The cost of public health interventions to respond to the 10th Ebola outbreak in the Democratic Republic of the Congo

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ABSTRACT

The 10th Ebola virus disease (EVD) outbreak in the Democratic Republic of the Congo (DRC) drew substantial attention from the international community, which in turn invested more than US$1 billion in EVD control over two years (2018–2020). This is the first EVD outbreak to take place in a conflict area, which led to a shift in strategy from a pure public health response (PHR) to a multisectoral humanitarian response. A wide range of disease control and mitigation activities were implemented and were outlined in the five budgeted Strategic Response Plans used throughout the 26 months. This study used the budget/expenditure and output indicators for disease control and mitigation interventions compiled by the government of DRC and development and humanitarian partners to estimate unit costs of key EVD control interventions. Of all the investment in EVD control, 68% was spent on PHR. The remaining 32% covered security, community support interventions for the PHR. The disbursement for the public health pillar was distributed as follows: (1) coordination (18.8%), (2) clinical management of EVD cases (18.4%), (3) surveillance and vaccination (15.9%), (4) infection prevention and control/WASH (13.8%) and (5) risk communication (13.7%). The unit costs of key EVD control interventions were as follows: US$66 182 for maintaining a rapid response team per month, US$4435 for contact tracing and surveillance per identified EVD case, US$1464 for EVD treatment per case, US$59.4 per EVD laboratory test, US$120.7 per vaccinated individual against EVD and US$175.0 for mental health and psychosocial support per beneficiary. The estimated unit costs of key EVD disease control interventions provide crucial information for future infectious disease control planning and budgeting, as well as prioritisation of disease control interventions.

INTRODUCTION

On 1 August 2018, the Ministry of Public Health (MOPH) in the Democratic Republic of the Congo (DRC) officially declared the 10th Ebola virus disease (EVD) outbreak, which came 3 weeks after declaring the end of the 9th EVD outbreak in Equateur. This outbreak was DRC’s largest outbreak and the second largest EVD outbreak in the world, occurring for the first time in a conflict zone. In July 2019, it was designated a Public Health Emergency of International Concern by the World Health Organisation (WHO). The Ministry of Public Health and development partners mobilised substantial resources to respond to the outbreak. There is limited literature surrounding the costs and the analysis of spending on services and interventions taken to control EVD.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ The 10th Ebola virus disease (EVD) outbreak in the Democratic Republic of the Congo (DRC) was the largest EVD outbreak in the country and the second largest in the world.
⇒ The Ministry of Public Health and development partners mobilised substantial resources to respond to the outbreak.
⇒ There is limited literature surrounding the costs and the analysis of spending on services and interventions taken to control EVD.

WHAT THIS STUDY ADDS

⇒ Coordination and clinical management of EVD cases accounted for the largest share of the resources mobilised for the EVD public health response. It includes wide innovations (vaccination, treatment, laboratory, infection prevention and control and community engagement) that would change future responses to EVD outbreaks including its lethality.
⇒ The high unit costs for some EVD control services are partially due to the low local capacity in DRC, and thus localising disease control interventions and building local capacity would improve health system resiliency and sustainability in coping with disease outbreaks.

WHAT THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The unit cost analysis provides crucial information on prioritisation of disease control interventions to improve planning and coordination for future EVD responses.
⇒ It also provides fundamental cost information for examining the cost-effectiveness of specific EVD response interventions in the future.
attacks by armed groups on response staff and facilities including EVD treatment centres and health centres,\(^3\) the outbreak was officially declared over on 25 June 2020. The country subsequently entered a period of 90 days of heightened surveillance lasting until September 2020, hence, maintaining rapid response efforts to ensure that any new cases were contained. The outbreak was localised in the North Kivu, Ituri and South Kivu provinces, encompassing 29 health zones and a total population of 6.3 million. By the end of the outbreak, 3481 confirmed EVD cases and 2299 deaths\(^5\) were reported. The case fatality rate was estimated at 66%, in line with the previous EVD outbreaks.\(^6\,7\)

To contain the EVD epidemic, the MOPH, in collaboration with the international community, implemented a series of Strategic Response Plans (SRPs), aiming to break chains of transmission of EVD infections. The SRP had four main iterations (SRP-1–SRP-4). SRP1-3 focused purely on public health responses (pillar 1 of SRP4), and then the EVD response shifted to a multisectoral/humanitarian response under SRP-4. The multisectoral response, secondary to the activation of the level 3 Interagency Standing Committee (IASC) for Infectious Diseases, contained four pillars with the introduction of the Ebola Emergency Response Team (EERT) due to the fragility and conflict environment in which the outbreak took place. Pillar 1 (public health response) across all SRPs generally included coordination, defined as support for Emergency Operations Centre (EOC) at the central, provincial and health zone level, logistics, surveillance activities, supporting health facilities and schools with infection prevention and control (IPC) measures, clinical management of EVD cases, psychosocial support of EVD patients and front-line workers, risk communication and community engagement (RCCE), and safe and dignified burials.\(^8\) Pillars 2 supported the public health response by strengthening security and logistics for the overall response. This was particularly needed in circumstances where security is of concern. Pillar 3 strengthened support to affected communities (eg, cash for work interventions, provision of food and water, and routine health services). The two pillars aimed to ensure a more holistic response given the challenges due to violence and reticence. Considering reticence on the part of communities towards public health measures, it was paramount to address additional community needs apart from the EVD response, which was not deemed to be a priority for the community. Pillar 4 focused on regional preparedness for future outbreaks, which was not part of the DRC EVD response. These pillars were organised to provide a strategic and coordinated response to the EVD outbreak.

Despite the severity of EVD and the frequency of outbreaks,\(^9\) there is limited literature surrounding the costs and analysis of spending on services and interventions to control the disease. The analyses of costs and spending are important given the large sum of investments dedicated toward EVD response efforts. Controlling EVD outbreaks is costly. During the ninth EVD outbreak in DRC, the funding from the WHO alone, either through direct disbursement from the WHO or channeled through the WHO, amounted to US$67 million.\(^10\) However, this does not provide a full spectrum of resources spent on the EVD response. Several studies were conducted after the 2013-2016 EVD outbreak in West Africa. However, their main focus was to capture the general economic impact of EVD on affected countries.\(^11\,12\) One study attempted to quantify the cost of an EVD case during the 2015 outbreak.\(^13\) In this study, the cases examined were organised by severity and outcome. The cost per Ebola case was estimated by gathering the median cost of supportive care treatment, personal protective equipment (PPE), personnel and productivity losses due to mortality. Another study examined the cost-effectiveness of early response and estimated the cost of management of EVD cases and productivity loss.\(^14\) These costing analyses were conservative and only targeted the direct provider and societal costs per EVD case. There is a significant gap in the literature surrounding the cost estimation of an EVD public health response. Prior studies barely estimated detailed costs for key disease control interventions (eg, surveillance and coordination) except treatment. Furthermore, there is no existing literature that attempts to quantify an EVD public health response by looking at the unit cost of health services alongside the treatment of cases. Costing analyses encompassing the entirety of the EVD public health response are needed for adequate planning and budgeting of future responses, policies and interventions.

This study attempts to fill this gap through an in-depth analysis of detailed data on budget/spending and the output data of key Ebola response interventions (eg, the number of treated patients and the number of individuals tested for EVD) collected by the MOPH to estimate the unit cost of key services and interventions employed during the 10th EVD public health response. We hope that providing estimates of the cost of EVD response activities will help inform decision-makers and international donors in preparing responses for future epidemics and pandemics.

**METHODS**

**Costing perspective**

This costing study was conducted from the healthcare system’s perspective. Given that donors generally funded the 10th EVD response, the cost estimated in this paper was mostly about the cost to donors. Costs incurred by patients and society, such as the cost of transportation or loss of productivity, etc, were excluded from the analysis. Furthermore, gifts-in-kind, such as vaccines, which did not have a cost value to local health systems, were assigned costs based on known expenditures collected from WHO and GAVI.

**Key services for costing**

This costing study focuses on public health interventions taken to control the Ebola outbreak, which fell into Pillar
A top-down costing approach was used to estimate the unit costs of select interventions in pillar 1 for services that we were able to link the budget/spending to the number of services delivered, obtained from MOPH. For services for which such a linkage was not possible, we used a bottom-up approach by reviewing detailed budget parameters to estimate the unit cost.

For the top-down approach, the unit cost was estimated using the budget and the associated population or beneficiaries. The detailed budget and expenditure monitoring for SRP-1 to SRP-4.1 was led by the MOPH, with the support from development partners (eg, WHO and the World Bank). Where disbursement data existed, then it was used to conduct the analysis. However, if the disbursement data was not available, then we used funders’ budget information as a proxy. The disbursement data in SRP-1–SRP-3 had a similar structure and a detailed disbursement breakdown for each of the major interventions, including all nine interventions listed in Table 1.

The public health response in SRP-4 and SRP-4.1 had a similar category of budget/spending as SRP-1–SRP-3, but with fewer categories of the detailed breakdown of the key interventions. SRPs-4 and SRP-4.1 had eight broad categories of the budget/spending instead of nine categories in SRP-1–SRP-3. Some categories were not consistent with SRP-1–SRP-3. For example, vaccination in SRP-1–SRP-3 had a separate spending category while in SRP-4 and SRP-4.1, it was integrated with surveillance and contact tracing. Thus, we could not determine how much was spent on vaccination under SRP-4 and SRP-4.1. When estimating the unit cost of vaccination using the top-down approach, we only used the spending from SRP-1 to SRP-3 and the number of people vaccinated under SRP-1–SRP-3 to calculate the cost.

Among all the services, the costs for establishing and maintaining a rapid response team (RRT) were estimated using a bottom-up approach. To estimate the cost of an RRT, we reviewed the budget of an agency such as WHO, which played a key role in coordinating the Ebola response. The key costing components for an RRT included: (1) personnel, which included international and local epidemiologists, nurses, social mobilisers and a driver; (2) equipment, such as boots and thermometers; (3) supplies, such as sanitation kits and PPE kits; and (4) travel. The average number of each type of personnel was obtained from interviews with key informants and the operational guidelines. Their salaries were based on the unit cost used during the budgeting phase. The items for equipment and suppliers were also based on the operational guidelines, while the unit cost of equipment and suppliers was obtained from literature or budget. The setup cost of a rapid response included the cost of equipment and training, while the rest of the cost, such as the cost of personnel, renting of office space, office supplies and travel, was categorised as recurrent cost or maintenance cost.

For the cost of treatment of EVD cases and suspected cases, the budget/spending from all SRPs had information on the amount of funding to different levels of health facilities, such as hospitals, treatment centres, referral centres, and triage health posts. Such information does not match the output data on treatment, which has information on the number of EVD cases who were treated and the treatment outcomes (healed or deceased). To estimate the cost, we designed a questionnaire and collected spending data, the number of different types of patients treated (suspected and confirmed EVD cases), and the length of stay for suspected and confirmed EVD cases, from the International Medical Corps (IMC) as an example. In the EVD treatment centre, the average length of stay for a suspected case is 3.5 days, and 14.3 days for a confirmed case. The average daily treatment cost per EVD patient was estimated using a bottom-up approach, the unit cost was estimated using the budget and the associated population or beneficiaries.
days for a confirmed EVD case. We first used the length of stay to assign a weight to suspected cases and one to the confirmed case and estimated the total number of equivalent confirmed cases. Then, the total spending was divided by equivalent confirmed cases to estimate the cost per confirmed case. The cost per suspected case was then estimated as the product of the cost per confirmed case by the weight of the suspected case.

Data sources and data analysis
For services using the top-down costing approach, data on budget and expenditure for SRP-1–SRP-4.1 was compiled by the World Bank and WHO. Budget was also collected from some implementation agencies, such as WHO which was mainly responsible for the coordination, surveillance, IPC and clinical management, and from IMC which provided treatment services for confirmed and suspected EVD cases. The key output indicators such as the number of vaccinated individuals, the number of lab tests (eg, PCR using GeneXpert and biochemistry tests), and the number of individuals receiving psychosocial support, were obtained from a database compiled by the MOPH.

For services using the bottom-up costing approach, most data on the quantity of inputs were obtained from EVD response guidelines or budget from implementation agencies, while the unit cost information was either obtained from literature or the budget from the implementation agencies.

Patient and public involvement
As this research used data at the programme or institutional level, patients were not directly involved in any aspect of the study.

RESULTS
We first analysed the distribution of budget/spending of all SRPs and then calculated the unit cost for each of the services/interventions. Table 2 shows the total amount disbursed for all the SRPs during the 10th Ebola outbreak in DRC in 26 months, not only the public health response interventions but also the additional interventions included in pillars 2–4 of SRPs 4 and 4.1. The total planned budget was US$1.28 billion and the committed funding was US$1.18 billion, which accounted for 92.5% of the budgeted amount. Of all the SRPs, SRP-4 and SRP-4.1 had the largest spending, representing 76.5% of the total spending, while SRP-1–SRP-3 accounted for 23.5% of the total spending.

Of all the spending, 68.0% went to public health responses, such as rapid response, contact tracing, treatment of EVD cases, vaccination and so on (figure 1). About 10% of funding was used for strengthening the security of Ebola treatment centres and implementers (MOPH, UN agencies and NGOs). 19.8% of the funding was used for community support interventions for public health activities and 2% for provincial preparedness.

Table 3 shows the spending on public health response by different categories. Of the total amount spent on the EVD response, US$766.53 million was spent on public health interventions. The distribution of expenditures was as follows: (1) coordination, which contained a wide range of activities ranging from direct command and control activities at national and local levels, to coordination activities between state authorities, technical and financial partners, to maintaining specialist units at

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Budget and spending on the Ebola response</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SRPs</strong></td>
<td><strong>Period</strong></td>
</tr>
<tr>
<td>SRP-1</td>
<td>August–October 2018</td>
</tr>
<tr>
<td>SRP-2</td>
<td>November 2018–January 2019</td>
</tr>
<tr>
<td>SRP-2.1</td>
<td>February 2019</td>
</tr>
<tr>
<td>SRP-3</td>
<td>March–July 2019</td>
</tr>
<tr>
<td>SRP-4</td>
<td>July–December 2019</td>
</tr>
<tr>
<td>SRP-4.1</td>
<td>January–September 2020</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
</tr>
</tbody>
</table>

*Assumed to be fully funded. SRP-2.1 and SRP-4.1 are extensions of SRP-2 and SRP-4, respectively.
Table 3    Share of funding by public health response (pillar 1) activities

<table>
<thead>
<tr>
<th>Interventions</th>
<th>Amount (US$ in million)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coordination</td>
<td>143.89</td>
<td>18.8</td>
</tr>
<tr>
<td>Risk communication and community engagement</td>
<td>105.21</td>
<td>13.7</td>
</tr>
<tr>
<td>Surveillance, contract tracing, POE/C and vaccination</td>
<td>122.24</td>
<td>15.9</td>
</tr>
<tr>
<td>Laboratories</td>
<td>14.97</td>
<td>2.0</td>
</tr>
<tr>
<td>Clinical management of Ebola cases</td>
<td>141.13</td>
<td>18.4</td>
</tr>
<tr>
<td>IPC/WASH</td>
<td>105.81</td>
<td>13.8</td>
</tr>
<tr>
<td>Safe and dignified burials</td>
<td>40.33</td>
<td>5.3</td>
</tr>
<tr>
<td>Psychosocial support</td>
<td>33.88</td>
<td>4.4</td>
</tr>
<tr>
<td>Operational support (including incentive payment)</td>
<td>59.07</td>
<td>7.7</td>
</tr>
<tr>
<td>Total</td>
<td>766.53</td>
<td>100</td>
</tr>
</tbody>
</table>

IPC, infection prevention and control; POE/C, point of entry/control; WASH, water, sanitation and hygiene.

Table 4    The unit costs of key interventions for the Ebola control

<table>
<thead>
<tr>
<th>Services/interventions</th>
<th>Total spending (US$ million)</th>
<th>Quantity</th>
<th>Unit cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rapid response team</td>
<td>11.92</td>
<td>2687</td>
<td>US$4435</td>
</tr>
<tr>
<td>Contact tracing and surveillance</td>
<td>11.34</td>
<td>76</td>
<td>US$18 293</td>
</tr>
<tr>
<td>POE/C (per POE/C per month)</td>
<td>11.34</td>
<td>76</td>
<td>US$18 293</td>
</tr>
<tr>
<td>Laboratory test (per lab test)</td>
<td>14.97</td>
<td>244 193</td>
<td>US$59.40</td>
</tr>
<tr>
<td>Laboratory test (per identified Ebola case)</td>
<td>14.97</td>
<td>3481</td>
<td>US$4166</td>
</tr>
<tr>
<td>Confirmed cases in treatment centre (per case)</td>
<td>1.85</td>
<td>1264</td>
<td>US$1464</td>
</tr>
<tr>
<td>Suspected cases in treatment centre (per case)</td>
<td>–</td>
<td>–</td>
<td>US$358.38</td>
</tr>
<tr>
<td>Confirmed cases in transit centre (per case)</td>
<td>0.32</td>
<td>1476</td>
<td>US$219.28</td>
</tr>
<tr>
<td>Suspected cases in transit centre (per case)</td>
<td>–</td>
<td>–</td>
<td>US$220.01</td>
</tr>
<tr>
<td>Vaccination (per vaccinated individual)</td>
<td>18.95</td>
<td>157 067</td>
<td>US$120.70</td>
</tr>
<tr>
<td>Psychosocial support (per beneficiary)</td>
<td>30.00</td>
<td>171 423</td>
<td>US$175.00</td>
</tr>
<tr>
<td>Prevention, coordination, community engagement, operation and monitoring and evaluation (per capita per month)</td>
<td>427.1</td>
<td>6 300 365</td>
<td>US$2.71</td>
</tr>
</tbody>
</table>

POE/C, point of entry/control.

Combining the total spending and the quantity of service delivered for the public health response interventions for pillar 1, we estimated the unit cost of interventions, which is presented in table 4. The cost per RRT was estimated to be US$66 182 per month, the majority of which covered the recurrent cost (ie, salaries, cost of suppliers and travel), whereas the cost for equipment and training to set up an RRT was minimal (ie, 24.0%). The cost of contact tracing (more than 250 000 contacts)
and surveillance per identified EVD case is estimated to be US$4435. The cost of a lab test was estimated to be US$59.4. We estimated that 70.2 lab tests were needed to identify an Ebola case, and thus the cost of lab tests per identified Ebola case was estimated to be US$4166. The treatment cost per confirmed EVD case was estimated to be US$1464 and US$358 per suspected EVD case. However, the cost at the transit centre per confirmed and suspected EVD case was similar, about US$220.0 per case. The vaccination cost was estimated to be US$120.7 per vaccinated individual and the cost of psychosocial support was estimated at US$175.0 per beneficiary.

**DISCUSSION**

This is the first study to systematically map resources for an EVD response and link these resources with services delivered to estimate the unit cost of key interventions to control an EVD outbreak. Our analysis shows the composition of the expenditures of the EVD response from 2018 to 2020 and provides crucial cost information on EVD response interventions for further use.

We found that significant resources in the EVD response were dedicated to coordination and treatment. Coordination accounts for 18% of the total budget of the response. The cost of coordination had many components, including the operational costs for the EOC or Incident Management System in Goma and in health zones, planning and monitoring meetings, and logistics including vehicles, generators, internet, phone, security items and support staff, etc. High coordination costs were also linked to the lack of pre-existing infrastructure and logistics means for the response and a poorly funded humanitarian sector. Coordination costs included rental for the EOC, office space, field accommodation for staff, vehicles, helicopters, travel cost, electricity (eg, generators), security, Very Small Aperture Terminals, mobile communications, support staff, furniture, support to meetings, internet technology equipment, fees for media communication, etc.

EVD is a deadly disease and outbreaks repeatedly occur in the African region, drawing great attention both domestically and internationally. The 10th EVD outbreak resulted in the involvement of a number of actors in addition to the MOPH such as humanitarian and development donors, United Nations agencies and international or local non-government organisations (NGOs). Various implementation agencies played different roles in the EVD response. It is crucial to have coordination bodies at both the national and subnational levels (provincial and health zone) for command and control, and to ensure alignment and harmonisation among various stakeholders. Field coordination was required to ensure that the response was closer to those affected by EVD and to ensure more effective community-based interventions.

The 10th Ebola response was first led by the MOPH with the support of WHO and partners. As insecurity increased and the outbreak spread to more health zones as well as provinces, a surge occurred. This resulted in shifting the UN family’s support from the public health response to an integrated multisectoral/humanitarian response, which includes additional pillars to a traditional public health response. After the activation of the level 3 IASC for Infectious Disease outbreaks, the coordination model (international support) also shifted and was led by the MOPH and supported by the United Nations, which also led to a sharp increase of funding in SRP-4 and SRP-4.1. Indeed, coordination shifted to the EERT in May 2019, with WHO leading the public health response and other agencies (eg, UNICEF and World Food Programme) and NGOs implementing the multisectoral response.

There was a pre-existing humanitarian coordination that had been present due to years of protracted conflict in Eastern DRC. Humanitarian response was poorly funded even before Ebola, which created frustration among communities and humanitarian stakeholders. Due to concerns related to health security, the Ebola response received more funding to meet additional needs in the community beyond the public health response. However, challenges in the coordination of the Ebola response were documented, including a slow adaption of multisectoral and holistic responses to the Ebola outbreak in a complex humanitarian setting with conflicts that had unique needs and unclear roles and responsibilities of stakeholders.

This study shows that lab costs account for about 2% and the unit cost per lab test was estimated at US$59.4. Decisions regarding prioritisation of funding were made by bilateral and multilateral donors and the Government, as indicated by priorities in the SRPs. The laboratory budget was determined by existing needs at the provincial and health zone level for EVD diagnosis. One lesson from the previous and existing COVID-19 pandemic to effectively control potential outbreaks is through early detection and early diagnosis. This requires qualified lab staff and well-equipped laboratories to perform the task. Given the low capacity of lab tests in many African countries, including DRC, strengthening the laboratory capacity has been ongoing and it contributes to the resilience of the country to respond to future pandemics. New laboratories were established as part of the response, and the Africa Centers for Disease Control and Prevention (CDC) collaborated with international partners to host a training course for Ebola diagnosis at the regional level. Technology, such as GeneXpert, has significantly changed the efficiency of virus detection, shortening the duration of diagnosis of Ebola substantially. It allowed the decentralisation of laboratories at a lower cost compared with traditional PCR technology. This is an investment that could last long term and is much needed given the relatively high infectious disease burden in DRC and the need for rapid detection of outbreaks. Such an investment may take time as it not only requires rehabilitation of laboratories, training for lab technicians, but also needs to ensure sufficient supplies and equipment, as well as functioning supply chains. During the COVID-19
pandemic, improvements in identifying COVID-19 cases were observed in DRC due to the improved lab capacity in DRC. However, despite the improvements, the investment may not be sufficient and the shortage of the laboratory network in DRC was documented. Subsequently, many donors provided significant investment in the development of laboratory networks.

Multidisciplinary RRTs are crucial in maintaining response capacity for immediate deployment to hotspots in the field. RRTs are equipped with the capacity to deploy rapidly in order to efficiently and effectively respond to a public health emergency in coordination with other response efforts. This rapid response had played a role in controlling disease outbreaks and could be used throughout all stages of an outbreak response. However, maintaining a response team is costly. This study estimated the maintenance cost to be about US$86 000 per month per team. Much of the cost was for the salary of team members. Often, an RRT consists of two international staff and five local staff. The staff salary was a major cost driver and accounted for 85% of the total cost. The high cost was linked to the fact that at the beginning of the epidemic, there were more international staff and staff from other provinces because many areas were experiencing EVD for the first time. The high cost of having a response team could be significantly reduced by building local capacity. In fact, subsequent outbreaks (12th and 13th EVD responses) used more locally trained staff. If international staff could be replaced by local experts, this would save 31% of the cost of maintaining an RRT, according to the calculation with the salary scale from local experts. Another way to reduce the cost of the RRT is to better control the disease itself. However, it is important to note that there had been weak health systems with an overstretched workforce, thus raising an issue about resilience. If fewer health zones are affected by EVD, fewer RRTs would be needed in the country. WHO and Africa CDC have been working on building capacities of RRTs in the African region. Having a localised response, with increased capacity at the most decentralised level has proven to be effective.

During the 10th EVD outbreak, the Ebola vaccine (rVSV-ZEBOV-GP manufactured by Merck co) was widely deployed in DRC, with more than 300 000 vaccinated. The efficacy of the vaccine was reported to be 97.5%. In DRC, the ring vaccination approach was taken, with which direct and indirect contacts of a probable and confirmed Ebola case were vaccinated. The success of ring vaccination depends on the effective identification of all cases and their contacts and the speed of the vaccination (the Ebola response was targeting a period of 48 hours). However, tracing close contacts in a low-resource setting with limited technology is time-consuming. It was even more challenging in DRC given the insecurity and community resistance, and only a handful of contacts were traced. There were additional challenges that contact tracing posed due to population displacement secondary to conflict, and mistrust towards the response. Ring vaccination with rVSV-ZEBOV was first implemented in Guinea during the 2013–2016 West African Ebola outbreak, thus necessitating the deployment of Guinean staff to assist with the implementation of the ring vaccination strategy. The high salary of international staff was the main driver of the high vaccination cost. However, as an experimental vaccine, it requires a strict protocol with certified supervisors to ensure the licensing of the vaccine. Future use of the vaccine with local staff should be cheaper. Despite the high cost, the Ebola vaccine is expected to be cost-effective in this setting and has shown to play a role in limiting the spread of EVD. Ring vaccination was later transitioned to local teams, which led to improved trust and lower costs (SRP-4.1). As part of future outbreaks, an important lesson learned is to build the capacity of local teams from the onset of the response, thus making the Ebola vaccine more cost-effective. Besides the high cost of the vaccine, which is often subsidised by the donor community, mistrust of vaccines is another issue that impedes successful vaccination. Some new vaccination strategies, such as a mixed vaccination strategy that combines targeted population vaccination with ring vaccination, and targeted geographical vaccination, have been proposed, along with community engagement activities.

The cost to treat a confirmed case was estimated to be US$1464 with an average length of stay of 14.3 days while suspected cases had an average length of stay of 3.5 days. The unit cost for managing a confirmed case is about 1.8 times as high as what was estimated by Bartsch et al in Guinea, Liberia, and Sierra Leone, estimated at US$830 per case that requires intensive supportive care, but much lower than the estimate in the USA. The relatively higher unit cost is expected as we estimated the cost per case based on the total budget received in health facilities and the volume of patients treated in the same period. The high cost was also due to innovations in clinical care, including intensive care, the use of Bio secure Emergency Care Unit for Epidemics for individual care of patients allowing family members to visit patients and higher standard of protocols of care involving laboratories, etc. The budget may include capital investment (such as imagining equipment), which can last multiple years. Since we cannot distinguish them and the capital costs are not annualised, the unit cost is higher. The higher treatment cost in DRC could be also due to the insecurity in the country. The security cost was high and necessary. There had been cases where Ebola treatment centres were burnt and attacked. Additionally, in DRC, the treatment of Ebola cases was primarily done by international NGOs. Most government-led health facilities that provided care were also supported by NGOs and WHO and had limited capacity to manage Ebola cases. The high salary for international staff compared with local staff created tension among them. The frustration of local health personnel weakened the health system in responding to the Ebola outbreak. There were significant challenges in having local staff deal with the EVD
outbreak and neglect other critical public health interventions such as critical routine immunisation. Additional hands were needed to avoid further disruption of the fragile health system with humanitarian needs. In the future, it is important to integrate proper Ebola care and triage at the level of national health facilities. Making treatment available at local health facilities, closer to communities allows for improved time between symptom onset and treatment. To ease the burden on health systems in the context of large outbreaks, proper triage of Ebola patients is needed. With support from partners, DRC built a triage system (transit centre), where triage was conducted based on the symptoms and laboratory tests, to prevent overwhelming the treatment centres. The unit cost of managing confirmed and suspected EVD cases is similar at US$ 220 in a transit centre. There is no major difference in terms of the length of stay between the two types of patients (confirmed and suspected), and the confirmed EVD cases were often transferred to the treatment centre once they were confirmed.

Mental health and psychosocial support (MHPSS) accounts for 4.4% of the total costs. Similar to the COVID-19 pandemic, the Ebola outbreak causes significant panic and fear, not only among the people and families of those who are infected but also among those who are not. In DRC, this was further exacerbated by ongoing conflict and attacks from armed groups. The increased prevalence of mental health during outbreaks and pandemics of diseases has drawn increasing attention from policy-makers and demands immediate actions to address it. It is an integral part of the overall emergency response. Please note that most of the MHPSS were combined with food and non-food items distribution during the response, which may increase the unit cost of MHPSS. It was extremely important to provide food and non-food items to contacts, as this ensured increased compliance with contact tracing. Similar support was provided to Ebola survivors, which was extremely crucial. However, the effort to address mental health was still lacking. The coverage of MHPSS services remained low due to various reasons, such as the shortage of specialists, the lack of screening approaches, and the failure to integrate such measures into the health system. Task shifting and technology deployment (eg, remote consultation) could help improve the delivery of MHPSS.

The DRC had significant experience regarding the response to Ebola outbreaks, as it had previously responded to nine EVD outbreaks prior to this one. However, this outbreak was the first outbreak that occurred in the provinces of North Kivu, South Kiv, and Ituri, and the first outbreak occurred in a conflict region. Experienced teams had been deployed from Kinshasa, the capital as well as other provinces. However, the biggest challenge was to adjust the response in the context of conflict. Armed groups attacked not only response teams but also treatment centres, requiring an adjustment to the response strategy. This was also a region that had experienced more than two decades of conflict, and with that came distrust towards the international community and responders from Kinshasa. Displacement of populations also required a more innovative approach regarding contact tracing.

Several limitations of this study should be acknowledged. First, since this study mainly uses a macro costing approach to derive the unit cost, we are not able to estimate the detailed composition of the unit costs by types, such as the personnel cost, supply cost, drug cost, etc. Second, the macrocosting method, though straightforward and efficient in estimating costs, lacks accuracy. In some circumstances where there was no expenditure information, we had to use the budget to estimate the unit cost. Additionally, because most output measures were aggregated across SRPs, we are not able to estimate the cost difference among SRPs. Third, due to different categorisations of the cost under different SRPs, we had to merge, disaggregate or discard some cost information. Thus, there is some costing information lost during the analysis. For example, since the cost of vaccines was combined with surveillance and contact tracing in SRP-4, we had to ignore the data and used the cost of vaccines from SRP-1 to SRP-3 to calculate the cost. Fourth, the budget for regional preparedness went to multiple countries including DRC. To provide a full picture of the 10th EVD response, we included it in the expenditure analysis. Fifth, we relied primarily on the budget/spending data from development partners for this study, which focused on incremental capital and recurrent costs of interventions. It is likely that some cost items were missed in the study, such as the cost of laboratory buildings if owned by the government. Nevertheless, this study provides unit cost estimates for comprehensive EVD responses, providing useful costing information for planning and prioritisation.

Responding to an EVD outbreak is a multisectoral effort, requiring the mobilisation of substantial resources for different purposes. In active conflict zones, additional costs are required to ensure the security of response teams, which makes the operational costs even higher. It is important to note that these costs were likely higher due to additional security and logistic costs, due to ongoing conflict and repeated attacks from armed groups. Some interventions are costly, such as RRTs and EVD case management. To enhance the efficiency of the use of resources to deliver life-saving interventions, building local capacity and preparedness for pandemics could be a viable option and necessitate substantial upfront investments with potential long-term benefits. Enhancing the efficient use of resources means not only deploying resources on the front line of the battle of the pandemic (eg, laboratory testing, contract tracing and case management), but also addressing recurrent issues that affect the health system for effective management of highly communicable disease, such as IPC and isolation infrastructure. Lastly, it is critical to leverage the use of innovations, such as new vaccines, medicines and treatment protocols, for more effective control of the pandemic.
although it generates difficulties in comparing the cost to previous responses in West Africa.

In conclusion, this study highlights the importance of localising disease control interventions and building local capacity to improve health system resiliency and sustainability in coping with disease outbreaks. This is the first study that examined the cost and analysis of spending on services and interventions taken to control an outbreak of EVD. Determination of unit cost during an outbreak is critical as it allows for improved planning and coordination and provides important information on the prioritisation of disease control interventions for the future. However, due to the limitation of the collection data, we could not examine the evolution of unit cost during the different stages of the epidemic and under different delivery models (eg, using international personnel vs local personnel). Thus, it is important to develop standardised and well-accepted approaches for costing and planning for future health emergencies, especially in conflict zones.

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