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Authors

Kirsch, Thomas D
Moseson, Heidi
Massaquoi, Moses
[et al.](#)

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Impact of interventions and the incidence of ebola virus disease in Liberia—implications for future epidemics

Thomas D Kirsch,^{1,2} Heidi Moseson,³ Moses Massaquoi,⁴
Tolbert G Nyenswah,⁴ Rachel Goodermote,¹
Isabel Rodriguez-Barraquer,¹ Justin Lessler,¹ Derek A T Cumings^{1,5} and
David H Peters¹

¹Johns Hopkins University, Bloomberg School of Public Health, Baltimore, MD, USA, ²Department of Emergency Medicine, Johns Hopkins University School of Medicine, Baltimore, MD, USA, ³Department of Epidemiology & Biostatistics, University of California, San Francisco, San Francisco, CA, USA, ⁴Liberian Ministry of Health, Tubman Blvd, Monrovia, Liberia and ⁵Department of Biology and Emerging Pathogens Institute, University of Florida, FL, USA

Corresponding author. Thomas D. Kirsch, MD, MPH, Department of Emergency Medicine, 5801 Smith Ave, Davis Building, Baltimore, MD 21209, USA; Tele: 410 955 8191; E-mail: tkirsch1@jhmi.edu

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Abstract

To better understand the impact of national and global efforts to contain the Ebola virus disease epidemic of 2014–15 in Liberia, we provide a detailed timeline of the major interventions and relate them to the epidemic curve.

In addition to personal experience in the response, we systematically reviewed situation reports from the Liberian government, UN, CDC, WHO, UNICEF, IFRC, USAID, and local and international news reports to create the timeline. We extracted data on the timing and nature of activities and compared them to the timeline of the epidemic curve using the reproduction number—the estimate of the average number of new cases caused by a single case.

Interventions were organized around five major strategies, with the majority of resources directed to the creation of treatment beds. We conclude that no single intervention stopped the epidemic; rather, the interventions likely had reinforcing effects, and some were less likely than others to have made a major impact. We find that the epidemic's turning coincided with a reorganization of the response in August–September 2014, the emergence of community leadership in control efforts, and changing beliefs and practices in the population. Ebola Treatment Units were important for Ebola treatment, but the vast majority of these treatment centre beds became available after the epidemic curve began declining. Similarly, the United Nations Mission for Ebola Emergency Response was launched after the epidemic curve had already turned.

These findings have significant policy implications for future epidemics and suggest that much of the decline in the epidemic curve was driven by critical behaviour changes within local communities, rather than by international efforts that came after the epidemic had turned. Future global interventions in epidemic response should focus on building community capabilities, strengthening local ownership, and dramatically reducing delays in the response.

Keywords: Ebola/Ebola virus disease (EVD), Liberia, infectious disease, global health, health policy

Key Messages

- The epidemic curve began decreasing before most global efforts were in place, limiting their impact on stopping the epidemic's spread.
- Future global interventions should focus on strengthening local leadership, individual and community behaviour change, along with better body management and burial.
- Early models of the Ebola outbreak in Liberia and the resulting global strategies highlighted less important interventions, notably the rapid building of ETUs, and proved inaccurate.

Introduction

Now that the Ebola virus disease (EVD) epidemic in Liberia has abated, it is important to learn from the lessons of its defeat. Recent work has claimed that building Ebola Treatment Units (ETUs) (Chowell and Viboud 2015) or that deploying the United Nations Mission for Ebola Emergency Response (UNMEER) (WHO Ebola Response Team, 2015) were responsible for defeating the epidemic. These claims, however, have not been substantiated with a systematic evaluation of the timing of interventions in relation to the actual epidemic curve. Understanding which interventions impacted the epidemic is critical to building resilient health systems in Liberia and for future management of public health emergencies around the world. The purpose of this paper is to systematically assess the major areas of intervention during the Liberia EVD outbreak, and to examine their relationship with changes in the epidemic curve.

The first case of EVD in West Africa occurred in Guinea near the Sierra Leone and Liberian border in December 2013, but EVD was not confirmed until March 20, 2014. The first cases in Liberia were reported in Lofa and Margibi counties during the third week of March, but were seemingly quickly contained with fewer than 20 suspected cases reported (Dahn 2014a). In late May, however, cases re-emerged and spread rapidly to the capital city, Monrovia (Montserrado County) and throughout the rest of the country by the end of September 2014. Over 8,000 suspected, probable and confirmed EVD cases were recorded by the Liberian Ministry of Health and Social Welfare (MOHSW) from March through December 2014, of which over 3,000 were laboratory-confirmed (Figure 1) (WHO 2015a). By the end of 2014, hundreds of millions of dollars had been spent to stop the Liberian epidemic (World Bank 2014a). Cases of EVD in Liberia peaked at 420 reported during the second week of September, the same week the United States government announced a US\$319 million response plan, the World Bank announced US\$105 million in funding for West Africa, and the United Nations (UN) released 'EVD Outbreak Overview of Needs and Requirements' that outlined nearly US\$1 billion in funding needs (UNOCHA 2014a). Thereafter, the number of new cases per day began decreasing rapidly, even though these funds and related activities had not yet been executed.

Early models of the outbreak predicted that up to 1.4 million EVD cases would occur in Liberia and Sierra Leone by January 2015 without appropriate interventions (Shaman *et al.* 2014; Meltzer *et al.* 2014; Fisman *et al.* 2014; Lewnard *et al.* 2014). The United States Centers for Disease Control and Prevention (CDC) model predicted that without 70% of patients isolated in ETUs or at home, cases would triple every 30 days, and that 20 000–50 000 ETU beds were needed in Sierra Leone and Liberia before 2015 (Meltzer *et al.* 2014). These models reinforced plans

to massively expand ETU bed capacity as a central response strategy.

In August 2014, the World Health Organization's (WHO) *Ebola Response Roadmap* outlined key strategies for stopping the epidemic, including (WHO 2014a):

- Build ETUs to safely isolate and treat infected persons
- Set up laboratories to test and identify infected persons
- Identify EVD cases through surveillance and contact tracing
- Safe burial and body management
- Social mobilization to educate people about preventing EVD

We create a detailed timeline of the interventions implemented during the EVD outbreak in Liberia, and map these efforts to the epidemic curve in an effort to highlight which interventions likely did, as well as which likely did not, have an impact on the draw-down of the epidemic.

Methods

In addition to personal knowledge gained from work in Liberia during the epidemic, we systematically reviewed documents from the Liberian MOHSW, Liberian Ministry of Finance, Liberian Incident Management System (IMS), UN, CDC, WHO, UNICEF, Liberian Incident Management System (IMS) Logistics Cluster, International Federation of the Red Cross (IFRC), United States Agency for International Development (USAID), and various local and international news media. Documents were identified from publically available sources such as ReliefWeb, the Liberian government and websites of the listed organizations. Some documents were only available to the authors who led and participated in the Incident Management System (IMS) meetings during the response.

The strategies outlined in the *WHO Roadmap* serve as the framework for this analysis, with the addition of financing and international activities. We thus describe the timeline of the Liberian EVD response in seven areas: 1) National and international initiatives; 2) Financial commitments; 3) Health care and ETUs; 4) Laboratory services; 5) Contact tracing; 6) Safe burial/body management; and 7) Social mobilization.

Epidemic curve in Liberia

The most common indicator of efficiency of transmission of an infectious disease is the reproduction number (R_t). R_t is an estimate of the average number of individuals infected by each case. The reproduction number is used as an indicator of an epidemic's trajectory: an R_t below 1 signifies a declining epidemic, while an R_t above 1 signifies a growing epidemic. We estimated R_t using the EpiEstim R package and data from the Liberian Viral Hemorrhagic Fever database following the method outlined by Cori *et al.* (2013).

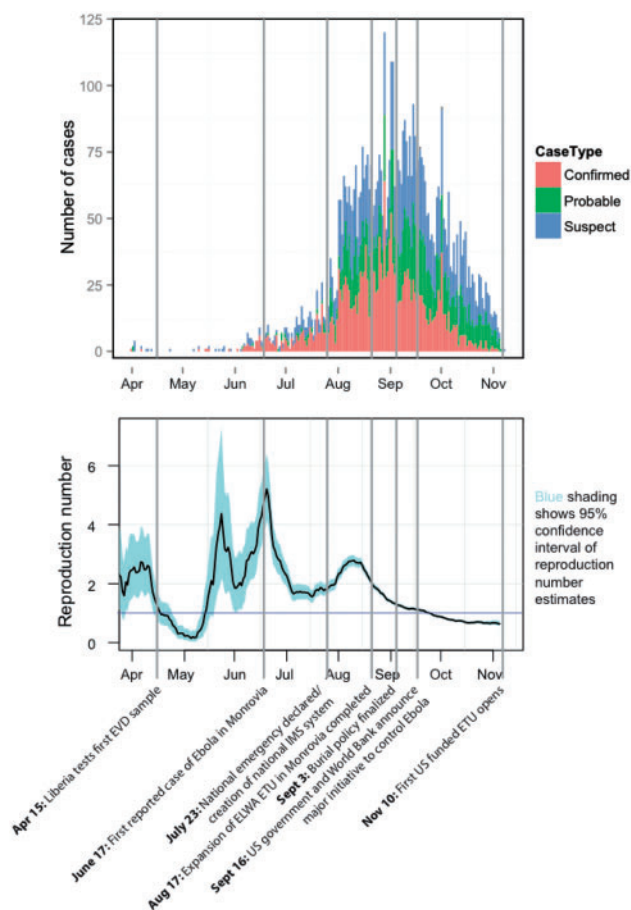


Figure 1. Confirmed, probable and suspected cases of EVD and the outbreak reproductive number in relation to key events, Liberia 2014

Results

Timeline of government and international interventions in 2014

After the first EVD case was confirmed in March 2014, the Government of Liberia (GOL) released a 3-month EVD response plan with a budget of US\$1.2 million. The plan had three pillars: (1) Communication and social mobilization; (2) Case management/treatment and surveillance; and (3) Water sanitation and hygiene (WASH) (WHO 2014a). The MOHSW established the first Ebola Response Taskforce to manage response activities. Simultaneously, assistance from international actors began with the WHO release of the West Africa EVD report, and support from Médecins Sans Frontières (MSF) for the training of Liberians in EVD management and advice on the construction of an ETU in Monrovia (WHO 2014b). Early international partners included the WHO, MSF, IFRC, Samaritan's Purse, Pentecostal Mission Unlimited Liberia, Clinton Health Access Initiative, Global Communities, PLAN-Liberia, United Nations Population Fund and UNICEF (WHO 2014c; Dahn 2014b).

In April, staff from the CDC, WHO and IFRC arrived in Liberia (IFRC 2014a; Dahn 2014c). Early activities included response coordination, data management, infection prevention, surveillance and epidemiologic investigation, opening a laboratory, and social mobilization, including a national hotline for the public (WHO 2014d; WHO 2014e). On April 9, as President Sirleaf addressed the nation about EVD, the last EVD case for almost 2 months was

confirmed (Office of the Press Secretary to the President 2014). As of May 2, no new cases had been identified and the first wave of the epidemic was considered over (UNICEF 2014a). With the end of the first wave, Ebola Task force meetings became less frequent and international organizations reduced staff, but the training of health professionals in EVD care, surveillance and prevention continued (Dahn 2014d).

On May 25, however, the second wave of the epidemic began when a patient who had contracted EVD in Sierra Leone died in Liberia's Lofa county. Eleven new suspected cases were generated (UNICEF 2014b), daily National Task Force meetings resumed, and EVD burial teams were reactivated (UNICEF 2014c).

Several weeks later, on June 17, the first EVD cases were reported in Liberia's densely populated capital, Monrovia, a city of 1.2 million people. These cases turned the remote, rural outbreak into an urban epidemic (BBC 2014). Control of the National Ebola Taskforce (NTEF) was transferred from the MOHSW to the Ministry of Internal Affairs (MIA). MSF called the West African outbreak 'out of control' and urgently called for a massive response on the part of the international community (Winter 2014). International organizations began redeploying staff, and ministers of Health from West Africa met to create a regional framework to strengthen EVD collaboration.

By July, cases had been confirmed in three counties (Montserrado (Monrovia), Lofa and Margibi). Public mistrust and denial were widespread and persisted despite increasing case counts, and led to the attack of several EVD health teams by rural residents (WHO 2014f). On July 22, President Sirleaf declared a State of Emergency, closed schools, furloughed non-essential government staff and closed Liberia's land borders (UNICEF 2014d). Critically, with the support of the CDC, she created the Incident Management System (IMS) chaired by the MOHSW to separate the functions of emergency response from routine health services. Further, she expanded the National Taskforce and the IMS to include the WHO, CDC, UNICEF, United Nations Mission in Liberia (UNMIL), MSF, USAID, and the European Union, among others (Pillai *et al.* 2014). President Sirleaf also created the Presidential Advisory Committee on Ebola (PACE) as the highest decision making group on the Ebola response, chaired by the President herself. The goal was to establish a clear chain of command, ensure accountability, improve efficiency, assist with identifying gaps, and permit national level public health practitioners to focus on a whole-of-country response.

The global community organized a meeting of senior health officials from West Africa, world governments, and the UN in Accra, Ghana on July 2-3 to better coordinate the international response (WHO 2014g; UNICEF 2014e). On July 24, the WHO raised the 'health threat level' from a Level 2 to a Level 3 event and the first EVD case outside West Africa was confirmed in Nigeria (WHO 2015b).

By early August, cases had been confirmed in 13 of Liberia's 15 counties. The State of Emergency was extended to 90 days and a full-time IMS chief was appointed (UNICEF 2014f; Pillai *et al.* 2014). The affected areas were quarantined using military roadblocks, and public mistrust remained widespread—mistrust that may have motivated the looting of an EVD holding centre in Monrovia on August 16. Strict control measures including quarantines of neighbourhoods and a nightly nationwide curfew were imposed; however, these led to riots and food shortages that eventually prompted the lifting of the quarantine (UNICEF 2014g; USAID 2014a; Onishi 2014). By the end of the month, a growing awareness of the need for decentralized control spurred the GOL's creation of

county-level Ebola Taskforces to strengthen local coordination (Dahn 2014e).

The attention of the global community increased dramatically in August, as case counts continued to rise. The US Ambassador to Liberia declared an 'EVD disaster' on August 4 and the US Office of Foreign Disaster Assistance (OFDA) deployed a large team to the three affected countries (Guinea, Liberia and Sierra Leone) (USAID 2014a, b). The WHO declared the Ebola outbreak a 'Public Health Emergency of International Concern' (PHEIC), the highest level of international alert, and high-level delegations from the UN and CDC arrived in Liberia late in the month (WHO 2014h; USAID 2014b).

In early September, the GOL further established its leadership of the EVD response to several important interventions, including the transfer of suspected cases from rural communities to a Monrovia ETU and heightened efforts to remove dead bodies from streets and homes.

As daily case counts peaked in September, large-scale international commitments were finally announced. On September 7, President Obama committed the entire US government to stopping Ebola in West Africa. A week later, on September 16th he announced US\$319 million for the response, making the epidemic a National Security Priority. The plan included deploying up to 3,000 military personnel to build 17 ETUs with 1700 beds total (White House 2014a). That same day, the UN released the *Ebola Virus Disease Outbreak Overview of Needs and Requirements* report that outlined \$1 billion of needed activities throughout West Africa (UNOCHA 2014b), and the World Bank approved an additional \$105 million for the West Africa response, with US\$52 million specifically for Liberia (World Bank 2014b). On September 18, the UN created UNMEER, the first UN mission for an emergency health response (WHO 2014i). The next week, on September 25th the UN Secretary-General and world leaders met to accelerate the global response (UN News Centre 2014).

As all of these efforts began to get underway in September, Liberia saw the highest number of reported weekly cases, but also the beginning of the decline: the R_t crossed below 1 on September 24th. The epidemic had peaked and the number of cases rapidly decreased (Figure 1).

As October began, EVD had been reported in all counties, the Liberian Ambassador to the USA stated that the country 'may be close to collapse' (Kay 2014), and the head of UNMEER arrived in Liberia. By October 15, >600 US government personnel had arrived in West Africa (USAID Press Office 2014). Response management continued to improve and the first 'Comprehensive Ebola Response Dashboard' was used by the IMS to measure progress toward specific goals for each strategy (MOHSW 2014a). GOL efforts focused on coordinating international partners, securing the additional funds, finalizing policy and creating standard operating procedures for each arm of the response. By late October, a 'rapid response team' strategy was in development for the rapid deployment of personnel to areas with new cases to investigate, quarantine and begin treatment (CDC Newsroom 2014).

On November 4, the UN and WHO called for additional international funding, while establishing five logistics hubs throughout Liberia. President Obama similarly requested \$6 billion for the domestic and global EVD response (USAID 2014c). As case counts began to decline, the State of Emergency was lifted on November 13, and President Sirleaf announced her hope of defeating EVD by Christmas (USAID 2014d). With the highest incidence of transmission ongoing in Monrovia, a separate Montserrado-specific IMS and Emergency Operations Center



Figure 2. Bi-weekly and cumulative funds pledged for the EVD response (millions of US Dollars), Liberia, 2014. The vertical red line indicates the date (September 24, 2014) when the reproduction number fell below one, and the EVD epidemic began to decline

were created on November 28 to address the unique urban epidemic (MOHSW 2014b).

Throughout December, the domestic political focus began shifting to the restoration of economic and government activities and the re-establishment of the healthcare system. On December 16, the UN Economic Commission for Africa asked for further debt cancellations for Liberia (UN Economic Commission for Africa 2014).

As 2014 came to a close, over 62 countries had committed US\$2.3 billion to the EVD response in West Africa, including US\$806 million specifically for Liberia (White House 2014b). However, only US\$106 million had been disbursed in Liberia prior to epidemic peak in mid-September (Figure 2) (UNOCHA 2015). As of October 24, the GOL reported that only 30% of the required US\$380 million EVD response funds had been committed and only US\$41 million had been disbursed (MOHSW 2014c).

Although transmission had not been stopped by Christmas, there were fewer than 15 weekly confirmed cases in just four counties by early January 2015. Intervention activities consequently shifted towards rapid isolation and improved contact tracing. On February 19, what was thought to be the last EVD case was confirmed until another isolated case was confirmed on March 19. Seven weeks later, the country was declared EVD-free on May 9, 2015 (MOHSW 2015a). Since that time, there have been three isolated case clusters, all thought to be due to transmission from EVD survivors, but no ongoing transmission in the country (WHO 2015c).

Health care treatment and isolation

The construction of ETU beds was a central strategy of the response. The WHO and MOHSW set an initial target of 2400 ETU beds, with the US government committing to construct up to 1700 beds toward that goal. However, construction was slowed by Liberia's weak transportation infrastructure and the need for high-quality infection control capabilities. Difficulties in recruiting and training healthcare workers arose as a result of fear and uncertainty surrounding the high rate of infection and death among those treating EVD patients, which further delayed the opening of ETUs (UNICEF 2015).

As of August 1, there were fewer than 100 ETU beds in Liberia (Figure 3), and existing health facilities are closed due to the high rate of health care worker infection. Construction had begun on

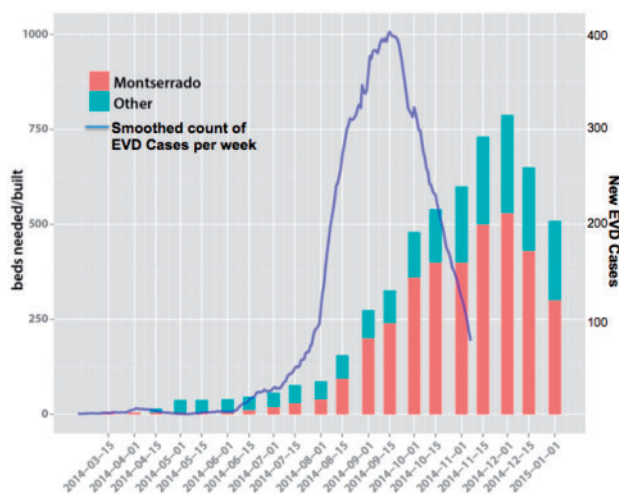


Figure 3. Number of Ebola treatment beds in Montserrado and other counties compared to weekly reported cases, Liberia, 2014

new ETUs, however, and two were opened in Monrovia by September 1 (ELWA2 and ELWA3), for a total of 240 beds in Monrovia, adding to the 40-70 beds available at a facility in Lofa County (Nyenswah *et al.* 2014). On September 21, Island Clinic ETU opened in Monrovia with 120 beds, as did two smaller holding units in Bong and Bomi counties. These units provided critically needed beds for the overflow from existing ETUs, as well as for the sick still left in the community. These additional beds, however, immediately filled to beyond capacity. Only Montserrado and Lofa counties had ETU beds at this time - consequently, all suspected cases outside of Lofa were transferred to Monrovia, regardless of country of origin (WHO 2014j). Yet, by the time these additional ETUs opened in Monrovia, the peak of the epidemic had already passed.

By the end of October, cases had been reported in all 15 counties. Five hundred ETU beds were operating in Monrovia with almost 200 additional beds in four other counties. Yet with the rapid decline in new cases after September, the new ETUs operated below capacity from the time they opened. In Monrovia, ETUs were approximately half full, and in some areas, new ETUs never admitted a single case (MOHSW 2014d). The first ETU funded by the United States opened the second week of November, and was the only US-funded ETU to be opened and functional in 2014 (USAID 2014e). By December 1, there were nearly 800 ETU beds in the country, but fewer than 20% were occupied (MOHSW 2014e).

During the peak of the epidemic when ETU beds were still scarce, the GOL and international partners implemented a strategy of isolating and keeping suspected EVD patients in their homes (rather than transferring them to an ETU), while providing caregivers with 'home hygiene kits' to reduce their risk of becoming infected while caring for the suspected case. As the incidence of EVD peaked in late September, the GOL, MSF, UNICEF and several NGOs distributed 50 000 of these kits in Monrovia, with 90% distributed by October 28. An additional 40 000 kits were distributed in other counties by November (USAID 2014c).

Laboratory support

Establishing multiple laboratories to test for EVD was a pillar of the response strategy. Testing is essential to confirm or exclude EVD cases so that only those infected are treated in the high-risk ETU environment, and also to more effectively target contact-tracing

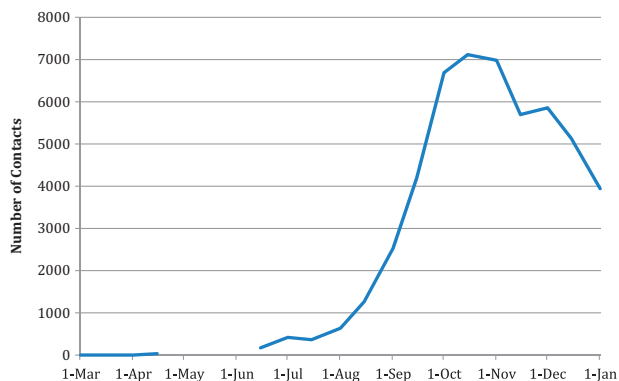


Figure 4. Contacts being traced by date, Liberia, 2014

resources to confirmed cases only. The first Liberia EVD lab opened early in the outbreak (mid-April), but the second did not open until the end of August (USAID 2014f). A third opened mid-September as the epidemic began declining and a fourth the first week of October (White House 2014c). Three more laboratories opened outside of Monrovia in December. The labs provided important information to the ETUs for the diagnosis, isolation and discharge of their patients. However, during 2014, the results were rarely shared with the County Health Team in the patient's county of origin, thus preventing efficient contact tracing and limiting the utility of testing.

Surveillance and contact tracing

Contact tracing was another key priority of the National Strategy (WHO 2014a), the purpose of which is to identify potentially exposed individuals (contacts), and to provide them with education and daily monitoring so that if symptoms develop, they can be isolated before becoming infectious. From the start of the epidemic, the MOHSW collected data on the number of new contacts line listed followed and discharged after 21 days or lost to follow-up. Regular and consistent reporting was a challenge making the quality of the data questionable (IMS Meeting Minutes). From April to September 15, the number of reported contacts followed daily increased from 30 to 4,199. Contacts peaked at nearly 7,000 on November 1, and then fell to approximately 4,000 by the year's end (Figure 4) (MOHSW 2014f, 2015b). However, there were clear inaccuracies in reporting, with identical numbers reported by counties for weeks in a row and with discrepancies between the WHO and UN reports of > 1,000 for the number of daily contacts reported.

Initially, contact tracing was not standardized across or even within counties, but beginning in October, standard operating procedures were created. However, even into December, multiple organizations were still conducting contact tracing independently, often in overlapping areas, with uncoordinated reporting (MOHSW 2014g). There are no early records of the number of trained and active contact tracers, but as of October 15, there were 2,224 trained contact tracers reported to the IMS, increasing to 5,845 by mid-December (MOHSW 2014e,h;). Of concern, the MOHSW on October 23 reported that only 40% of contacts were under active surveillance, ranging from 51% in Monrovia to 22% in Margibi. Extensive listing of all contacts for each case was not being done, as the target ratio for expected number of contacts per case was 7:1, but only three contacts were being reported for each case nationwide, ranging from 2:1 to 14:1 in the counties (MOHSW 2014c).

The ideal indicator of the effectiveness of contact tracing is the percentage of new cases that are already being followed on a tracing

list (a perfect system would have 100% of new cases already being traced). However even in February 2015, with only seven newly confirmed EVD cases, only one of these was on a tracing list. Thus, even with 90% fewer cases compared to September 2014, only 14% of new cases were under active surveillance (MOHSW 2014g).

Body management

Given the highly infectious nature of EVD corpses and the intimate burial practices common in Liberia, safe burial was a crucial EVD control strategy. Safe burial teams were trained and deployed early in the outbreak, but accurate records from body management teams were limited until October 2014. In April, the WHO and MOHSW began training healthcare workers in EVD infection prevention, case management and safe burials (WHO 2014c). However, it was not until mid-June when EVD transmission came to Monrovia that specific safe burial teams were created (UNICEF 2014h), with early efforts led by the Environmental health department, MOHSW and later by the Liberian National Red Cross Society (LNRCS) and IFRC (IFRC 2014b). In July, the MOHSW, LNRCS and IFRC started training and the MOHSW began identifying the locations for the safe burial of EVD bodies (UNICEF 2014i; IFRC 2014c). However, between the end of July 2014 through early November 2014, cremation of Ebola-infected bodies was the preferred strategy of the response to reduce transmission—although this prompted much public outcry. Resources and logistics remained limited, delaying team deployment to the counties. By September 1, 16 burial teams were operational in Monrovia. The Safe Burial Standard Operating Procedure was also completed, and included requirements for safe burial and laboratory testing for all deaths in Liberia, regardless of EVD status (WHO 2014k; MOHSW 2014i). By the end of the month, as EVD incidence peaked, there were between 54 and 65 trained burial teams in eight counties, including six new teams in Montserrado (MOHSW 2014j). However, persistent mistrust and misinformation continued to limit the effectiveness of these teams—resulting in families hiding bodies, or in some instances, outright attacking of safe burial team members (UNOCHA 2014c).

By October 24, 90% of bodies reported to government were safely buried within 48 h (Figure 5), and 22 burial teams were operating in Montserrado. However, a national safe-burial cemetery had still not been opened (MOHSW 2014c). By November 1, an average of 150 suspected EVD bodies were buried weekly (IFRC 2014d). As 2014 ended, the number of teams was reduced and 98% of bodies

reported to the government were collected within 48 h in Montserrado (MOHSW 2014k).

Social mobilization

Social mobilization and community outreach efforts were a fundamental component of the EVD response and complemented all other activities. Increasing EVD awareness and changing behaviours and practices were essential to stopping the epidemic. Central strategies included the engagement of local leaders, chiefs, imams and pastors, as well as the creation of radio dramas, town hall meetings, and skits performed by community members. Early in the outbreak, the GOL and WHO conducted awareness programs in Lofa County, and the IFRC, LNRCS, MSF, Pentecostal Mission Unlimited and Samaritan's Purse trained volunteers for awareness outreach campaigns, independently and with the County Health Teams (WHO 2014c). The MOHSW requested that the LNRCS lead social mobilization campaigns at the county level because of their large number of volunteers in communities across Liberia. At the end of June, the LNRCS/IFRC had trained 300 volunteers and reached 77 401 people through community outreach (IFRC 2014e).

Early on, activities included the GOL establishment of a national 'Ebola Hour' on the radio to increase EVD awareness, as well as the creation of an Ebola hotline in collaboration with private cellular telephone companies to provide answers to public concerns (Dahn 2014f; MOHSW 2014j). On August 7th, the GOL opened a fully-staffed Ebola call centre which received nearly 1,000 queries in the first two days alone (USAID 2014a). UNICEF and the MOHSW developed educational materials on Ebola that were distributed via nine radio stations throughout the country (UNICEF 2014h).

In September, direct community outreach efforts were increased, with a 'train-the-trainer' conducted on September 12 by UNICEF, WHO and MOHSW. The 42 trainers then trained over 2,000 volunteers in all 15 counties, with 400 trained by the end of the month (UNICEF 2014j,k). By October 1, 433 729 people (over 10% of the population) had been directly contacted by social mobilization activities. However, by October 23, only 5,203 of the estimated 10 000 needed social mobilization volunteers had completed training (MOHSW 2014l). To bolster these efforts, USAID created a \$6.5 million fund (Ebola Community Action Platform - ECAP) to give large and small grants for social mobilization activities. The funds, however, were not distributed to organizations until late in 2014 through March 2015, long after the epidemic peak (USAID 2015).

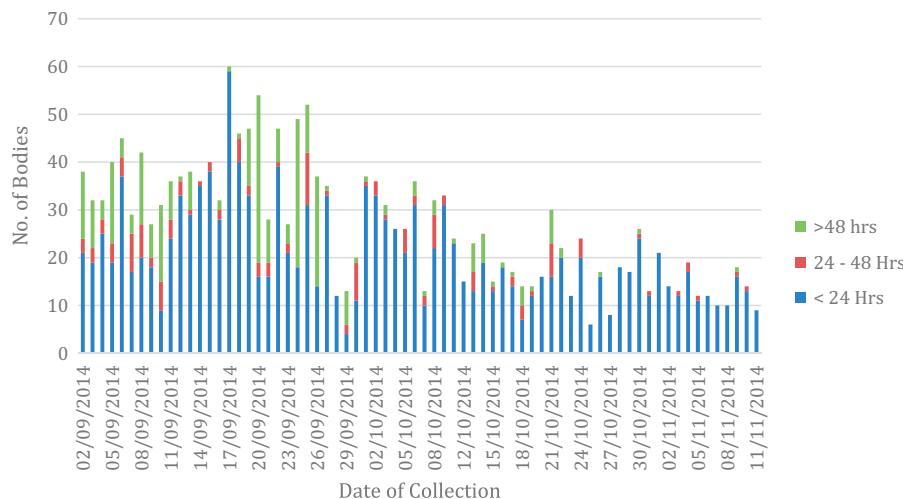


Figure 5. Total bodies collected from communities and ETUs and response time for Red Cross in Montserrado County, Liberia, 2014.

In October, the IMS Social Mobilization committee created a mapping registry of all local and international organizations working in the 15 counties, and documented the types of social mobilization activities they were conducting, including house to house mobilization, journalist training, town criers, distribution of print materials, and community meetings.

Suspicion and disbelief remained a major obstacle early in the response- a July 2014 survey of 3,466 Liberians found that 84% still did not believe that EVD even existed in the country (Samaritan's Purse 2014). Yet, by the end of September, another survey found that 98% of people in five counties believed that Ebola was real and 89% were concerned that they were at risk of contracting the disease (Kobayashi *et al.* 2014). Social mobilization activities appeared to be succeeding in changing population knowledge and attitudes toward EVD. This is a remarkable turn-around in attitudes and may represent the most important aspect of the response.

Discussion

Despite the dire forecasts by scientific models and politicians, the Government of Liberia, together with local communities and the early international partners, managed to reduce transmission of EVD even as the massive global intervention was only beginning to ramp up. Based on numbers from the VHF, the R_t began decreasing in mid-August and dropped below 1 the week of September 24, just after the number of reported weekly cases peaked. While it is not possible to establish causality for any single intervention or set of interventions in stopping the epidemic, it is clear that the early projections did not come to pass. Due to the timeline of interventions, some activities are less likely than others to have significantly changed the course of the epidemic.

Too little, too late

A primary focus of early discussions and models and the resulting global strategy was the construction of ETU beds. It is likely that the ETUs opened in Monrovia in August and September did contribute to reducing transmission and boosting morale, but the epidemic curve decreased before any of the US-funded ETU beds opened (or were even proposed), and the majority of these beds were never used. ETUs did, however, play a crucial role in treating and isolating patients and likely helped to reduce case-fatality rates.

The early focus on building thousands of ETU beds was partly influenced by projections based on models. In addition to the CDC paper (Meltzer *et al.* 2014), another early model predicted the impact of several interventions (building new ETUs, case finding through contact tracing, and the distribution of household protective kits) on EVD transmission in Monrovia/Montserrado County (Lewnard *et al.* 2014). This model assumed interventions were completed between October 15 and November 15, including the construction of 2,400–4,800 ETU beds in Montserrado alone. The authors stated, 'Our predictions suggest that current commitments are grossly inadequate to provide beds for all infected individuals...'. Without completed interventions, the model projected 42 669 reported (170 996 unreported) EVD cases and 27 175 (90 122 unreported) deaths by December 15. However, by that date, with fewer than 500 ETU beds opened there were 3,359 reported deaths; 88% less than predicted by the model.

The construction of most ETUs occurred between October and December 2014, when nearly 2,000 additional beds were under construction even though the number of cases was declining dramatically. By January 2015, more than a dozen new ETUs had opened

with few new cases occurring. As a result, the MOHSW reduced the number of proposed beds to 1,333. More recent articles have used modelling to conclude that EVD treatment beds played a large role in reducing EVD transmission, but the assumption that beds were available and used by infected persons is overstated (Merler *et al.* 2015; Washington and Meltzer 2015).

The use of home hygiene kits to reduce transmission in households was another strategy explored in predictive models and implemented as an intervention, but their widespread distribution in Monrovia did not begin until after the peak of transmission. Kits were distributed even later in the counties, but may have had greater utility in these rural areas given the limited access to EVD beds until December or later.

Similarly, despite claims, the establishment of UNMEER as the primary UN organization to address EVD in the region occurred well after the epidemic numbers began declining (WHO Ebola Response Team, 2015). UNMEER certainly contributed to the efforts, but it arrived too late to take credit for turning the epidemic around.

Laboratories provided important information to the ETUs for the diagnosis, isolation and discharge of their patients and tests confirmed the presence of EVD in new areas. But the impact of the laboratories on transmission was limited for two important reasons: laboratory capacity was very limited (only two labs) until after the epidemic peak, meaning that testing was not widespread and, more importantly, the names of laboratory-confirmed cases were not provided back to the county teams responsible for contact tracing and isolation. This meant that families did not know if a relative had actually contracted EVD, and, more significantly, all contacts, even those of suspected cases not likely to be infected, had to be traced with the same effort as confirmed cases. This stretched already thin contact tracing resources even further.

Safe burial

Dead bodies with EVD are highly infectious, and traditional burial practices may have been the single greatest driver of early EVD infections in Liberia. Thus, safe burial was a crucial strategy nationwide that required social interventions to change funeral practices, and the training and logistics necessary for the rapid collection and safe burial of the dead. Interventions within this strategy started early with both social mobilization and safe burial teams and may have had a significant impact on reducing transmission. By June, safe burial teams were well established in the north of the country and in Monrovia, and by mid-October, there were well-equipped teams across the country with safe burials happening within 48 h of reporting.

The behavioural changes are harder to quantify. Traditional beliefs and the resistance to cremation led to the continuance of unsafe burials in some areas. Several burial teams were attacked in Liberia as late as September and ongoing reports of unsafe family burials were reported in Sierra Leone in 2015 (BBC 2015). But there were clear changes in practices after social mobilization efforts.

Contact tracing

Contact tracing has been an important part of ending the transmission of EVD in other outbreaks; however, given substantial weaknesses in implementation in Liberia, it is unlikely that it had a major impact on this epidemic. Efforts to trace the contacts of each case began early, but were hampered by a variety of difficulties. There were many gaps in the flow of information between case finders, the laboratories, the ETUs, the safe burial teams and County Health

Teams. Further, due to insufficient pay and bottlenecks in funding for communication and transportation infrastructure, many contact tracers were not able to effectively carry out their daily tracing duties. Resistance from contacts, who sometimes fled, and were required to self-quarantine in their homes for the full 21-day incubation period, also further limited the effectiveness of tracing. In October 2014, the contact tracing was more strictly organized by the use of standard operating procedures and a unified leadership, thus improving the system. However, as late as February 2015 when there were few new cases, the contact identification rate remained poor.

Response management

As the leader of the response, the GOL undertook nation-wide activities to stem the epidemic. The GOL was transparent about the presence of EVD in the country from the beginning and led aggressive information and social-mobilization efforts soon after the first EVD cases were detected. When the epidemic spread to Monrovia, the government strengthened their efforts with the creation of a new Incident Management System with new full-time response leadership in August. Learning from the violent reaction to neighbourhood quarantine in Monrovia, the GOL changed course to better engage community groups to ensure local ownership for control efforts. This transparency and ability to adapt the response to changes in the epidemic was a key strength of the GOL response.

Behaviour changes

The extent to which unquantified factors such as human behaviour change can reduce transmission is unclear, but appears to have played a major, if not the key role, in stopping EVD transmission. Between July and the end of September 2014 when the epidemic turned, the acceptance and fear of EVD increased from 14% to 98% of the population (Samaritan's Purse 2014; Kobayashi *et al.* 2014). From the beginning of the epidemic, a massive communication effort throughout the country educated the population about EVD transmission and prevention.

In many senses, all of the control strategies employed helped to educate the population and change high-risk behaviour, from safe-burial teams to contact tracers visiting households and neighbourhoods. Nation-wide efforts such as radio programs and the call centre reached large groups, and were complemented by local community-led organization in turning the epidemic. In some areas, such as Lofa County, communities organized themselves to provide isolation and transport of potential patients, and to provide hygiene interventions (e.g. wash stands) and promote safe burial. After the quarantine riots in Monrovia in August, communities were more aggressively engaged to help identify sites for the isolation and treatment of patients, and in promoting their use. A more active community engagement strategy was also pursued by the re-organized IMS and creation of county IMS leadership to help communities to 'own' the solutions to the epidemic. These activities helped turn the vicious cycle of distrust, stigma and non-cooperation in case finding and body management that characterized the first half of the epidemic, to a more virtuous cycle of engagement, better case finding, trusted care and safer burial evident later in the epidemic. When a resurgence of cases occurred in November 2015, the community was more actively involved in case finding, clinical care, and isolation and the small cluster of cases was limited to single families.

Conclusion

Many of the policies and strategies developed and implemented by the global community were implemented after the decline in new EVD cases in Liberia. This paper provides a detailed timeline of the interventions and resources that were targeted toward ending the EVD epidemic in Liberia, in relation to the epidemic curve. This comparison serves to inform future responses about what may have contributed to the decline of the Liberian EVD epidemic, and what likely did not. No single intervention can claim responsibility for changing the epidemic; however, the timeline makes clear that the steep decline in cases occurred before the majority of interventions by the international community were implemented, and that the need for ETU beds was vastly overestimated as an early strategy. It seems likely that interventions had reinforcing effects on each other, but that behaviour changes were the core driver of the epidemic's decline. The lessons of what actually happened in the epidemic should be that:

- Behaviour changes by individuals and communities were critical to changing the epidemic curve. This was likely facilitated by active community engagement and communications (social mobilization), but also occurred organically by communities and households.
- Local leadership was critical in organizing efforts, responding to changing conditions, and providing positive direction, but could not have occurred without international monetary, technical and logistical support.
- Removing infected bodies from the community and safe burial likely had an important effect in reducing the epidemic.
- Whereas ETU beds were important for providing treatment for EVD, the vast majority of the ETU beds was constructed too late and after the epidemic curve had turned.
- Future efforts to strengthen health systems should focus on building community capabilities and local leadership, and not simply on building more physical infrastructure.

Ethical Approval

This study proposal was reviewed by the Institutional Review Board at the Johns Hopkins University School of Medicine and was deemed exempt, as it does not involve human subjects, and utilizes publicly available records.

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