola was developed in collaboration with ASPR and the U.S. Department of Transportation (DOT), National Highway Traffic Safety Administration (Table 1).

Environmental and Waste Management

All levels of health care facilities and EMS providers needed plans for the transport and disposal of waste generated by either persons under investigation or persons with confirmed Ebola. Fear, public perception, and the regulatory framework around handling Ebola-associated wastes proved to be common issues. These issues were encountered in health care facilities, patients' homes, businesses that the patients frequented early in their disease, and a commercial passenger aircraft on which one patient flew while ill.

Although EBOV is susceptible to both physical and chemical inactivation, it is classified as a category A infectious substance[¶] because of its associated high mortality rate. Therefore, items that are or might be contaminated must be treated onsite or packaged and transported to a hazardous waste or medical waste treatment site by a carrier with a special DOT permit. Once treated, the waste is no longer infectious and can be managed in accordance with state and local regulations regarding solid wastes. Unforeseen was the volume of waste generated, most of which was used PPE, and the packaging required for the waste because the packaging used was too large for the doors of most incinerators.

During the Ebola response, CDC collaborated with federal and state agencies and multiple other private and nongovernmental organizations to develop guidance for cleaning and disinfection applicable to various settings that included patient residences, commercial passenger and medical transport aircraft, ambulances, and health care facilities. Other guidance covered handling of medical, laboratory, liquid, and other wastes and the protection of waste handlers and sewage and wastewater workers from contact with untreated human wastes (Table 1).

[¶] DOT Hazardous Materials Regulations (HMR, 49 CFR, Parts 171-180); Ebola virus is classified as a category A infectious substance by the DOT and the United Nations. Category A refers to an infectious substance in a form capable of causing permanent disability or life-threatening or fatal disease in otherwise healthy humans or animals.

Conclusion

Coordination of preparedness efforts among CDC and state and local public health entities, health care organizations, and other HHS partners, the product of longstanding partnerships, was central to the rapid implementation of a comprehensive U.S. domestic response. The United States quickly deployed laboratory testing for EBOV. The closely integrated system of U.S. border entry risk assessment and postarrival monitoring was pivotal to reducing public concern and facilitating active, timely management of symptomatic travelers. Vulnerabilities in infection control capacity exposed during the early outbreak response resulted in ongoing intensive efforts for improvements at the national, state, and local levels. The importance of support functions (e.g., waste management, laboratory testing, and EMS), which are needed to successfully care for patients with a complex, unfamiliar, and often fatal disease such as Ebola, have been underscored. The tiered approach to health care preparedness for Ebola highlighted the critical functions needed at each level and made possible the prioritization of training and other interventions. This tiered approach is likely to be transferable to the next public health response to future threats; nine regional treatment centers designated by HHS to become special regional treatment centers for patients with Ebola have enhanced capabilities that can be used to treat patients with other severe, highly infectious diseases. The United States is now better prepared and continues to work to strengthen and support rapid and successful responses to the next infectious disease threat.

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Modeling in Real Time During the Ebola Response

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Summary

To aid decision-making during CDC's response to the 2014–2016 Ebola virus disease (Ebola) epidemic in West Africa, CDC activated a Modeling Task Force to generate estimates on various topics related to the response in West Africa and the risk for importation of cases into the United States. Analysis of eight Ebola response modeling projects conducted during August 2014–July 2015 provided insight into the types of questions addressed by modeling, the impact of the estimates generated, and the difficulties encountered during the modeling. This time frame was selected to cover the three phases of the West African epidemic curve. Questions posed to the Modeling Task Force changed as the epidemic progressed. Initially, the task force was asked to estimate the number of cases that might occur if no interventions were implemented compared with cases that might occur if interventions were implemented; however, at the peak of the epidemic, the focus shifted to estimating resource needs for Ebola treatment units. Then, as the epidemic decelerated, requests for modeling changed to generating estimates of the potential number of sexually transmitted Ebola cases. Modeling to provide information for decision-making during the CDC Ebola response involved limited data, a short turnaround time, and difficulty communicating the modeling process, including assumptions and interpretation of results. Despite these challenges, modeling yielded estimates and projections that public health officials used to make key decisions regarding response strategy and resources required. The impact of modeling during the Ebola response demonstrates the usefulness of modeling in future responses, particularly in the early stages and when data are scarce. Future modeling can be enhanced by planning ahead for data needs and data sharing, and by open communication among modelers, scientists, and others to ensure that modeling and its limitations are more clearly understood.

The activities summarized in this report would not have been possible without collaboration with many U.S. and international partners (http://www.cdc.gov/vhf/ebola/outbreaks/2014-west-africa/partners.html).

Background

During CDC's response to the 2014–2016 Ebola virus disease (Ebola) epidemic in West Africa, U.S. and international public health decision-makers and stakeholders needed information early in the epidemic. This information included the number of Ebola cases that could be expected over time; the resources and personnel needed to respond adequately; and the impact of interventions, such as Ebola treatment units

(ETUs), community care centers (CCCs), and safe burials. On August 4, 2014, CDC activated a Modeling* Task Force (CDC Modeling) and incorporated the task force into its incident management structure.

Models were used at the outset of the Ebola response in early September 2014 to estimate the impact of the epidemic with and without intervention. These models indicated not only that public health agencies had the means to stop the epidemic by using existing tools and strategies but also that the international community needed to act quickly with sufficient resources to stop the spread of the epidemic. The simple models (*1*–*3*) used by CDC Modeling enabled decisions to be made quickly during the response. This report summarizes 1) CDC Modeling's role, accomplishments, and impact; 2) key issues, challenges, and lessons learned; and 3) suggestions for modeling in future responses.

Personnel conducting this assessment comprised both CDC Modeling staff and other CDC staff. All documents produced by CDC Modeling during August 4, 2014–July 13, 2015, were assessed: five publications, approximately 40 internal memoranda that included multiple versions documenting the modeling process, 1,000 technical consulting e-mails, and 30 presentations, as well as numerous meeting notes. In-depth after-action discussions with CDC Modeling staff aided understanding of how models were developed and used in the response, the difficulties encountered, and the impact of the models on decision making. Other assessments were the amount and type of data used (data requirements), how readily data were available, and the time available before response leadership needed preliminary results (turnaround time). Within the context of CDC's Ebola response, "impact" referred to the use of models to provide information for the response and make decisions. Models associated with major projects that resulted in a publication, written report, or internal memorandum were categorized into 1 of 3 phases of the West African epidemic curve: 1) start and incidence acceleration, 2) peak and incidence deceleration, and 3) final phase and extinguishing (Figure). Eight reviewed projects resulted in either a publication or an internal, predecisional memorandum.

* For practical purposes, modeling is divided into two broad categories: statistical modeling and mathematical modeling. Statistical modeling is used when analysts have all, or almost all, the data from a given population, in an identified time step and locale, needed to analyze potential differences over time, between subgroups, or both. For this modeling, analysts use accepted means of statistically testing hypotheses, such as the *t* test or regression statistical models. Usual results include causality between variables. Mathematical modeling is used when not all the data are available to answer a given question. Analysts then either use data collected from different populations, often at different points in time and locales, or make assumptions based on expert opinion. Using these "islands of data," analysts then construct a series of equations or simulations that describes the situation (e.g., disease transmission, logistics, or interventions). Usual results include possible decisions that could mitigate or improve a situation.

CDC Role, Accomplishments, and Impact

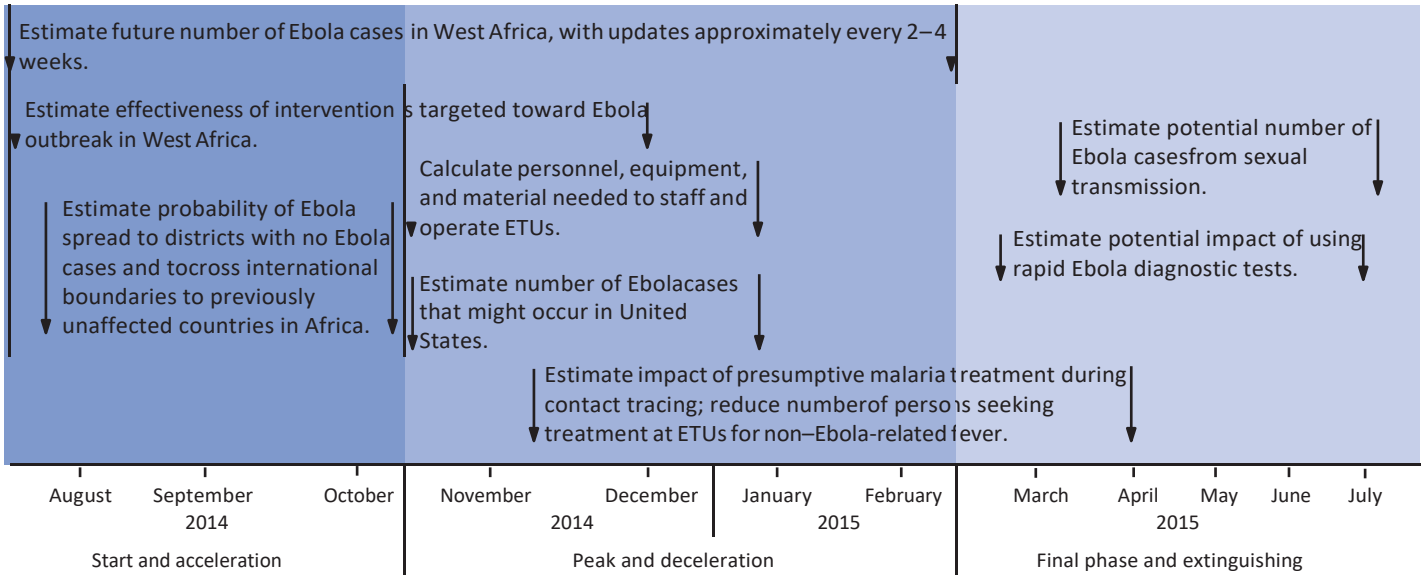
Start and Acceleration

Initial modeling questions concerned resource needs and thus predicted the number of Ebola cases that could be expected over time with and without isolation, treatment, and safe burials. These estimates enabled CDC Modeling to evaluate the impact that interventions, such as ETUs, CCCs, and safe burials, could have on the epidemic. On the basis of these questions and the knowledge available at the time about virus characteristics and transmission, CDC Modeling developed a simple Microsoft Excel spreadsheet–based model called EbolaResponse (*4*). This model included input values that could be easily changed (e.g., the number of Ebola patients placed in ETUs) and thus, could estimate potential outcomes if the disease remained unchecked and assess the relative impact of interventions. Because data from the field were limited, CDC Modeling calculated a correction factor for underreporting (*4*). In late August 2014, the correction for underreporting was estimated to be approximately 2.5; in other words, the true case count was 2.5 times greater than the reported case count.

By using data available through late August 2014, CDC Modeling estimated that 550,000 total reported Ebola cases could occur in Liberia and Sierra Leone (1.4 million when corrected for underreporting) by January 20, 2015, if no additional interventions or behavior changes occurred and if current parameters continued without change (*4*). Conversely, CDC Modeling predicted that transmission would decline substantially by mid-January 2015 if approximately 70% of Ebola patients were placed into ETUs or CCCs (or an equivalent) and if safe burials were conducted when needed. If this 70% goal could be reached, it would "bend the curve," causing transmission to drop off substantially. If a large-scale response was delayed, the projected number of cases at the epidemic's peak most likely would more than double and thus require more resources to control (*4*).

Initial estimates from EbolaResponse were published in September 2014 (*4*), with scenarios predicting that each month of delayed response would cause approximately 3.1 times more cases. Perhaps the most important message contained in the report was that public health agencies and the international community needed to act quickly with sufficient resources to stop the epidemic. On the basis of this information and other factors, including the United Nations Ebola virus disease outbreak overview of needs and requirements document (*5*), CDC leadership and U.S. government officials recommended a rapid increase in aid for the Ebola response. International donors provided approximately U.S. $154.6 million to support Ebola response activities in West Africa, including approximately $71 million from the United States (*5*). By March 2015, 10 countries had supplied approximately U.S.

FIGURE. Timeline* of CDC Modeling Task Force projects for decision making in response to the Ebola epidemic in West Africa — August 2014–July 2015



Abbreviations: Ebola = Ebola virus disease; ETUs = Ebola treatment units.
* Arrows indicate approximate start and completion dates of projects.

$2.2 billion in aid, with the United States providing approximately $1.05 billion of that amount (*6*). Later analyses demonstrated how the increase in resources helped to ensure that the actual number of cases was far less than if prompt action had not been taken (*7*).

In another modeling project, CDC Modeling analyzed the regional spread of Ebola in West Africa. CDC Modeling used geographic information systems software and various regression models to identify factors that could be used to calculate the probability of individual areas becoming affected next (*8*) and helped to provide data to decision-makers about allocating resources for surveillance, especially in the countries surrounding Guinea, Liberia, and Sierra Leone.

CDC also needed data on the staff, equipment, and materials required to operate a typical ETU. CDC Modeling helped conduct a cost analysis to determine the budget needed to start up and run up to 1,000 ETU beds for 6 months, using the cost per bed from an interagency partner and publicly available data. CDC used this information internally to help guide resource allocation decisions.

Another study estimated the impact of ETUs and CCCs on Ebola transmission (*7*). Results suggested that during September 23–October 31, 2014, hospitalizing approximately 20% of all Ebola patients in ETUs prevented an estimated 2,244 cases. In addition, placing 35% of patients in CCCs or equivalent community settings that prevent transmission through reduced contact with patients, coupled with the use of safe burials, prevented an estimated 4,487 cases. Together, these interventions prevented an estimated 9,097 cases (*7*). The findings of this analysis provided evidence that interventions were working.

In September 2014, CDC Modeling began producing weekly predecisional memoranda for internal CDC use only, which provided estimates of the number of active cases (e.g., persons with Ebola and in need of a bed, either in an ETU or CCC) based on updated case counts from the field. These weekly updates provided senior leadership with situational awareness about the epidemic as it evolved. As data and case reporting improved through November 2014–March 2015, the need for projections to support decision making declined. However, projections indicated that the situation could change quickly and bolstered the need for public health agencies to avoid becoming complacent (*4*) (CDC, unpublished data, 2014).

Peak and Deceleration

As the epidemic progressed, public health officials developed plans to increase ETU capacities and developed methods to isolate patients in non-ETU settings to disrupt Ebola transmission (*5*,*6*). Senior U.S. leadership authorized personnel, funds, and supplies to help control the Ebola epidemic (*5*,*6*). Various philanthropic organizations and the U.S. Public Health Service agreed to operate ETUs and CCCs built by the U.S. military and others, and funded by the U.S. government. The governments of the United Kingdom, France, China, and other countries also helped to build and support treatment units that were run by

international nongovernmental organizations and agencies (*9*). Once increased resources were allocated, questions arose about stocking and staffing the ETUs and preventing Ebola's spread to patients within ETUs whose illnesses had been misclassified as Ebola. In one analysis, modelers considered ways to prevent Ebola's spread to febrile persons with malaria whose illness had been misclassified as Ebola. Modelers analyzed the feasibility of treating all contacts of Ebola patients for malaria to prevent the onset of febrile malaria and subsequent admission to ETUs. If implemented, the intervention could avert admissions even for low levels of treatment compliance (*10*). Only a few clinics used this strategy. Although these strategies were implemented on a small scale, they might be useful on a wider scale for future responses.

CDC Modeling also contributed to the domestic U.S. response when the first imported case of Ebola prompted CDC and health departments to collaborate to improve hospital preparedness. State and local public health planners needed to know where in the United States travelers from West Africa were most likely to arrive, where they might seek treatment, and whether the United States had enough facilities designated to treat patients with Ebola. In a research letter, CDC Modeling and the U.S. Department of Health and Human Services' Biomedical Advanced Research and Development Authority estimated the rate of new Ebola cases expected in the United States based on three categories of persons arriving from Liberia, Sierra Leone, and Guinea: 1) travelers who were not health care workers, 2) health care workers, and 3) medical evacuees (*11*). The rate of new infections in the United States was multiplied by treatment length to determine the number of Ebola patients expected to need treatment at any given time while the epidemic in West Africa continued. According to this analysis, the capacity of Ebola treatment centers in the United States (49 hospitals with 71 total beds) was sufficient to care for the model's highest estimated number of patients with Ebola, with a large reserve capacity if epidemic conditions worsened (*11*).

Final Phase and Extinguishing

By May 2015, transmission of Ebola in West Africa had diminished substantially, and the response focused on eliminating transmission (*12*). Ebola virus was cultured from the semen of male Ebola survivors several months after clinical illness. Therefore, sex partners of these Ebola survivors could be infected but unaware of their infection while the illness is incubating. CDC Modeling was asked to project how often a person who acquired Ebola through sexual transmission and in whom the illness is incubating might arrive from West Africa into the United States (*13*). Using data from May and June 2015, modelers estimated that the projected frequency of a person traveling from West Africa who has acquired Ebola through sexual transmission and whose Ebola is incubating to be one traveler every 2.75 to 8.3 years (CDC, unpublished data, 2015). These estimates were specific for May and June 2015. As long as a resurgence of Ebola does not occur, the risk of importation will decline over time as the number of survivors capable of transmitting Ebola declines.

CDC Modeling produced a predecisional memorandum for internal CDC use that provided estimates of the potential impact of rapid Ebola diagnostic tests, specifically, the ability to rapidly test a patient with fever or other symptoms possibly indicative of Ebola. Although nucleic acid tests are more accurate, they require well-established laboratories and fully trained personnel. Rapid diagnostic tests produce quick results, are simple to perform, and do not require electricity, which is an important consideration in remote areas. Decision-makers needed to know the best possible strategies for using rapid diagnostic tests and how decreasing or low prevalence of Ebola might affect potential strategies for using these tests. The model results suggested that using rapid tests during low-prevalence periods most likely would require a second sequential confirmatory test at the treatment center to decrease the false-positive test results (CDC, unpublished data, 2015). This modeling provided evidence to support the use of rapid Ebola tests in low-prevalence settings as an effective screening tool to rule out Ebola infection (<1% false negatives), enabling patients with Ebola-like symptoms, but with negative rapid test results, to be treated outside of Ebola isolation units. In addition, this modeling predicted the number of false-positive (and true negative) rapid test results that could be expected at various disease prevalence levels in the community (CDC, unpublished data, 2015).

Key Challenges and Lessons Learned

Throughout the response, relevant data were not always available, and available data frequently contained inconsistencies that took time and effort to resolve. In addition, reporting delays made the incidence of Ebola difficult to accurately calculate, a crucial input in the models produced by CDC Modeling. Expert opinion was needed when data were not available (e.g., when data from the field were limited and a correction factor was used to estimate the actual number of cases). Even when adequate data existed, because no data sharing agreements had been developed and executed, questions arose about who owned the data and who could use them for analysis. As a result, some modeling projects were delayed.

The urgency of the Ebola response required a short turnaround time for projects. CDC Modeling typically was given ≤1 week to answer questions. To reduce errors and ensure the reproducibility and accuracy of the estimates in this short time frame, the CDC Modeling had two teams that

cross-checked each other's calculations, and other modelers at CDC reviewed the calculations during the clearance process. Each team had to clearly document its modeling methods so that other modelers could replicate the model. Therefore, for each model, CDC Modeling provided a technical appendix accessible to scientists within and outside of CDC.

Models and findings needed to be shared with the public, technical experts, responders, and other stakeholders. However, communicating about modeling is difficult when persons unfamiliar with modeling have difficulty interpreting what the estimates mean and understanding the nature of assumptions, uncertainty, and context. For example, if one assumption is disputed, nonmodelers might perceive this dispute as a reason to dismiss the entire model, rather than understand that defining assumptions and improving inputs is part of model development. Publishing manuscripts in scientific journals was, by itself, insufficient for communication. The immediate and primary purpose of the models was to provide information for decision-making, whereas publishing articles about the work provides information for future emergency responses.

Modeling in Future Responses

The benefits of incorporating modeling into major emergency responses were clear in the 2014–2016 Ebola epidemic response (*14*). Models provided critical decision-making tools in real time and helped demonstrate to public health authorities that the epidemic could be stopped by using existing tools and strategies (*4*). Although initial model estimates of Ebola represented a worst-case scenario, the international community responded to ensure that these dire predictions would not be realized (*14*). The following comments were made regarding the accuracy of CDC models that forecasted the trajectory of the epidemic: "the model predicted that when the tipping point was reached, transmission would decline rapidly. This prediction was shown to be accurate in the following months in Liberia and Sierra Leone The predictions also closely matched the actual case trajectory after effective intervention" (*14*).

In future emergency responses, modeling can be improved in several ways. First, flexibility is needed to enable data collection to focus on data needs relative to the size of the epidemic and to collect the types of data modelers can use to produce improved, more accurate models (e.g., number of cases that can be expected over time based on available knowledge about pathogen characteristics and transmission, as well as the impact that interventions could have on the epidemic). For example, in a large-scale epidemic, data collection might focus on small amounts of very specific data from sentinel surveillance (*1*). Second, data-sharing agreements should be in place before an event. Finally, promoting ongoing dialogue will ensure that scientists and audiences understand data limitations and what can and cannot be reliably concluded from models.

Modeling is an important but underused public health tool. Prioritizing modeling in future responses will take hard work, commitment, education, and an openness in public health to new disciplines and approaches.

Acknowledgment

CDC Ebola response staff in Atlanta and in affected countries.

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Safe and Effective Deployment of Personnel to Support the Ebola Response — West Africa

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Summary

From the initial task of getting "50 deployers within 30 days" into the field to support the 2014–2016 Ebola virus disease (Ebola) epidemic response in West Africa to maintaining well over 200 staff per day in the most affected countries (Guinea, Liberia, and Sierra Leone) during the peak of the response, ensuring the safe and effective deployment of international responders was an unprecedented accomplishment by CDC. Response experiences shared by CDC deployed staff returning from West Africa were quickly incorporated into lessons learned and resulted in new activities to better protect the health, safety, security, and resiliency of responding personnel. Enhanced screening of personnel to better match skill sets and experience with deployment needs was developed as a staffing strategy. The mandatory predeployment briefings were periodically updated with these lessons to ensure that staff were aware of what to expect before, during, and after their deployments. Medical clearance, security awareness, and resiliency programs became a standard part of both predeployment and postdeployment activities. Response experience also led to the identification and provision of more appropriate equipment for the environment. Supporting the social and emotional needs of deployed staff and their families also became an agency focus for care and communication. These enhancements set a precedent as a new standard for future CDC responses, regardless of size or complexity.

The activities summarized in this report would not have been possible without collaboration with many U.S and international partners (http://www.cdc.gov/vhf/ebola/outbreaks/2014-west-africa/partners.html).

Background

Because of the size and scope of the 2014–2016 Ebola virus disease (Ebola) epidemic in West Africa, CDC leaders activated the Incident Management System (IMS) and began coordinating its response from CDC's Emergency Operations Center on July 9, 2014. At CDC, the IMS comprises a staffing structure and standardized operating procedures that are used to coordinate various response components and functions in areas such as surveillance, laboratory testing, operations, and logistics (*1*). Before the 2014–2016 epidemic, CDC had responded to smaller Ebola outbreaks, usually in remote rural areas in Uganda, the Democratic Republic of the Congo, and other areas of Africa, without the need for an IMS activation. CDC typically deployed multidisciplinary teams of four to 10 staff, for whom CDC's Division of Emergency Operations (DEO) provided field equipment and travel arrangements. In the field, the deployed team was primarily responsible for arranging logistics, such as lodging, transportation (air and ground), meals, and specimen shipments. In some instances, if available, the team might have received additional logistic support from CDC country offices; U.S. embassies; or international partners, such as the World Health Organization's Global Outbreak Alert and Response Network or Médecins Sans Frontières. DEO is available 24 hours a day, 7 days a week for field staff to coordinate additional assistance. This logistic support model functioned well for most prior small-scale outbreak responses.

In the early stages of the 2014–2016 Ebola epidemic, CDC used this same model for logistic support. Small teams were deployed to Guinea, Liberia, and Sierra Leone and received limited support from the Global Outbreak Alert and Response Network and the U.S. Embassy or Consulate in-country. As the response mission in-country grew more complex and the teams grew in size, CDC needed to adapt to adequately deploy and support field teams.

By the end of July 2014, as the number of Ebola cases was rapidly increasing, CDC decided to deploy at least 50 staff members to the

three countries within 30 days. To do so required a shift in how the agency thought about and managed responses to Ebola outbreaks.

New Environment, New Workforce

CDC has large numbers of experienced staff working across the globe on major public health issues every day. From the start of the Ebola response, the agency had to balance maintenance of ongoing global (and domestic) public health efforts with surge staffing requirements for the response. Maintaining this balance required training and preparing staff from throughout CDC for challenging international assignments, the first international experience for many responders. CDC faced many challenges in identifying and preparing responders for this unique response, including deployments for ≥30 days, austere living conditions, food and water safety, language barriers, harsh climate conditions, coordination with new partners, frequent rotations of staff and leadership into and out of the response, transportation issues, exposures to endemic infectious diseases, and the risk for exposure to the potentially fatal Ebola virus. Each concern factored into CDC's emergency response in West Africa.

Initially identifying experienced staff to deploy who met travel requirements was not difficult. As the response continued, increasing in size and scope, that was no longer the case. When the CDC director initially called for "50 deployers within 30 days" in July 2014, staff were identified with predeployment preparations well under way within 2 weeks. Those persons reported to West Africa with basic responder preparedness: mission awareness, deployment location, local points of contact, and basic physical health assessment, as well as medical kits (malaria prophylaxis, antibiotics, and first aid supplies), communications equipment (laptops, cell phones, and satellite phones), and field equipment (backpacks, insect repellent, sunscreen, ponchos, flashlights, respirators, and personal protective equipment).

Responding to the Challenge

The CDC IMS is the agency's implementation of the National Incident Management System, used governmentwide in the United States to manage emergency response operations. At CDC, standard emergency management–based general staff sections support the science-based teams and task forces, which are the mechanisms CDC uses to apply its subject-matter expertise to the public health consequences of an incident. At IMS activation, these specialized teams and task forces are scaled up at CDC headquarters in Atlanta, Georgia, to coordinate the scientific aspects of each unique response. Similarly, IMS logistics, planning, operations, finance, and other general staff sections must grow to effectively manage the day-to-day operations of the response. For instance, the IMS logistics section usually is staffed with two or three persons at the start of an activation. During the Ebola response, 23 staff members from across CDC rotated through the IMS logistics section to meet the growing needs of the response. Contractors, term-limited external hires, and staff from the Federal Emergency Management Agency further augmented the IMS logistics section, a solution likely to be considered in future large-scale responses.

Before this Ebola response, the only occasion for which had CDC deployed 50 persons simultaneously to an international location, let alone to multiple locations, was in 2000 in response to the earthquake in Haiti. Within 2 months of IMS activation for Ebola, approximately 100 staff members were in West Africa every day, and by January 2015, approximately 200 were in the field daily. During the first year of CDC's activation, from July 2014 through June 2015, approximately 1,400 deployments had occurred to the three West African countries most heavily affected, totaling approximately 53,000 person-days of deployment time. At the time of deactivation on March 31, 2016, there had been 2,292 deployments to Guinea, Liberia, and Sierra Leone (Table); this includes the

TABLE. Number of CDC-supported international deployments and number of days deployed, by country or region — July 1, 2014–March 31, 2016*

Country/ Region	No. deployments†	No. days deployed			Total no. person-days deployed†,§
		Mean	Maximum	Minimum	
Sierra Leone	1,099	36	276	2	39,791
Liberia	619	32	135	2	20,112
Guinea	442	36	131	2	15,872
All other Africa deployments¶	222	19	62	1	4,190
All other international deployments**	79	7	49	2	592
Total	**2,461**	**33**	**276**	**1**	**80,557**

* Deployment dates on or after July 1, 2014, and return dates on or before March 31, 2016, entered into Preparedness Workforce Management System as of April 24, 2016, 1 pm Eastern daylight time. Deployments include staff from other agencies and partners supported through the CDC Emergency Operations Center (i.e., U.S. Department of Health and Human Services, 43 deployments; Council of State and Territorial Epidemiologists, 35 deployments; and other partners) but do not include some deployments of Public Health Agency of Canada (PHAC), Field Epidemiology Training Program (FETP), and other staff not processed by the CDC Emergency Operations Center. At the time of deactivation on March 31, 2016, there had been 2,292 total deployments to Guinea, Liberia, and Sierra Leone (this includes the PHAC, FETP, and others not included in the table).

† One person can be deployed multiple times.

§ Number of days CDC-supported responders were deployed using deployment start date and end date. Numbers might differ slightly from those provided in previous reports.

¶ Benin, Burkina Faso, Cameroon, Côte d'Ivoire, Democratic Republic of the Congo, Egypt, Equatorial Guinea, Ethiopia, Ghana, Guinea-Bissau, Mali, Mauritania, Niger, Nigeria, People's Republic of the Congo, Senegal, The Gambia, and Togo.

** Belgium, Canada, France, Germany, Italy, Luxembourg, Singapore, Switzerland, and United Kingdom.

Public Health Agency of Canada (PHAC), Field Epidemiology Training Program, and others not included in the table.

Whereas CDC's DEO normally processes approximately 300 emergency international travel requests each year, the Ebola response required processing of this many travel requests each month. In addition to the sheer quantity of deployments, CDC adapted to various travel-related challenges. For example, many airlines cancelled flights to and from Guinea, Liberia, and Sierra Leone for fear of spreading Ebola. By November 2014, only one airline had flights twice a week, which necessitated innovative approaches to travel coordination to get boots on the ground as quickly as possible. Compounding this challenge was severe winter weather in the United States and Europe, which affected departure and transit points, and labor stoppages occurred at European transit points. Because of the limited number of available and willing carriers to and from West Africa, CDC had few options for shipping supplies and equipment. To meet this need, deployed staff often hand-carried critical items in their personal luggage. To ensure the safe transfer of specimens from patients suspected or confirmed to have Ebola to CDC laboratories, CDC contracted special charter flights to transport thousands of specimens to Atlanta.

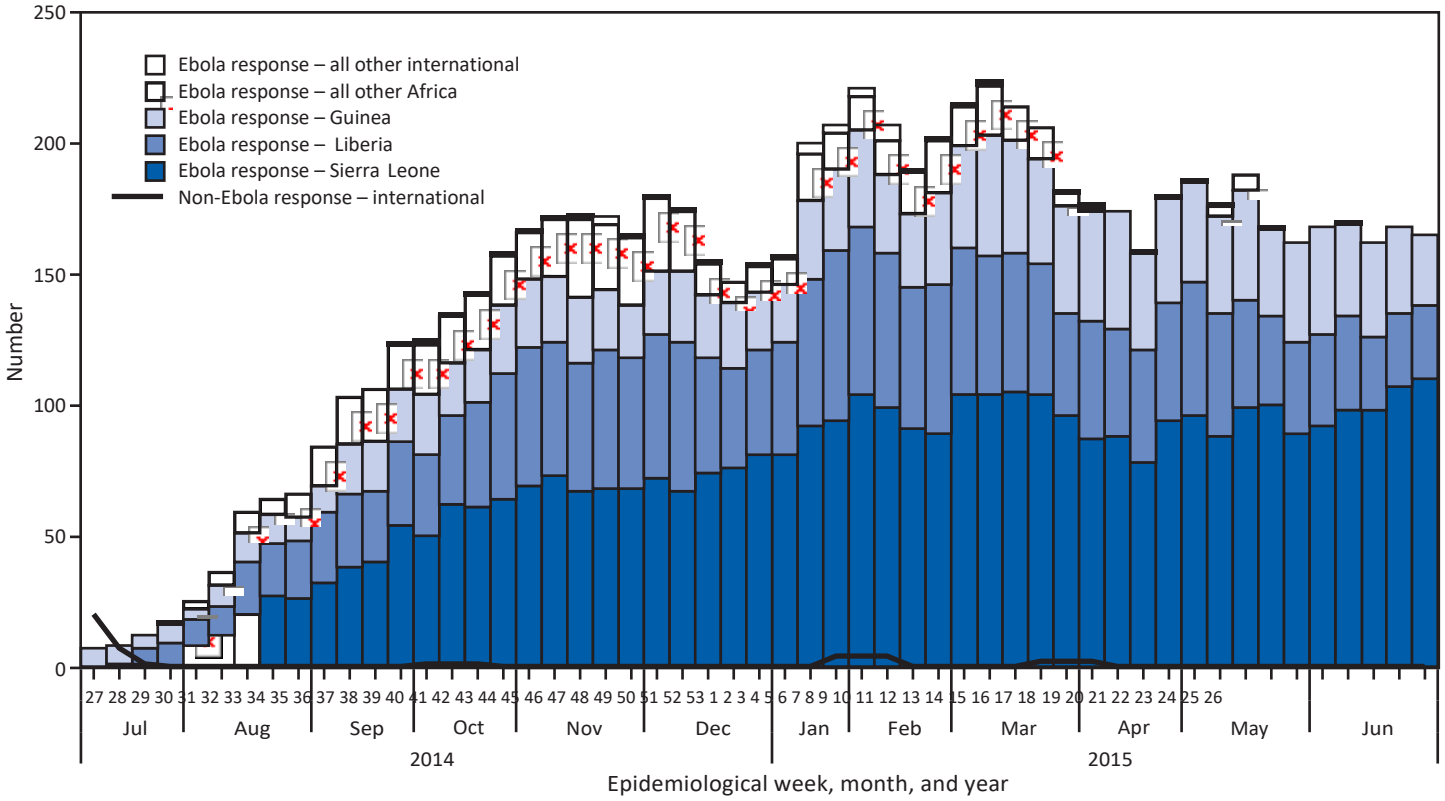
In the affected countries, deployed staff adapted to a number of logistics-related and other challenges. For example, as international partners expanded their own response operations in West Africa, CDC had to find ways to procure a sufficient quantity of increasingly scarce, safe, long-term lodging in all three highly affected countries. To ensure the effectiveness and safety of responders, CDC equipped them to work in austere conditions with communications and personal equipment, such as satellite phones, global positioning system trackers (to enhance the monitoring of location of staff for safety purposes), portable power supplies, water purifiers, "bug huts" to avoid mosquitoes and other pests, and lightweight sleeping bags. Enhanced coordination between logistics and procurement staff within the IMS became critical in ensuring rapid purchase and shipping of needed equipment and supplies.

Early in the response, agency leaders realized that CDC's previous model for logistic support of Ebola responses had to adapt to ensure deployed staff were prepared and equipped adequately to respond. Not only was the number of staff in-country beyond the capability of the field teams to self-support but also the absence of CDC country offices in any of the three countries, volume of deployments (Figure 1), and pointed feedback from early deployed staff drove changes in how staff were prepared for deployment and supported. Logistics staff were deployed to each of the three affected countries to coordinate in-country transportation; lodging; inventory management; supply shipments; procurement requests with the IMS Logistics Section in Atlanta; and, with the United Nations, in-country flights. CDC established close partnerships with the U.S. embassies and the U.S. Agency for International Development's Disaster Assistance Response Team to meet these new mission requirements.

Response operations must rapidly adjust in accordance with lessons learned during any response, for which Ebola has been a prime example. For IMS activations, the IMS Evaluation Team conducts in-progress and after-action reviews to evaluate lessons learned and then tracks implementation of tasks to address identified issues. Because of the size and scope of the Ebola response, beginning in August 2014, the IMS Evaluation Team and CDC's Worklife Wellness Office implemented Real-Time Evaluation (RTE) approaches to identify health and safety risks to responders to make appropriate course corrections during the response. RTE, increasingly used in international humanitarian emergencies, is defined as "an evaluation in which the primary objective is to provide feedback in a participatory way in real time (i.e., during the evaluation field work) to those executing and managing the humanitarian response" (*2*,*3*). The RTE approach included three voluntary opportunities for responders to provide feedback: 1) a structured survey completed online or in person that solicited information about a responder's predeployment, deployment, and postdeployment experiences, 2) individual comment submissions sent through a CDC intranet-based submission system, and 3) in-person postdeployment group debriefs. The Worklife Wellness Office also implemented a predeployment and postdeployment well-being assessment process comprising three validated instruments (*4*–*6*) with confidential follow-up as needed. This new assessment process was integrated into medical history and physical screening processes used by CDC's Occupational Health Clinic to ensure confidentiality and ease of access by deployed staff.

As the first deployed staff reported back to CDC, they confirmed many of the challenges listed above but, more importantly, provided awareness of new and long-term preparedness needs that, when addressed, would improve the effectiveness of hundreds of future deployments. Among these new challenges were preparation for the constant concern about exposure to Ebola with every personal or surface encounter. Of more impact perhaps was preparation of CDC staff for the death from Ebola of an international colleague who shared an office (or even a computer) with those CDC staff members. One of the most unexpected challenges was preparation of staff and their families for the stigma some deployed staff encountered after returning home, such as a spouse being asked not to come to work or a child denied entry to school. Within the first month after the response began, CDC started reevaluating its preparedness efforts to address these issues and

FIGURE 1. Approximate number of staff deployed internationally who were managed by the CDC Emergency Operations Center, by week — July 2014–June 2015



Abbreviation: Ebola = Ebola virus disease.

to better provide for the health, safety, security, and resiliency of its most valued resource.

Staffing issues can challenge even small-scale responses. Identifying personnel who have skill sets that match the needs of the response and the ability to handle the rigors of a complex response in austere international settings requires strong coordination between in-country team leadership, staffing recruiters, employee supervisors and emergency coordinators in home centers or programs, and the staff to be deployed. Before a person deploys, the IMS leadership needs to address several key factors: ensuring the role in the field is well defined and the staff member to be deployed has the requisite skills for the job; ensuring he or she is ready mentally and emotionally; ensuring he or she has supervisory approval to leave the "day job" for at least 30 days and often much longer and that other staff can fill the void; and last but by no means least, determining how quickly the staff member can be prepared to deploy. Although hundreds of CDC personnel have deployed domestically over the years and are considered "deployment-ready," few were prepared (in the early activation period) for international deployments, requirements for which include appropriate medical clearance and vaccinations, security training, and possession of a U.S. government (not personal) passport. Many had never considered volunteering to deploy internationally and therefore often required several weeks to complete vaccination requirements; online and in-person security training; passport and visa processing; and of critical importance, make any necessary personal and family arrangements. To meet new and more rigorous U.S. Department of State requirements for overseas travel, approximately 637 staff completed High-Threat Security Overseas Training, and many others completed the week-long Foreign Affairs Counter-Threat Course during the first year of the response. Although these delays occasionally exacerbated staffing gaps in the Ebola response, one positive long-term outcome of preparedness is a much larger deployment-ready international responder workforce at CDC.

Ideally, international responders would deploy long enough (≥3 months) to become familiar with the local context and environment, acquire tacit knowledge and skills specific to their roles, and establish meaningful and effective relationships with partners. However, work and personal commitments within a volunteer responder workforce limited the ability to recruit persons for such long deployments, which in turn led to the need for higher than optimal numbers of persons to address identified staffing gaps for the response. Although

intense staffing efforts resulted in approximately 2,844 persons participating during the first year of the response, either in the field or in the CDC IMS, critical staffing gaps required constant recruitment efforts within CDC and were met through the hiring of additional staff, acquisition of contract assistance, and use of partner agency personnel (e.g., other operating divisions of the U.S. Department of Health and Human Services, U.S. Public Health Service Commissioned Corps, Federal Emergency Management Agency, National Disaster Medical System, PHAC, and academic institutions).

In addition to logistic and staffing support for the international component of the Ebola response during this period, CDC deployed approximately 1,300 staff throughout the United States, including to five CDC quarantine stations at major airports, where enhanced entry risk assessment and management of travelers from Ebola-affected countries was conducted; approximately 63 hospitals to assess Ebola readiness; Anniston, Alabama, for CDC-conducted Ebola treatment unit training (*7*); and Texas, Ohio, and New York for response activities related to patients with Ebola. Although CDC adapted to the surge and unique needs of internationally deployed staff, it still needed to ensure capacity to provide logistic and resiliency support for the domestic staff.

Establishing the Deployment Risk Mitigation Unit

CDC staff deploying to West Africa during the early months of the outbreak had limited preparation for the environment and conditions they would encounter. No one working in the Ebola response was untouched by the physical and mental toll of the work itself (e.g., long hours, long deployments, changing demands) or by the mental and emotional toll of observing Ebola's devastating impact on West Africans. In addition, deployed personnel shared concerns about being exposed to, or becoming ill with, Ebola.

By September 2014, returning responders increasingly voiced concerns about health, safety, security, and well-being. Feedback indicated that better training and preparation were required to help responders anticipate on-the-ground needs and do their jobs safely. CDC needed to be able to reassure concerned communities, families, and employers. To accomplish this, the CDC IMS activated a new team, the Deployment Risk Mitigation Unit (DRMU).

Initially a team of four (unit lead, predeployment coordinator, in-country coordinator, and postdeployment coordinator), the DRMU was tasked with supporting the health, safety, security, and well-being of CDC responders and their families throughout the deployment process. The DRMU coordinated predeployment educational activities, developed medical evacuation (medevac) procedures with the U.S. Department of State (for Ebola-related and non–Ebola-related health conditions), provided requisite health and safety supplies for in-country use by deployed staff (e.g., first aid kits, fire extinguishers, door stops to prevent unwanted entry into rooms at night), and recruited and deployed field safety officers to Guinea, Liberia, and Sierra Leone.

The DRMU collaborated with the IMS Deployment Coordination team, U.S. Department of State (for medevacs), CDC's Occupational Health Clinic, Employee Assistance Program, National Institute for Occupational Safety and Health, IMS Logistics Support Section, and other organizations. The DRMU led, oversaw, supported, or coordinated implementation of several strategies to address concerns about health, safety, security, and well-being, including predeployment assessments, training, and preparedness; placement of safety officers in affected countries; reintegration and acceptance of returning deployed personnel and their families into workplaces, schools, and the community; and postdeployment physical and resiliency monitoring.

The DRMU helped develop, implement, and evaluate more robust and thorough predeployment briefings for staff. These briefings had always been a routine part of emergency deployments, but based on input from returning personnel deployed to the Ebola-affected countries, they were expanded to include sessions on Ebola and infectious disease prevention; cultural awareness; safety precautions in-country; personal protective equipment; mental and emotional resiliency; guidance on team organization; and coordination with partners, such as the U.S. Agency for International Development's Office of Foreign Disaster Assistance, the lead U.S. government agency in-country. Briefings were held twice a week to share these lessons learned with personnel preparing to deploy for the first time.

Advanced planning for the medevac of deployed CDC personnel proved especially challenging because of the variety of staff possibly affected (CDC civil servants, locally employed staff, non–U.S. citizen employees, U.S. citizen nonemployee) and potential variety of circumstances (exposed, possibly exposed, febrile, or afebrile). Because of the difficulty of distinguishing Ebola from other diseases endemic to the area (e.g., malaria) (*8*) and because of the global panic surrounding importation of Ebola cases, routine medevac procedures were disrupted. Although U.S. citizens and legal permanent residents were assured of a medevac to the United States, non–U.S. citizens working for CDC were not.

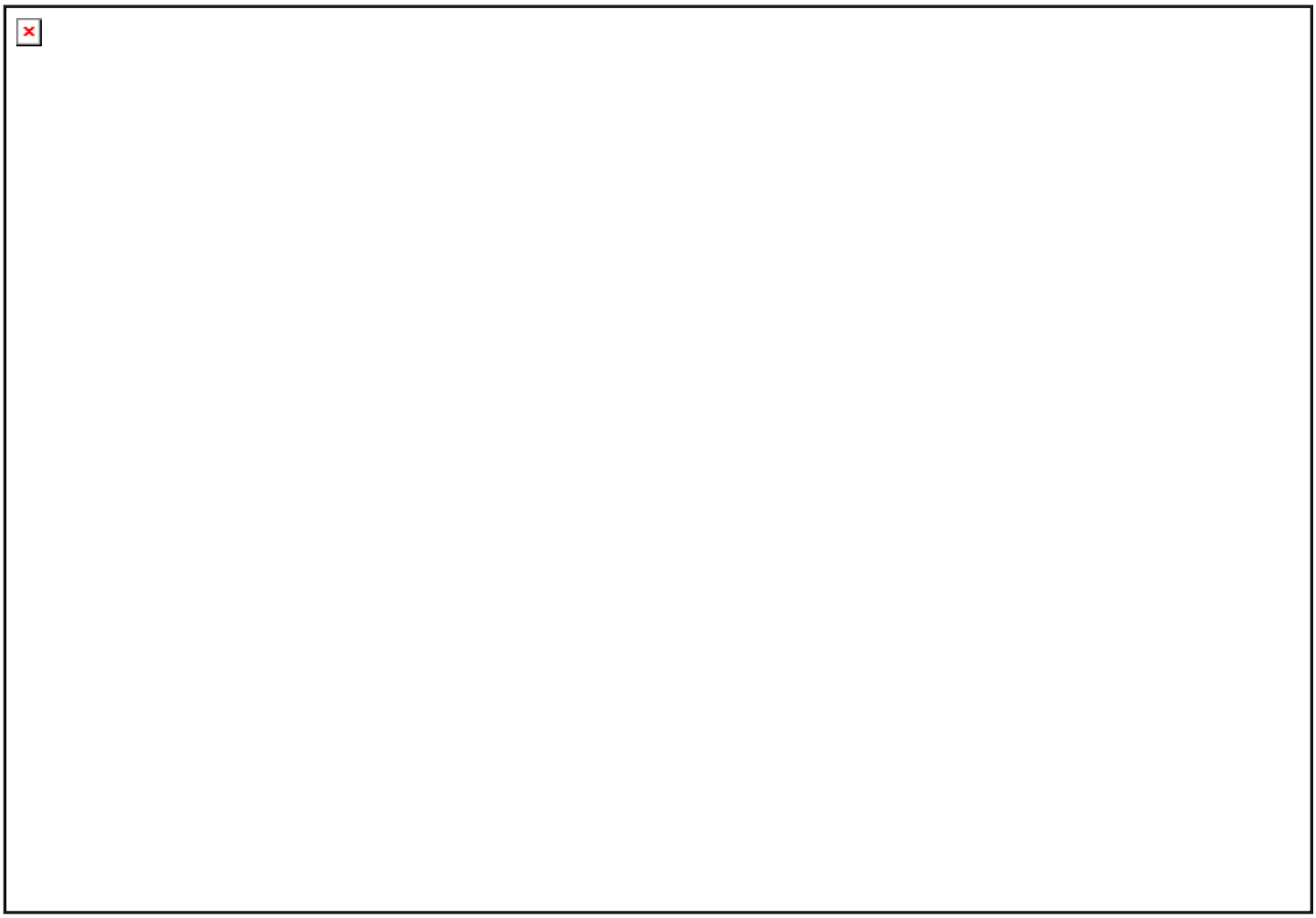
Any U.S. citizen CDC staff member determined to have been exposed to Ebola or to be febrile was required to travel home on an aircraft arranged by the U.S. Department of State,

using the Aeromedical Biologic Containment System (ABCS). The ABCS is an isolation chamber, originally developed by CDC and others after the epidemic of severe acute respiratory syndrome in 2003 and designed to isolate persons having airborne illnesses, but capable of transporting only one person per flight (Figure 2). The ABCS was not otherwise commercially available and could be deployed only with the approval of the U.S. Department of State.

Resolving how to effect a medevac was substantially more complicated for non–U.S. citizen CDC staff. Because of immigration laws, evacuating non-U.S. citizens to the United States was highly problematic. Successfully locating medevac companies agreeable to transporting febrile persons traveling from Guinea, Liberia, or Sierra Leone to another country was a challenge. Then, many countries (even home countries) were themselves initially unwilling to accept an evacuee unless that person had completed a 21-day monitoring period elsewhere. Sorting through the myriad issues and the case-by-case nature of medevacs required substantial time and frequent coordination between CDC, the U.S. Department of State, and other U.S. and international government agencies. Ultimately, none of CDC's deployed staff required medevac for febrile illness.

While the DRMU addressed predeployment and postdeployment health, safety, security, and well-being concerns from CDC's Atlanta headquarters, field safety officers extended that support to teams working in-country. Field safety officers reported directly to the DRMU throughout the response, providing situational awareness on the most pressing health and safety issues. Moreover, the field safety officers worked with country leadership to address issues related to accountability (knowing the location of deployed responders, daily); encourage use of the buddy system among staff traveling outside the capitals; decrease generally risky behaviors (e.g., not wearing

FIGURE 2. The Aeromedical Biologic Containment System installed in a Gulfstream III aircraft*



* Names of specific vendors, manufacturers, or products are included for public health and informational purposes; inclusion does not imply endorsement of the vendors, manufacturers, or products by CDC or the U.S. Department of Health and Human Services.

seat belts); and support overall well-being (e.g., serving as confidantes to deployed personnel, encouraging behaviors that enhanced resiliency).

Field safety officers also served as a conduit for information between the DRMU and the U.S. Embassy Health Units as well as the regional security officers in Guinea, Liberia, and Sierra Leone. These regular interactions with the U.S. Embassy in each country enabled field safety officers to improve working relationships between the Embassy and deployed personnel, especially crucial when services from the U.S. Embassy Health Units or regional security officers were needed. Finally, field safety officers identified on-the-ground health, safety, and well-being issues that had deleteriously affected (or had the potential to deleteriously affect) responders' ability to conduct their work. Among many of their accomplishments: field safety officers successfully helped identify and stop an outbreak of foodborne illness among deployed personnel by inspecting the suspected kitchen source for the outbreak and by collaborating with management to implement changes to operations and food-handling practices.

The ongoing findings of the RTE, as well as postdeployment physical and resiliency monitoring and outreach, demonstrated that deployed personnel appreciated these interventions and reported improvements in their predeployment process, logistic and resiliency support throughout the deployment, and availability of resources postdeployment to reduce stress or improve well-being. As a result of these efforts, CDC responders experienced remarkably improved conditions while traveling to West Africa later in the 2014–2016 Ebola response compared with conditions experienced during the early phase of the response and those usually experienced in international deployments.

Lessons Learned

To mount a timely and effective response while ensuring the safety and well-being of deployed staff, CDC must be able to identify and prepare a cadre of staff willing and able to deploy internationally on reasonably short notice. Although some preparations, such as international visas and final medical clearance, cannot be completed until the destination is known, most actions can be completed well in advance, such as acquiring and maintaining an official U.S. government passport, completing annual medical and respirator clearance, and completing required safety and security training. Other personal preparations involve taking care of the "home front" (e.g., by providing for family members, pets, and residences).

The size and complexity of the Ebola response highlighted the need for focus on developing processes, plans, and procedures to acquire, access, use, and deploy assets, whether personnel or other resources, before an activation; doing so during a response often is not the most efficient, timely, or safe way to operate. Readiness for the next large response requires CDC to document and institutionalize a variety of procedures, such as returning retirees to the workforce, deploying non-CDC staff, providing safety and resilience training to more staff, and increasing the number of CDC staff who have skills in different languages.

Establishment of the DRMU reflected a change in how CDC views and manages deployment risks. The DRMU significantly improved the preparation of CDC staff for deployment and, equally important, assisted in staff reintegration into the agency and their families upon their return. The employment of deployed safety officers not only eased concerns of other deployed staff but also provided field team leadership with a dedicated resource to ensure staff were operating safely, despite the long hours and austere conditions.

Deployment of dedicated logistics personnel freed CDC scientific staff from the distractions of coordinating lodging, transportation, and other support needs while simultaneously facilitating coordination with embassies and consulates. Furthermore, by providing a single contact to the IMS Logistics Section in Atlanta, field team support requirements were more efficiently identified and fulfilled. Before the 2014–2016 Ebola response, CDC had few logistics staff with the background or skills to operate effectively overseas. Although not every future response will require deployment of logistics staff, the pool of available logisticians is greater now, and a program to maintain and improve their skills is being developed.

Conclusion

The 2014–2016 Ebola epidemic in West Africa required an unprecedented response from CDC. It challenged the agency's routine operations; logistics; staffing; and responder health, safety, and resiliency programs to rapidly adjust to new geographic environments and increased, ever-changing staffing needs. CDC used new resources, innovative problem-solving, and critical partnerships to support the scientific, public health, and emergency responses of persons deployed and help the affected countries end the Ebola epidemic.

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Implementing an Ebola Vaccine Study — Sierra Leone

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Summary

In October 2014, the College of Medicine and Allied Health Sciences of the University of Sierra Leone, the Sierra Leone Ministry of Health and Sanitation, and CDC joined the global effort to accelerate assessment and availability of candidate Ebola vaccines and began planning for the Sierra Leone Trial to Introduce a Vaccine against Ebola (STRIVE). STRIVE was an individually randomized controlled phase II/III trial to evaluate efficacy, immunogenicity, and safety of the recombinant vesicular stomatitis virus Ebola vaccine (rVSV-ZEBOV). The study population was health care and frontline workers in select chiefdoms of the five most affected districts in Sierra Leone. Participants were randomized to receive a single intramuscular dose of rVSV-ZEBOV at enrollment or to receive a single intramuscular dose 18–24 weeks after enrollment. All participants were followed up monthly until 6 months after vaccination. Two substudies separately assessed detailed reactogenicity over 1 month and immunogenicity over 12 months. During the 5 months before the trial, STRIVE and partners built a research platform in Sierra Leone comprising participant follow-up sites, cold chain, reliable power supply, and vaccination clinics and hired and trained at least 350 national staff. Wide-ranging community outreach, informational sessions, and messaging were conducted before and during the trial to ensure full communication to the population of the study area regarding procedures and current knowledge about the trial vaccine. During April 9–August 15, 2015, STRIVE enrolled 8,673 participants, of whom 453 and 539 were also enrolled in the safety and immunogenicity substudies, respectively. As of April 28, 2016, no Ebola cases and no vaccine-related serious adverse events, which by regulatory definition include death, life-threatening illness, hospitalization or prolongation of hospitalization, or permanent disability, were reported in the study population. Although STRIVE will not produce an estimate of vaccine efficacy because of low case frequency as the epidemic was controlled, data on safety and immunogenicity will support decisions on licensure of rVSV-ZEBOV.

The activities summarized in this report would not have been possible without collaboration with many U.S. and international partners (http://www.cdc.gov/vhf/ebola/outbreaks/2014-west-africa/partners.html).

Background to Trial Conception

By August 2014, the unprecedented scope and exponential growth of the 2014–2016 Ebola virus disease (Ebola) epidemic in West Africa raised concern that control might be impossible without vaccination and prompted research and public health communities to accelerate development of Ebola vaccines. During September 4–5, 2014, the World Health Organization (WHO) convened advisors to review the most promising vaccine candidates and to consider the ethics of using investigational products in the expanding epidemic. As a result of this meeting, WHO called for "a coordinated effort by the international community to remove unnecessary obstacles" to accelerate evaluation and licensing of Ebola vaccines while acknowledging that for these to occur, an extraordinary pace of vaccine development, evaluation, and production would be needed (*1*). The National Institutes of Health (NIH) and the U.S. Army Medical Research Institute of Infectious Diseases were already engaged in human phase I (*2*) trials of Ebola vaccines, and an NIH partnership was establishing a phase II/III double-blind, randomized, placebo-controlled trial in Liberia of two of the leading Ebola vaccine candidates.

Since March 2014, CDC had been focused on the Ebola outbreak response, and in September 2014, the agency began to consider launching a second U.S. government–sponsored phase II/III Ebola vaccine trial in Sierra Leone. The rationale was to develop an alternative approach to a blinded, placebo-controlled trial that was potentially less complex and thus easier to implement in Sierra Leone, where government agencies were struggling to respond to a devastating epidemic, yet an approach that would still provide data on efficacy, immunogenicity, and safety for vaccine licensure. If the vaccine were efficacious, vaccination of a large number of trial participants also could protect persons at high risk and potentially help control the worsening outbreak. Two distinct approaches in different sites would also mitigate the risk that one approach might not be successful.

In October 2014, CDC established a partnership with Sierra Leone to conduct an Ebola vaccine clinical trial, while a WHO-led international consortium began planning an Ebola ring vaccination trial in Guinea. The CDC–Sierra Leone trial, subsequently named STRIVE (Sierra Leone Trial to Introduce a Vaccine against Ebola), was led by the College of Medicine and Allied Health Sciences (COMAHS) of the University of Sierra Leone, the Sierra Leone Ministry of Health and Sanitation (MoHS), and CDC. CDC sent technical staff in late October to Sierra Leone to work with COMAHS and MoHS leadership to start trial planning. During the initial conception, two further key principles were articulated: 1) the trial was not to detract from the main epidemic response and 2) the trial would contribute to longer-term capacity building and transfer of skills within Sierra Leone.

Trial Design and Ethical Considerations

Early data from Sierra Leone suggested that health care workers (HCWs) had a 100-fold higher risk for Ebola than the general community (*3*); therefore, the study population was selected to include all staff at health care facilities (i.e., clinical and nonclinical workers) and other Ebola frontline workers (e.g., surveillance, burial, and ambulance team members). Power calculations indicated that at least 67 Ebola cases were needed in the study population to detect a vaccine efficacy of 50%, and facility censuses and disease rates calculated near the peak of the epidemic led STRIVE collaborators to initially target a population of 6,000 participants in the five most heavily affected of the 14 districts of Sierra Leone. The logistics of travel and vaccine transport on poor roads, especially in the rainy season, necessitated choosing, within the selected districts, centrally located chiefdoms with the highest numbers of HCWs and Ebola cases.

A modified stepped wedge design (*4*) was initially considered for the study: health facilities and teams of health care and frontline workers throughout the study area would each be randomized to receive vaccine at a specified time over a 6-month period until all staff in all facilities in the study area were offered vaccine. Ebola rates and adverse events would be compared at any one time between vaccinated and (up to that point) unvaccinated staff and facilities over the study period. However, several key logistic and methodologic limitations of this approach posed obstacles. First, the design required follow-up of the entire study population from the trial start; therefore, all staff in all facilities had to be enrolled before the first dose of vaccine could be administered. Second, once all staff in facilities were enrolled, very limited opportunity existed to expand the sample size, yet declining background rates of Ebola suggested this might be needed. Third, Ebola increasingly occurred in clusters as overall incidence declined; therefore, an imbalance of Ebola risk could easily occur between facilities with vaccinated staff and facilities with unvaccinated staff and lead to lower statistical power and unreliable results (*5*). Because of these limitations, STRIVE collaborators chose an individually randomized trial of health care and frontline workers assigned to different vaccination times. This approach would provide flexibility of implementation because staff in each facility could be enrolled independently from staff in other facilities (allowing for the possibility of increasing sample size easily), as well as more discrete units of randomization and greater statistical power. At screening and enrollment, participants were randomized to receive vaccine immediately (immediate vaccinees) or 18–24 weeks later (deferred vaccinees), and all were monitored monthly from enrollment until 6 months after

vaccination for Ebola and for serious adverse events, which according to the regulatory definition involve hospitalization or prolongation of hospitalization, death, or reported life-threatening illness or permanent disability (*6*). The STRIVE protocol was approved (*7*) by the Sierra Leone Ethics and Scientific Review Committee and the CDC Institutional Review Board (CDC-NCIRD-6689) and registered at https://clinicaltrials.gov (identifier NCT02378753).

In early discussions with Sierra Leone partners when deaths from Ebola were highest, the use of a placebo was ruled out because of the logistic complexity of implementing a placebo and concerns that placebo recipients might feel protected against Ebola and put themselves at risk. The lack of placebo opened up the study to several biases. For instance, immediate vaccinees might be assigned to a higher risk duty or be less careful in using personal protective equipment (PPE) than deferred vaccinees. Immediate vaccinees also might be more likely than persons who had not yet been vaccinated to report adverse events possibly associated with the vaccine or seek care for illness, thus biasing potential safety signals especially for milder adverse events. Reporting of Ebola was considered less likely to be susceptible to bias because Ebola generally has a severe clinical picture and surveillance is comprehensive. To reduce bias, STRIVE staff emphasized to each participant that the level of protection afforded by the vaccine was unknown and therefore Ebola prevention behaviors should not be relaxed. Design elements were added to measure bias, such as questions about use of PPE or changes in duties. Nonetheless, these potential biases complicated the comparison of frequency of events between the immediate and deferred vaccinees (especially adverse events, because ultimately, no Ebola cases were reported in the study population).

In addition to the main study, STRIVE planned two substudies. The first was a safety substudy of 400 participants (200 vaccinated, 200 unvaccinated) at the start of the trial with follow-up for adverse events on days 1, 3, 7, 14, and 28 after enrollment. The second was an immunogenicity substudy of 500 participants enrolled during June–September 2015 with blood draws at day 0, day 28, month 6, and once during months 9–12 after vaccination.

Because this clinical trial of an experimental live vaccine of unknown effectiveness and safety would be conducted in a population with high levels of poverty and low literacy in the midst of an Ebola epidemic, ethical issues were a foremost consideration. One concern was that fear of Ebola could lead to a skewed risk–benefit calculation by health care and frontline workers in their decision to receive a vaccine of unclear safety and efficacy. STRIVE staff also were aware that reimbursements for participation and free health care could further induce enrollment. Careful messaging about the uncertainty of protection afforded by the vaccine was used to prevent participants from undertaking tasks at work or in the community that could place them at greater risk for Ebola.

To maintain the balance between immediate and deferred vaccine arms and the integrity of randomization, each site was provided with sealed allocation envelopes in a predetermined sequence. To ensure that participants correctly perceived the envelope sequence as entirely random, enrollees were asked to choose one of five envelopes next in sequence. These ethical and communication concerns were addressed with guidance from Sierra Leone STRIVE leadership and other partners. Active and transparent communication of risks and benefits to participants and the public continued throughout the trial as the risk–benefit balance changed with ebbing Ebola incidence.

STRIVE was also positioned to help the outbreak response with the shared priority of early identification and diagnosis of suspected Ebola cases through the continued monitoring of participants. One complication identified early in trial planning was that during the phase I trials the vaccine could cause fever, myalgia, and fatigue in the first day or two after administration. Recent vaccinees could have a mild vaccine reaction that met the definition of suspected Ebola and be referred to Ebola holding centers where they could be unnecessarily exposed to Ebola. Identification and treatment of true Ebola among vaccinees could not be substantially delayed, nor could associated public health responses (e.g., contact tracing) be impeded. After discussions with the response leadership in Sierra Leone, STRIVE leaders slightly modified the suspected case definition for trial participants for the first 48 hours after vaccine receipt to allow for a short delay in determining whether a person had suspected Ebola if that person was a recent vaccinee exhibiting only symptoms consistent with vaccination.* Any vaccinees with Ebola exposure or exhibiting any Ebola symptoms that were inconsistent with vaccination at any time were immediately treated as having suspected Ebola.

Vaccine Selection

In late summer and early fall 2014, only limited data from nonhuman primate studies existed on the two leading vaccine

* Standard suspected Ebola case definition: Temperature ≥38°C (≥100.4°F) and three or more of the following symptoms: headache, loss of appetite, fatigue, muscle/joint pain, diarrhea, unusual bleeding, difficulty breathing, nausea, vomiting, abdominal pain, difficulty swallowing, or hiccups; OR illness after direct, unprotected Ebola contact or a breach in personal protective equipment in the past 21 days. Modified case definition applied to vaccine recipients in the first 48 hours after vaccination: same as for standard suspected Ebola case except that at least one symptom had to be one of the following symptoms not consistent with a vaccine reaction: diarrhea, unusual bleeding, difficulty breathing, nausea, vomiting, abdominal pain, difficulty swallowing, or hiccups.

candidates poised to begin phase I trials in humans at that time. Both candidates used live recombinant virus vectors encoding the surface glycoprotein of the Ebola virus (EBOV). One was the replication-deficient recombinant chimpanzee adenovirus type-3 vectored vaccine (ChAd3-EBOV), developed by the National Institute of Allergy and Infectious Diseases of NIH and licensed for development to GlaxoSmithKline (GSK); the second was the replication-competent, recombinant vesicular stomatitis virus vectored vaccine (rVSV-ZEBOV) developed by the Public Health Agency of Canada, licensed to NewLink Genetics Corporation then later to Merck and Co., Inc. (Merck), for further development.

In October 2014, a report suggested that a single dose of ChAd3-EBOV would protect macaques against lethal challenge of 1,000 plaque-forming units of EBOV administered intramuscularly (*8*). Although humoral and cell-mediated responses specific to the EBOV glycoprotein were elicited by the vaccine, protection seemed of short duration because deaths increased among macaques challenged at 10 months after initial vaccination. A second vaccination (a heterologous boost) of modified vaccinia Ankara with EBOV glycoprotein (MVA-EBOV), given a month after initial vaccination with ChAd3-EBOV, appeared more likely to provide durable protection (*8*). Challenge studies of rVSV-ZEBOV vaccine in nonhuman primates also provided evidence of protection and humoral immune response (*9*,*10*). Data on longevity of protection were not available for rVSV with EBOV glycoprotein, only for a vesicular stomatitis virus recombinant with Marburg virus, which, although related, is less virulent and therefore could not be used as proxy for Ebola virus (*11*).

By January 2015, some of the first human phase I data on immunogenicity and safety in small groups of healthy adults became available for both vaccines. Early results on humoral and cell-mediated responses of ChAd3-EBOV were promising overall, although somewhat mixed (*12*,*13*), and similarly encouraging humoral responses to rVSV-ZEBOV were found at day 28 after vaccination (*14*). These small studies of both vaccines had not detected any safety issues, but in mid-December 2014, a phase I study under way in Switzerland that used rVSV-ZEBOV was paused to assess episodes of reported arthritis that began during the second week after vaccination. In early January 2015, the study was resumed at a lower dose of vaccine (*15*). Investigators of other phase I studies in the United States examined their data but did not initially detect similar adverse events (*14*), although an association was detected later in some other trials also.

In early 2015, intensive public health control measures led to decreasing intensity of the Ebola epidemic in Sierra Leone, although the situation remained unpredictable. To provide useful data on efficacy for possible vaccine licensure, starting the trial as soon as possible was essential. Therefore, selection of a vaccine and filing by CDC (as trial sponsor) of an investigational new drug (IND) application became urgent. Although the use of a priming vaccination with ChAd3-EBOV boosted with a second vaccination with MVA-EBOV generally was seen as the best opportunity to provide durable protection with ChAd3-EBOV, this strategy presented several critical disadvantages. These included the need for longer follow-up (because of the interval between doses), the difficulty in attributing safety issues to two different products, the need for more space and staff to follow up and vaccinate participants twice, the need for more cold chain capacity, and the lack of human data on MVA-EBOV submitted to the Food and Drug Administration for evaluation in early 2015. Statistical power calculations made clear that comparing two vaccines would need an untenably large trial with HCWs, thus leaving the choice between a single-dose regimen of ChAd3-EBOV or rVSV-ZEBOV. An additional variable was that in early 2015, GSK and Merck were still examining data from dose-ranging studies to ascertain the optimum vaccine dose for trials and licensure.

STRIVE leadership convened expert groups that advised that, as a live replication-competent vaccine, a single dose of rVSV-ZEBOV was more likely to provide durable and rapid protection than ChAd3-EBOV. Moreover, ChAd3-EBOV was needed for other trials, and it was uncertain in January 2015 whether sufficient doses of GSK's final formulation of the vaccine would be available in time for STRIVE's launch. For these reasons, in late January 2015, STRIVE leadership at COMAHS, MoHS, and CDC selected a single dose of rVSV-ZEBOV at the manufacturer-recommended dose of 2×10^7 plaque-forming units/mL for the trial. At that time, <100 persons had received this or a higher dose of this vaccine in clinical trials. Merck and Newlink Genetics Corporation provided and shipped the vaccine doses necessary for the trial.

Establishing the Trial Platform

Trials conducted under IND regulations require a high level of rigor in methods and implementation and continuous monitoring and documentation for the data to be useful to the licensing pathway. Sierra Leone is still recovering from a civil war that ended in 2002, leaving a fragile infrastructure and limited clinical research capacity exacerbated by a paucity of physicians in the country (approximately 150 for a country of 6 million persons in 2010 [*16*]). In addition, the fundamental requirements for the trial (i.e., clinics for vaccination, office space for data management, a reliably powered and mobile cold chain that could keep the vaccine at the required -80°C

[-112°F], Internet access, and laboratory capacity) were either not available or adequate in Sierra Leone.

To meet the unprecedented challenge of sponsoring and leading an IND trial on short notice in this demanding context, STRIVE leadership at CDC began to identify relevant expertise throughout the agency, without detracting from the response. Insurance and medical evacuation considerations largely prevented use of nongovernment staff; therefore, efforts were initiated to hire external staff into U.S. government positions specifically for longer-term deployment. CDC also arranged with various partners to support the logistic needs and preparatory work for the trial and finding solutions to the many challenges (Table 1). The U.S. Department of Health and Human Services' Biomedical and Advanced Research and Development Authority committed expert staff and used existing mechanisms for clinical trials to fund and establish contracts to secure clinical monitoring, safety monitoring, data management, and cold chain assistance through multiple contract research organizations. The CDC Foundation raised donor funds that could be immediately used for early demands, such as infrastructure building, supplies, and hiring staff by an in-country nongovernment agency, eHealth Africa. WHO assessed the cold chain capacity in country and provided -80°C (-112°F) freezers necessary to store and transport the vaccine. Intellectual Ventures provided units of the newly developed Arktek, a system that uses alcohol-based refrigerants (phase-change materials) that can maintain -80°C temperatures for several days with no power, enabling vaccine transport and short-term storage at district enrollment sites (*17*).

Provision of power, Internet, and even water for basic use proved challenging throughout the trial. Developing a reliable source of power for the cold chain storage depots and offices for data entry required establishment of several combinations of backup generators, solar power, and battery systems that were supported by international engineering expertise from the German Federal Agency for Technical Relief.

Early on, in response to the epidemic, COMAHS (medical, nursing, and pharmacy schools) closed so as not to put students and staff at increased risk for Ebola during training; thus these students and staff were able to work for the trial. However, very few had prior training in Good Clinical Practice and the precepts of human subject research required for a trial under IND regulations. Therefore, in March 2015, at least 350 staff were trained on site by CDC, COMAHS, MoHS, and two of the contract research organizations, FHI360 and Emmes Corporation. Retraining continued as the trial progressed and procedural issues were identified.

Communication

During the epidemic, the highly charged social environment made the conduct of a large trial of an IND with very limited data from previous human trials particularly delicate. STRIVE created a communication plan to 1) increase awareness and confidence in STRIVE among stakeholders and opinion leaders; 2) educate potential study participants on the risks and benefits of trial participation, informed consent, and confidentiality; 3) anticipate and prepare responses to public rumors, misinformation, controversy, or questions about the trial; and 4) ensure clear, consistent messages among all study staff and partners. In December 2014, formative research, including in-depth interviews and focus groups, was conducted with the general public, public health leaders, and groups eligible for vaccination to understand their knowledge, attitudes, and beliefs about Ebola vaccines and the vaccine trial.

STRIVE leadership was committed to transparency about the proposed design and to sharing all data available on the vaccine. Leaders from COMAHS and MoHS conducted

TABLE 1. Challenges and solutions of implementing Sierra Leone Trial to Introduce a Vaccine against Ebola

Challenge	Solution
No -80°C (-112°F) freezers or method of transport at -80°C (-112°F)	Purchase and international shipping of freezers; phase change material transporters (Arktek)
No appropriate space for enrollment and vaccination	Identify, negotiate use, and renovate some facilities
No space for data entry and management	Build and renovate facilities
No reliable Internet for data entry, storage, and transmission	Installation of satellite routed Internet and wireless capacity
No reliable power for cold chain, laboratory, and participant follow-up sites	Installation of generators, solar panels, and backup batteries
Health status of population unknown; poor and dispersed health care access	Establish free medical care; provide supplies to upgrade intensive care unit at referral hospital
Misinformation and misconceptions on vaccines and the motives of the trial organizers	Focus groups, key informant interviews, informational sessions, extensive communication materials
Relevant supplies limited in country	Procure and ship supplies internationally
No basic equipment (e.g., centrifuges) in country for serology study	Procure and ship equipment internationally
No staff GCP training; inexperienced research staff	Conduct large scale, in person training; repeated retraining on operating procedures

Abbreviations: GCP = Good Clinical Practice; STRIVE = Sierra Leone Trial to Introduce a Vaccine against Ebola.

numerous outreach sessions with tribal and religious leaders of selected chiefdoms, district health leaders, and professional organizations to explain the proposed trial, to understand concerns, and to garner support and feedback. Study team members also met with leaders of every eligible health facility. This outreach established relationships between STRIVE staff and the health care community in the study areas, which enabled continuous dialogue on the trial. In February 2015, STRIVE leadership presented the trial plans to the full government and to the news media.

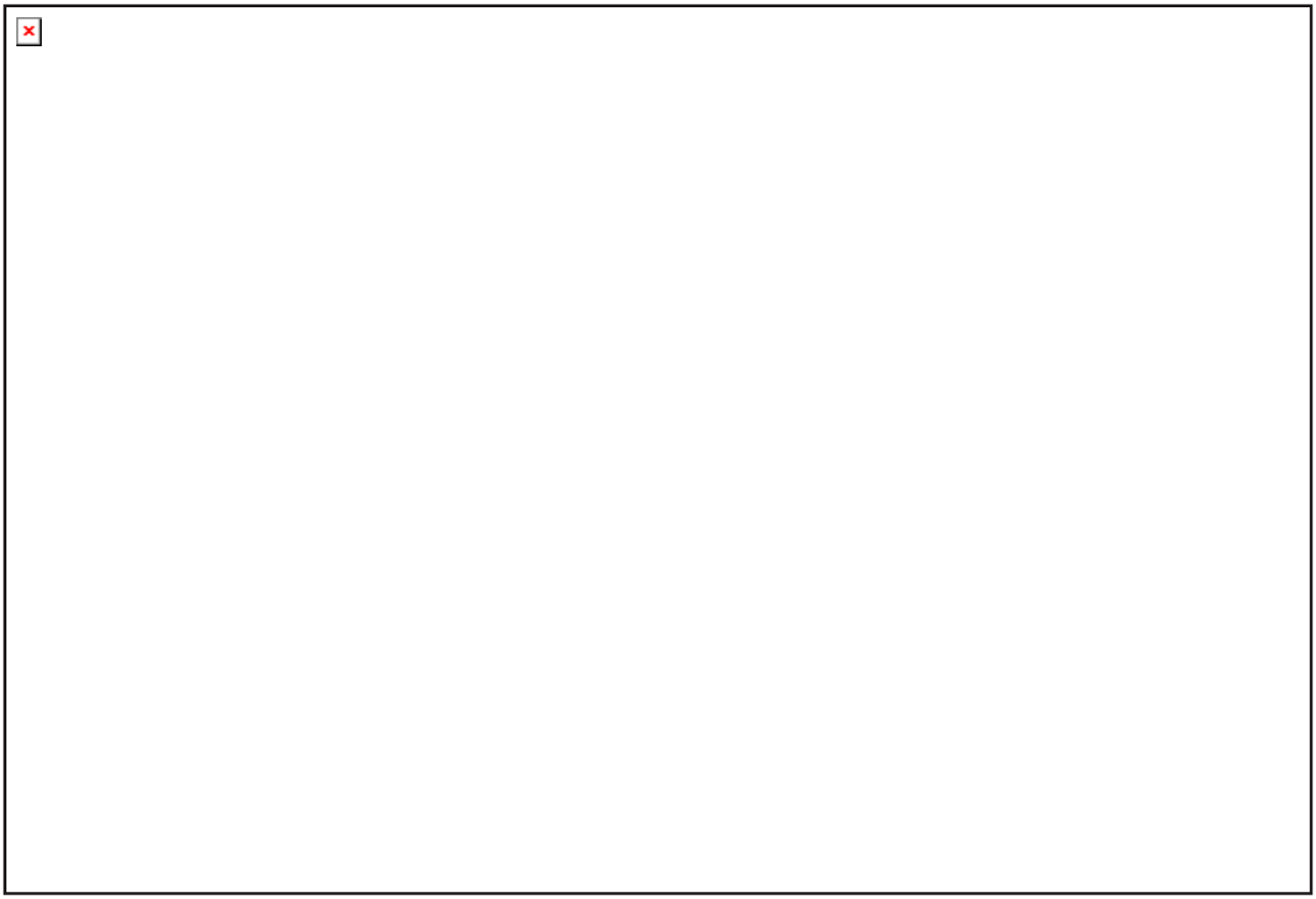
Beginning in March 2015, the STRIVE team held 175 informational sessions in facilities in the areas where the clinical trial was to take place to introduce it to potential participants using materials developed as a result of the formative research. At enrollment, participants were provided with similar materials on all aspects of the trial and an informed consent form. Participants also had 24-hour access to a hotline with trained staff to answer questions about the trial and procedures.

Trial Status

Seven trial enrollment sites were set up in five Sierra Leone districts (one in each of Western Urban, Western Rural, Bombali, and Tonkolili districts and three in Port Loko district). Enrollment and vaccinations began on April 9, 2015, in the Western Rural location; the other six sites were opened during the subsequent 11 weeks and remained open for varying periods, depending on the estimated size of the local population of eligible frontline workers and HCWs (Figure 1). Enrollment ended on August 15, 2015, and sites began reopening to vaccinate the deferred group on September 19, 2015. Vaccination was completed on December 12, 2015, and as of April 28, 2016, on the basis of preliminary data, 8,673 participants were enrolled and 8,016 vaccinated, of whom 3,826 received deferred vaccination (Figure 2).

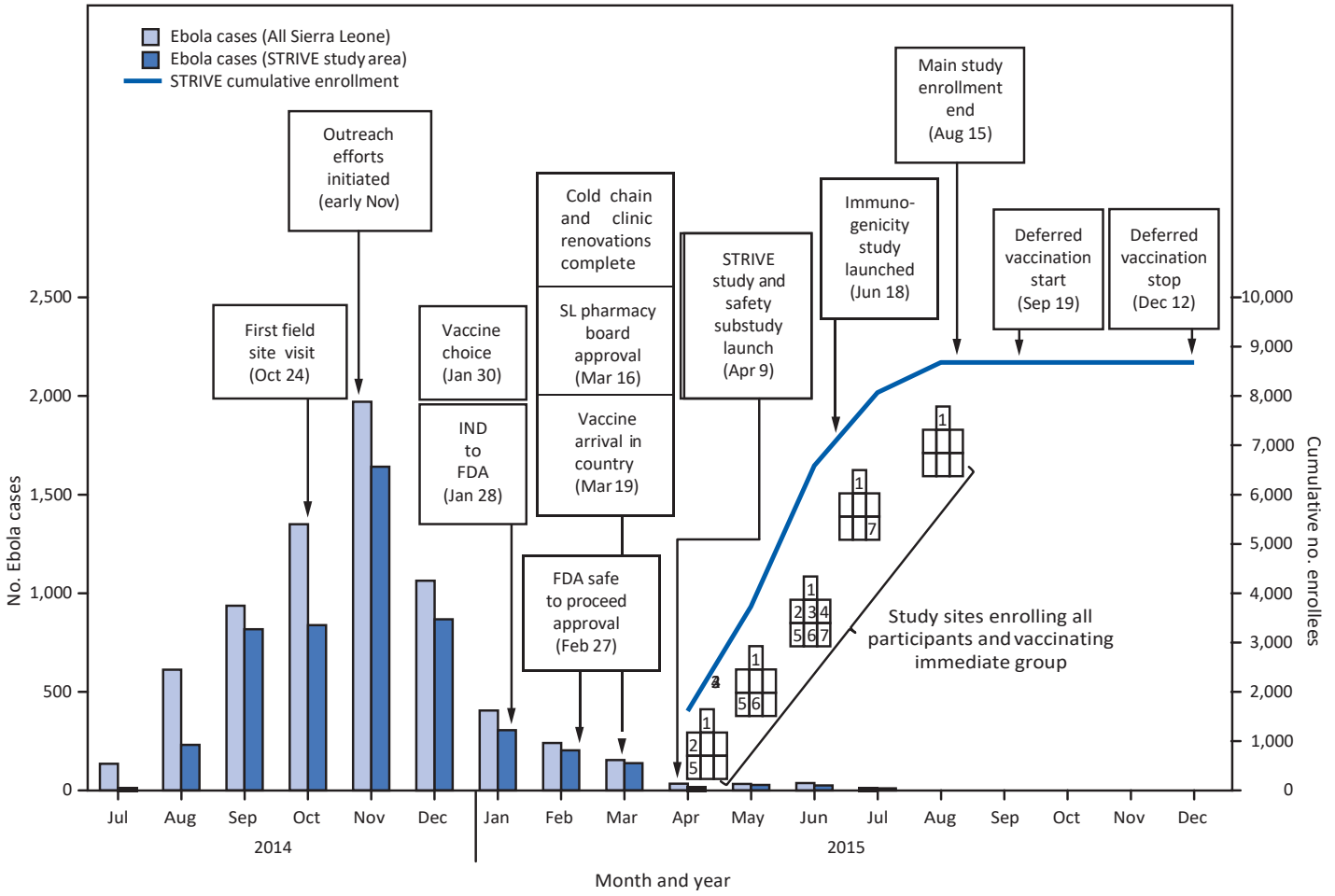
A total of 539 participants enrolled in the immunogenicity study. Of these, 509 provided baseline blood samples, of whom 466 (92%) provided a day-28 blood sample and 411 (81%)

FIGURE 1. Study sites and enrollment through October 2015 for the Sierra Leone Trial to Introduce a Vaccine against Ebola



Abbreviations: COMAHS = College of Medicine and Allied Health Sciences, University of Sierra Leone; STRIVE = Sierra Leone Trial to Introduce a Vaccine against Ebola.

FIGURE 2. Timeline of Sierra Leone Trial to Introduce a Vaccine against Ebola enrollment and implementation, by number of cases, enrollees, and month — seven sites,* Sierra Leone, July 2014–December 2015



Source: Sierra Leone National Emergency Response Center situational reports.
Abbreviations: Ebola = Ebola virus disease; FDA = Food and Drug Administration; IND = investigational new drug application; SL = Sierra Leone; STRIVE = Sierra Leone Trial to Introduce a Vaccine against Ebola.
* Active study sites (indicated by numbered boxes): 1 = Connaught Hospital (Western Urban district); 2 = College of Medicine and Allied Health Sciences Library, University of Sierra Leone (Western Rural district); 3 = Port Loko Government Hospital (Port Loko district); 4 = Holy Spirit Hospital (Bombali district); 5 = Magburaka Government Hospital (Tonkolili district); 6 = St. John of God Hospital, Lunsar (Port Loko district); 7 = St. John of God Health Center, Kaffu Bullom (Port Loko district).

provided a 6-month blood sample. The blood draws for months 9–12 after vaccination began in June 2016. The safety substudy enrolled 453 participants (227 immediate vaccinees and 226 deferred vaccinees) in April 2015. As of April 28, 2016, a total of 64 participants had illnesses that were investigated as suspected Ebola, of whom 60 provided specimens for testing, but none were confirmed as Ebola. No serious adverse events related to vaccination have been reported; the data from the safety substudy are generally consistent with data found in phase I trials of the vaccine, and no association of vaccine with arthritis has been noted.

The Future

On August 3, 2015, the WHO-led consortium conducting the ring vaccination trial in Guinea that used rVSV-ZEBOV (Ebola ça Suffit!) reported interim vaccine efficacy results of 100% (95% confidence interval: 75%–100%) and only one serious adverse event (a postvaccinal fever that resolved) (*18*). The trial design was one in which contacts and contacts-of-contacts of index cases (rings) would be vaccinated immediately or 3 weeks after the report of an index case. With these encouraging results, the ring trial expanded to Sierra Leone in September 2015 with the change that all rings receive vaccine immediately. As of April 28, 2016, ring vaccination has been

conducted in response to three cases. Regulatory agencies will be evaluating rVSV-ZEBOV and other Ebola vaccines for licensure as more data on efficacy, immunogenicity, and safety become available. Until that time, access to candidate vaccines requires enrollment in a clinical trial.

On November 7, 2015, WHO declared the end of EBOV transmission in Sierra Leone. In January 2016, however, two new cases were reported in Sierra Leone. Several factors contribute to a persistent risk for new Ebola cases and clusters: 1) an increase in standard patient care and handling with reduced protection; 2) increases in population movements, including introduction from neighboring countries; and 3) the persistence of viable EBOV in recovered patients, potentially resulting in recrudescence of illness or transmission through semen (*19*). Ongoing vigilance will be necessary, possibly in addition to a variety of vaccine approaches, to extinguish transmission altogether in the region. Gavi, the Vaccine Alliance has committed US $300 million to purchase a licensed vaccine and US $45 million for costs of vaccination campaigns (*20*).

Although STRIVE will not be able to measure vaccine efficacy because of the absence of reported EBOV transmission in HCWs during the study period, STRIVE will provide key data on safety, reactogenicity, and immunogenicity to inform licensure. The impact and accomplishments also extend beyond contributing data needed for vaccine licensure and support any vaccine deployment. These include lessons on acceptance of the vaccine; improved cold chain infrastructure, including various new technologies; capacity for basic laboratory work and data management; communication expertise; and staff experienced with this vaccine (Table 2). A longer-term benefit is a newly forged relationship between institutions in Sierra Leone and CDC, a relationship that has strengthened capacity in Sierra Leone to better and more rapidly investigate and control future infectious disease outbreaks and prevent any repeat of an Ebola epidemic of this scale.

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Disclosure of Relationship

The STRIVE study authors disclose that they have no financial conflicts of interest.

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TABLE 2. Present and future impact and accomplishments of Sierra Leone Trial to Introduce a Vaccine against Ebola

Impact	Accomplishments
Contribution to decision on licensing of Ebola vaccine	Generated data on • vaccine safety (serious adverse events*) for approximately 8,000 vaccinees; • vaccine safety (detailed reactogenicity) for participants randomized to either receive vaccine immediately (approximately 200) at enrollment or 18–24 weeks later (approximately 200); • vaccine immunogenicity among approximately 500 vaccinees; and • duration of humoral response among 300–500 vaccinees.
Supported rollout of licensed Ebola vaccines	Generated information about • vaccine acceptance in Sierra Leone communities, and • feasibility and logistics of use of Ebola vaccine with challenging storage and handling requirements. Developed communication plans and materials developed for trial built on research in community. Built cold chain capacity and power solutions to hold and transport vaccine at -80°C (-112°F).
Strengthened capacity to conduct public health research	Trained • at least 350 national staff in GCP and human subjects research, and • four national staff in laboratory practice. Built conference center for use as participant follow-up site. Developed foundation for long-term relationship between COMAHS and CDC.
Prevented Ebola infections	Vaccinated approximately 8,000 high-risk persons with vaccine that is likely effective during period when EBOV was still actively circulating.

Abbreviations: COMAHS = College of Medicine and Allied Health Sciences, University of Sierra Leone; Ebola = Ebola virus disease; EBOV = Ebola virus; GCP = Good Clinical Practice.

* According to the regulatory definition, serious adverse events involve hospitalization or prolongation of hospitalization, death, or reported life-threatening illness or permanent disability. Food and Drug Administration 21 CFR Part 600.80. Postmarketing reporting of adverse experiences. Federal Register 1991;62;52252–3.

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Ebola virus disease: a literature review

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ABSTRACT

Ebola virus disease (EVD) is a life-threatening viral disease with a fatality rate ranging from around 30% to 90%. The first EVD outbreak was reported in the 1970s in Zaire (now the Democratic Republic of the Congo). Until 2013, most outbreaks occurred in the Central Africa region, including Zaire, Sudan and Uganda. However, between March and October 2014, over 10 000 cases of EVD have been recorded in West Africa, such as in Guinea, Liberia, Sierra Leone, and Nigeria, and a few hospital or secondary infections of EVD have occurred in Spain and the United States of America. EVD is presently one of the world's most feared diseases. In this literature review, we describe the epidemiology, clinical features, diagnosis, and treatment of EVD.

1. Introduction

Ebola virus (EBOV) belongs to the family Filoviridae, the genus *Ebolavirus*, and frequently causes fatal infection in humans[1]. EBOV disease (EVD) may show multiple, serial, and nonspecific-disease symptoms including high fever, headache, vomiting, anorexia, diarrhea, and aching muscles[1-4]. Unexplained bleeding in the eyes, nose, gums, and gut occurs in the advanced stages[1-4]. The first outbreak of EVD was reported in 1976 in the Democratic Republic of the Congo[5]. Since then, there have been reports of small EVD outbreaks in some countries in Central Africa, including Sudan and Uganda[1,6], with an estimated 2350 cases of EVD occurring between the1970s and 2013. The disease can therefore be regarded as endemic to some areas of Central Africa.

In March 2014, an outbreak of EVD was reported for the first time in West Africa, in Guinea, and it spread rapidly to neighboring countries including Liberia and Sierra Leone, creating a serious epidemic[7]. This has caused major health concerns both in and beyond the region, with the World Health Organization (WHO) and numerous countries initiating health monitoring and containment measures[8,9]. We describe here the previous and current epidemics, epidemiology, clinical features, diagnosis, and treatment of EVD as described to date in the literature.

2. EVD epidemics from the 1970s to 2013

Summarized epidemics data from the 1970s to 2013 are shown in

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Table 1. EVD first emerged in 1976 in the Democratic Republic of Congo (DRC) and at around the same time in Sudan. Among these epidemic areas, 318 cases were recorded in DRC [case fatality rate (CFR): 88%] and 284 cases in Sudan (CFR: 53%)[5]. As the first reports of the epidemic occurred near the Ebola River, DRC, the disease became known as Ebola hemorrhagic fever (EHF)[7,10], and two different species of EBOV were confirmed: EBOV-Zaire (EBOV-Z) and EBOV-Sudan (EBOV-S). In 1977, one fatal case due to EBOV-Z was reported in Zaire, and EBOV-S subsequently reemerged with 34 cases, 22 of which were fatal, in Sudan in 1979.

No further cases were recorded until 1994, when a new species of EBOV was confirmed in a non-fatal case in the Ivory Coast and named EBOV-IC. One case was confirmed who had traveled from Liberia to Sierra Leone and had antibodies to EBOV, suggesting existence of EBOV-IC in Liberia[11]. These episodes suggest that EBOV had spread from areas in Central Africa to West Africa. In 1995, EVD due to EBOV-Z reemerged in the DRC[12]. An estimated 315 cases and 250 deaths (CFR: 81%) occurred during this large epidemic. The EBOV-Z species identified was shown to have a close genetic relationship with the strains isolated in 1976 in Zaire[13]. EBOV-S then emerged in Uganda during 2000-2001, resulting in an estimated 425 cases and 224 deaths (CFR: 53%). The EBOV species identified could be clearly placed among the EBOV-S strains isolated in 1976 in Sudan[1,14,15]. In 2004, an EBOV-S outbreak of 17 cases and 7 deaths (CFR: 41%) was reported in Yambio County, South Sudan. The index case had butchered a monkey, and human-to-human transmission was mainly through direct contact[16]. Outbreak of EBOV-Z occurred in the Republic of Congo in 2002-2003 with 143 cases (128 deaths, CFR: 89%) and in the DRC in 2007, with 264 suspected cases and 187 deaths (CFR: 71%) recorded[17,18]. In November 2007, a new EBOV species, designated Bundibugyo ebolavirus (EBOV-B), was identified in Western Uganda, and 149 suspected cases and 37 deaths had been reported by January 2008 as the outbreak neared conclusion[19]. In the 2008 Ebola outbreak, there were 32 cases including 15 deaths (CFR: 47%) in Kasai Occidental Province in the DRC[20,21]. In May 2011, a patient with suspected EHF died after contacting EBOV-S in Luwero District, Uganda[22], and the following year an outbreak among 11 patients resulted in 4 deaths from EHF in Kibaale District[23]. Another EVD outbreak occurred in the DRC

Table 1

Outbreaks of EVD from 1970s to 2014*.

Year	Outbreak location	Species	Human cases		
			Reported number of human cases	Reported number of deaths among cases	CFR (%)
1976	Democratic Republic of the Congo (formerly Zaire)	Zaire	318	280	88
1976	Sudan (South Sudan)	Sudan	284	151	53
1976	England	Sudan	1	0	0
1977	Zaire	Zaire	1	1	100
1979	Sudan (South Sudan)	Sudan	34	22	65
1989	USA	Reston	0	0	0
1990	USA	Reston	4 (asymptomatic)	0	0
1989-1990	Philippines	Reston	3 (asymptomatic)	0	0
1992	Italy	Reston	0	0	0
1994	Gabon	Zaire	52	31	60
1994	Côte d'Ivoire (Ivory Coast)	Taï Forest	1	0	0
1995	Democratic Republic of the Congo	Zaire	315	250	81
1996 (January-April)	Gabon	Zaire	37	21	57
1996-1997 (July-January)	Gabon	Zaire	60	45	74
1996	South Africa	Zaire	2	1	50
1996	USA	Reston	0	0	0
1996	Philippines	Reston	0	0	0
1996	Russia		1	1	100
2000-2001	Uganda	Sudan	425	224	53
October 2001-March 2002	Gabon	Zaire	65	53	82
October 2001-March 2002	Republic of the Congo	Zaire	57	43	75
December 2002-April 2003	Republic of the Congo	Zaire	143	128	89
November-December 2003	Republic of the Congo	Zaire	35	29	83
2004	Sudan (South Sudan)	Sudan	17	7	41
2004	Russia	Zaire	1	1	100
2007	Democratic Republic of Congo	Zaire	264	187	71
December 2007-January 2008	Uganda	Bundibungyo	149	37	25
November 2008	Philippines	Reston	6 (asymptomatic)	0	0
December 2008-February 2009	Democratic Republic of the Congo	Zaire	32	15	47
May 2011	Uganda	Sudan	1	1	100
June-October 2012	Uganda	Sudan	11*	4	36
June-November 2012	Democratic Republic of the Congo	Bundibugyo	36*	13	36
November 2012-January 2013	Uganda	Sudan	6*	3	50
March 2014-Present	Various contries	Zaire	15 113*	5 406	36

*: These data are based on earier reports[1-28]; CFR: Case fatality rate.

in 2012, and 13 of the 36 laboratory-confirmed cases died[24,25]. None of the abovementioned outbreaks had epidemiologic links[1].

3. Initial EVD epidemiology in 2014

An epidemiologic investigation of laboratory-confirmed cases indicated that the first fatality of the current 2014 outbreak occurred in December 2013 in Guinea[4]. The patient was a 2-year-old child, and 8 other deaths were confirmed between December 2013 and February 2014 in the same village (Meliandou village, Guéckédou Prefecture). The disease may have spread from some of these patients to others in neighboring prefectures such as Macenta, Nzérékoré, and Kissidougou[4]. Guéckédou and Macenta prefectures are bordered to the north by Liberia and Sierra Leone. The epidemiologic investigation reported 15 fatal laboratory-confirmed EVD cases[4]. EBOV-Z was identified as the causative agent and phylogenetic analysis suggested that an independent cluster had formed from the previously identified EBOV strains from the DRC and Gabon[4].

4. EVD epidemics in West Africa in 2014

The relatively small EVD outbreaks in Guinea may have spread to neighboring countries such as Liberia and Sierra Leone[26]. As of 16 November 2014, 15 113 EVD cases have been reported (confirmed, probable and suspected cases) in eight countries since the epidemic began. Among them, 5406 deaths have occurred (CFR: 35.8%)[27]. As of November 2014, EVD cases in Guinea, Liberia, and Sierra Leone amount to 1 971 (CFR: 60.4), 7 069 (CFR: 41.9%) and 6 073 (CFR: 20.6%), respectively[27], with some cases being reported further afield in Mali, Nigeria, and Senegal[27]. Four EVD patients reported in the United States of America and one in Spain have all involved in medical personnel or those who worked in the epidemic areas[27]. Detailed geometric data are shown in Figure 1.

5. Virology of EBOV

EBOV belongs to the family *Filoviridae* and the genus *Ebolavirus*[1,10]. Five EBOV species have been identified: EBOV-Z, EBOV-S, EBOV-IC, EBOV-B, and Reston ebolavirus. The prefix of the family name „filo‰ originates from the Latin word for thread or string. Virions have multiple morphological forms of very long filamentous rods or compact convoluted shapes (diameter around 80 nm, length 800-14000 nm)[1]. The EBOV genome is a single negative-sensed RNA (genome size 19 Kb). The virions contain 7 proteins: nucleoprotein, viral proteins 24, 30, 35, and 40, glycoprotein (GP), and L protein. The structure of the genome is similar among the species, but phylogenetic analysis has shown the species have formed independent lineages with wide genetic divergence (Figure 2). Notably, the virulence of each species may differ markedly from the others[1,3]. For example, EVD cases due to EBOV-Z and EBOV-S show high CFRs of over 70% and 50%, respectively, while the CFR for EBOV-B is around 27%[3,28]. Reston ebolavirus may have low or no virulence in humans, but it is thought that the virus is highly virulent in simians[1].

Phylogenetic analysis based on the *GP* gene sequences of EBOV detected in patients from the current epidemic areas have been confirmed as EBOV-Z strains and they have close genetic relationships

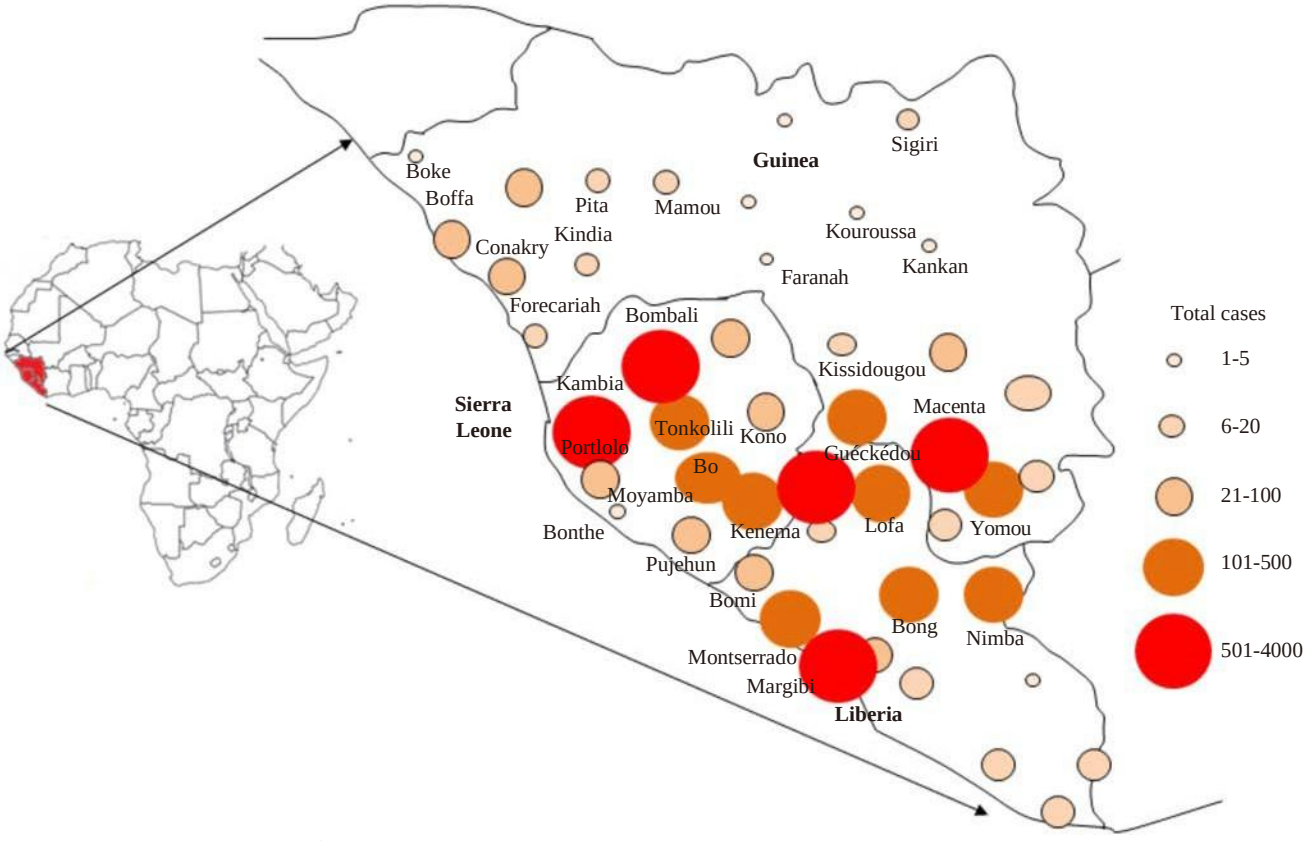

Figure 1. Detailed geometric data of the EVD outbreak.
The data shown are based on a report by the WHO[28].

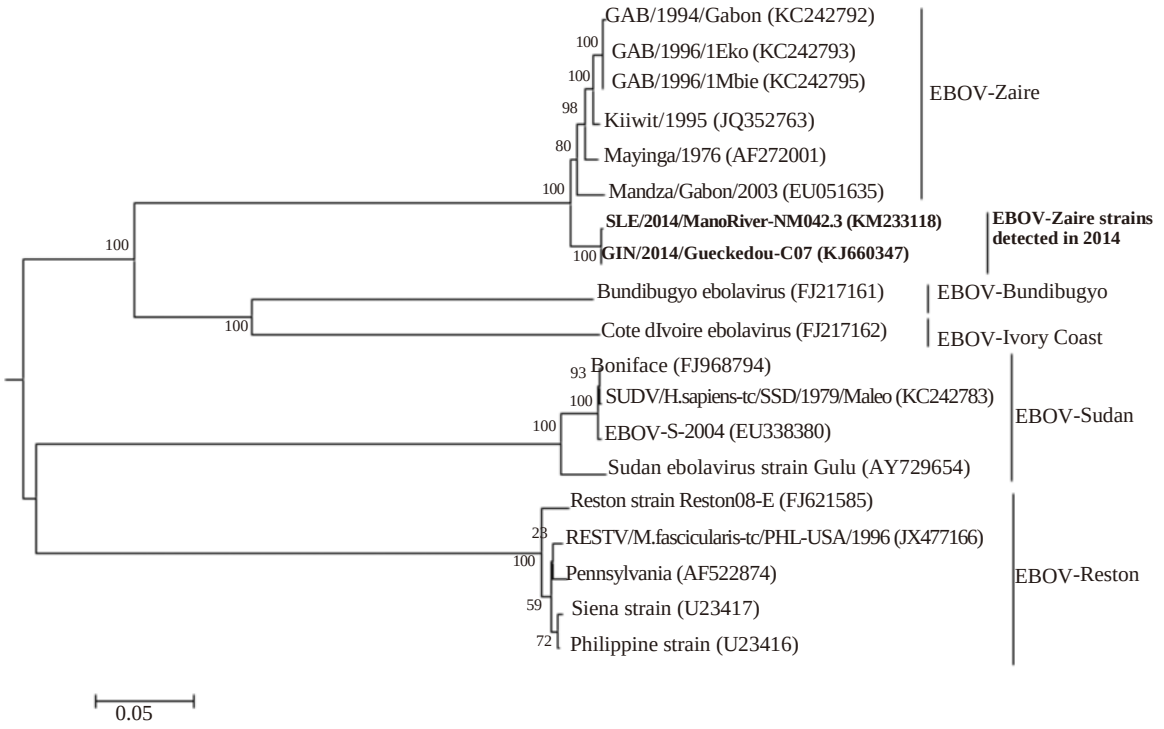

Figure 2. Phylogenetic tree of Ebola virus *GP* gene.
Distances were calculated according to KimuraÊs 2-parameter method and the tree was plotted by the neighbor-joining method (1000 bootstrap replications). Numbers at each branch indicate the bootstrap values of the clades supported by that branch.

(Figure 2)[28,29]. However, the genetic properties of these strains may be different from typical EBOV-Z[29]. In addition, the CFR for the present EBOV-Z epidemics is relatively low (around 40%-50%) compared with typical EBOV-Z[30], while in a recent report with laboratory confirmed cases, the CFR is 74% in Sierra Leone[31]. The reason for the difference in virulence among the strains is not known.

6. Transmission routes

Although the life cycles of EBOV species are not precisely known, the natural hosts (reservoirs) of EBOV are thought to be a species of fruit bat[32,33]. It is known that EBOV can transmit from bats to some species of simians[9], so EBOV-infected bats and simians may be an infectious source of EBOV when handled or consumed by humans[9].

It is thought that almost all human-to-human EBOV infections are due to direct contact with blood and/or body fluids (*e.g.*, saliva, mucus, vomit, feces, sweat, tears, breast milk, urine, and semen) from symptomatic/dead patients[7]. Thus, extreme care must be taken when handling the body fluids of patients with EVD to avoid infection[7]. Indeed, two thirds of the EVD cases in the Guinea epidemic during 2014 may have contacted the virus via unprotected (or unsuitably protected) contact with infected corpses during Guinean burial rituals.

7. Clinical features of EVD

EVD tends to cause the severest form of viral hemorrhagic fever in humans. Most EVD cases manifest as a sudden onset of influenza-like symptoms, such as high fever, chills, malaise, and myalgia[1,3,6,34], which may develop to systemic gastrointestinal symptoms (vomiting and diarrhea) and respiratory (chest pain and cough), vascular (conjunctival injection and edema), and neurological (headache, confusion, and coma) symptoms[1,3,6]. Hemorrhagic symptoms may follow, including petechiae, ecchymosis, and uncontrolled mucosal hemorrhage[1,3,6]. These symptoms can resemble other diseases however, such as malaria, cholera, typhoid fever, meningitis, and other viral hemorrhagic fevers. Cause of death is usually from multiple organ failure due to these complications[1,3,6].

General laboratory data are nonspecific to EVD[1,3,35]. In the early phase of the disease, leukocytopenia and lymphocytopenia may be evident in peripheral blood, and subsequent neutrophilia and thrombocytopenia are often seen[1,3]. In addition, elevation of ectopic enzymes such as aspartate transaminase and alanine aminotransferase is common[1,3]. Abnormalities may occur in the blood coagulation system, such as prolonged prothrombin and partial thrombin time. At the end stage, secondary bacterial infections such as pneumonia may develop[1,3]. In nonfatal cases, a high fever may continue for about 5 to 9 d, but symptoms improve around 7 to 10 days after onset[1,3,36]. At that time, a humoral antibody response may be noted.

There are no specific symptoms in the early stage of EVD; thus, laboratory confirmation is essential[1]. RT-PCR and/or immunological methods (ELISA) are generally used for detection, as with other viral infections[1].

8. Present status of therapeutic drug developments for EVD

At present, there is no approved definitive treatment, such as vaccines or anti-viral drugs, for EVD[3,34]. Therefore, symptomatic treatment methods including infusion of electrolyte and/or antibiotics are mainly used[1,3].

Two promising candidate vaccines against EVD have been reported to date. The US National Institute of Allergy and Infectious Diseases and GlaxoSmithKline have developed one candidate EVD vaccine, cAd3-ZEBOV[37]. The vaccine is a chimpanzee-derived adenovirus vector with an Ebola virus gene inserted. The second candidate, rVSV-ZEBOV, has been developed by the Public Health Agency of Canada in Winnipeg[38]. The availability of these drugs for clinical use is eagerly awaited.

The experimental drug ZMapp has been administered in 3 cases so far. It contains three monoclonal antibodies (mAbs) that are designed to neutralize EBOV[39]. The mAb cocktail binds to and neutralizes the GP protein of EBOV and has been shown to prevent infection in monkeys[39]. ZMapp was administered to 2 American EVD patients who were infected while treating EVD patients in Liberia during the recent epidemic[40], and both completely recovered from serious EVD; however, another Spanish patient treated with the same drug has died[40]. It is too early to tell how effective this experimental treatment will be.

Among the anti-viral drugs under development, a nucleic acid analog known as „favipiravir‰ may be applicable to the treatment of EVD[41]. This drug was originally developed as a treatment for influenza[41,42] and it inhibits the synthesis of viral RNA through the action of RNA-dependent RNA polymerase (RdRp) of influenza virus[42]. Some mechanisms of viral RNA synthesis are similar between EBOV and influenza viruses[43], so it is expected that the drug will have similar effects on the RNA synthesis of EBOV. Indeed, significant effects against EVD have been reported in mice[43]. We may therefore see favipiravir being tried clinically in the present EVD epidemic.

9. Conclusion

We have described current knowledge of EVD based on a review of the literature. With the knowledge we have thus far, it appears that it will be difficult to predict the extent and outcomes of EVD epidemics in the future. However, about 30 years ago, human immunodeficiency virus (HIV) infection suddenly emerged and spread throughout the world, and now, thanks to continuous efforts by the medical community, effective treatment methods against HIV infection are available, although the disease cannot yet be eradicated. EBOV and EVD are poorly understood at present, but there is hope that effective treatment methods to combat EVD will soon be developed.

Conflict of interest statement

We declare that we have no conflict of interest.

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