The cost of an Ebola case

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As the most recent outbreak of Ebola virus disease (EVD) in West Africa continues to grow since its initial recognition as a Public Health Emergency of International Concern, an unanswered question is what is the cost of a case of Ebola? Understanding this cost will help decision makers better understand the impact of each case of EVD, benchmark this against that of other diseases, prioritize which cases may require response, and begin to estimate the cost of Ebola outbreaks. To date, the scientific literature has not characterized this cost per case. Therefore, we developed a mathematical model to estimate the cost of an EVD case from the provider and societal perspectives in the three most affected countries of Guinea, Liberia, and Sierra Leone. Our model estimates the total societal cost of an EVD case with full recovery ranges from $480 to $912, while that of an EVD case not surviving ranges from $5929 to $18 929, varying by age and country. Therefore, as of 10 December 2014, the estimated total societal costs of all reported EVD cases in these three countries range from $82 to potentially over $356 million.

Keywords: Computational modeling, Economics, Ebola

Introduction

As the most recent outbreak of Ebola virus disease (EVD) in West Africa continues to grow since its initial recognition as a Public Health Emergency of International Concern,[1] an unanswered question is what is the cost of a case of Ebola? For the last outbreak/epidemic that required a global response (i.e. the 2009 H1N1 pandemic), we had estimates for the cost of an influenza case.[2–6] A review of the literature reveals no other studies determining the costs associated with an Ebola case. While the report evaluated the overall (macroeconomic) impact of EVD,[7] the current study is the only one known to date to estimate direct medical and productivity losses on a per-case basis.[7] Articles published by major news media outlets including *Businessweek* and the *New York Times* reported costs, but did not clearly provide scientific sources or methodologies generating these numbers.[8,9]

With the influx of resources from both public and private sources (e.g. $500 million pledged from the World Bank[7] and a total of $150 million pledged from Bill and Melinda Gates and Paul Allen),[10,11] one may ask why we need to know the cost of a case? First, the cost of a case gives us an idea of the impact that a case may have on society, the healthcare system, and the business sector and benchmark against other diseases; in this way, the cost per case can inform important policy decisions. For example, after the first estimation of the economic cost of influenza in the USA projected that total costs could exceed $7500 per case,[12] the CDC expanded its annual influenza vaccine recommendations to include all Americans over 6 months of age.[13] Secondly, knowing how the cost of a case may vary by presentation, clinical course, and outcome helps prioritize the allocation of resources after the current outbreak has passed. For example, our previous influenza work during the H1N1 pandemic has provided information that is useful to decision makers since the pandemic.[14–21] Thirdly, during the Ebola outbreak, other diseases do not cease their activity. Therefore, one may want to compare the impact of Ebola versus other currently active diseases to help make choices, even after the current outbreak subsides. Is an Ebola case more impactful than a case of another condition, such as measles, malaria, cholera, or meningitis? Finally, the cost of a case can help form the basis of cost–effectiveness and cost–benefit studies that will be important in the future with isolated cases and smaller outbreaks that cannot benefit from mass mobilization of resources and the world's attention.

It is important to note that in the context of the current outbreak in West Africa, the first two questions are less relevant as the global response is already underway (and would not likely change with

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a reliable cost per case estimate). However, the third use — as the basis for developing cost–effectiveness and cost–benefit studies — is particularly important to emphasize here. Such future work is critical to efficiently developing strategies to prevent or mitigate the effects of future cases and outbreaks. For example, cost–effectiveness studies for potential therapies could help determine which is best to target for future development, especially since there are no currently licensed vaccines or treatment. Therefore, we developed a computational model to estimate the costs of different types of Ebola cases for the countries where major outbreaks are occurring.

Methods

Using TreeAge Pro 2014 (TreeAge Inc., Williamstown, VA, USA), we developed a Monte Carlo simulation model to determine the direct medical costs and productivity losses (i.e. provider and societal perspectives) for four types of EVD cases: (1) those receiving supportive care who survive; (2) those receiving supportive care who die; (3) those receiving extensive supportive care who survive; and (4) those receiving extensive supportive care who die. In our model, cases receiving supportive care exhibited symptoms of fever, fatigue, vomiting, diarrhea, headache, and pain, while cases receiving extensive supportive care exhibited these symptoms in addition to bleeding, shock, and confusion. As the spectrum of EVD symptoms varies widely, these cases were chosen to represent the range of symptoms and costs related to the supportive care they receive.

Costs included supportive care based on symptoms, personal protective equipment (PPE), personnel wages, and productivity losses for absenteeism and mortality. Supportive care for Ebola patients followed the WHO's Clinical Management of Patients with Viral Haemorrhagic Fever: a pocket guide for the front-line health worker and their list of essential medicines necessary to treat Ebola cases.[22,23] Micromedex2.0 supplemented dosing information when not available in the guidelines.[24] Supportive care treatment for consisted of: paracetamol (adults: 650–1000 mg every 6 hours; children: 10–15 mg/kg every 6 hours) for fever and pain; oral rehydration salts (ORS) divided into two doses (loading dose: 75 kg in 4 hours given once; continuing dose for adults: 10 ml/kg in 6 hours; continuing dose for children: 5 ml/kg in 6 hours) for diarrhea, vomiting, and signs of dehydration; and metoclopramide (10 mg orally three times daily) for nausea/vomiting and it given in conjunction with ORS. Extensive supportive care consisted of: paracetamol and metoclopramide as described above; morphine (adults: 30 mg/24 hours; children: 15–30 mg/24 hours) for moderate/severe pain; diazepam (adults: 20 mg; children: 0.5 mg/kg) for convulsions; Ringers lactate (20 mg/kg/h) for shock; ORS (5 ml/kg in 3 hours) for diarrhea, vomiting, and signs of dehydration; and broad spectrum antibiotics (ceftriaxone, 2 g daily by IV). Table 1 provides treatment costs per day. The duration of hospitalization severed as a proxy for the duration of treatment.[25]

PPE followed the current WHO guidance.[26] PPE consisted of coveralls or gown (20% coveralls, 80% gowns, following purchased quantities[27]), face shield, double gloves, mask, N95 respirator, surgical hood, and shoe covers. While some PPE consists of boots, which can be worn for an entire shift, we modeled PPE with shoe covers as the total cost of shoe covers for an entire shift was similar to that of a pair of boots. We assumed seven suits per bed per day, as estimated by the WHO.[28] Personnel wages assumed one doctor and one nurse per patient. We assumed that, within 24 hours, taking into account the time to don/doff PPE (8 minutes to don, 20 minutes to doff) and the duration medical staff can wear PPE (1 hour), 16.4 patients could be seen by medical staff. The daily wage of a doctor and nurse (ratio of personnel wages to gross national income (GNI) divided by 365) divided by the number of patients seen, was applied to each patient for the duration of their hospitalization.

We considered productivity losses due to absenteeism (during hospitalization) and mortality. Life time lost wages served as a proxy for life time productivity losses, calculated from the remaining life expectancy from the age of death and the annual discounted GNI per capita.[29,30] A 3% discount rate converted all past and future costs into 2014 US dollars (USD). All input data were age- and country-specific when available.

Each simulation experiment sent 1000 EVD patients through the model 1000 times for a total of one million trials. Probabilistic sensitivity analysis (i.e. Monte Carlo simulation) simultaneously varied each parameter throughout the ranges listed in Table 1. Sensitivity analyses varied case patient age and country of origin. Results were then extrapolated based on the currently reported number of cases and deaths for each outbreak country (Guinea, Liberia, and Sierra Leone), following the proportion of cases by age for the current epidemic.[25,31] The reported total outbreak costs represent the range across EVD cases receiving supportive and extensive supportive care (i.e. cost assuming all cases that recover and die received supportive care to cost assuming all cases received extensive supportive care).

Results

Table 2 shows the median (95% credibility range) costs, separated out into treatment and PPE costs, personnel costs, and productivity losses, associated

with EVD in Guinea, Liberia, and Sierra Leone. The median treatment and PPE costs per case were similar across the countries, with difference in personnel costs and productivity losses (due to differences in GNI) accounting for the variation (as supportive care costs did not vary by country).

Total direct costs (treatment, PPE, and personnel costs) were similar for supportive care and extensive supportive care for EVD (the difference resulting from other drug treatments received), while those that survived incurred higher costs than those that died, as they tended to have a shorter duration of hospitalization and PPE.

Total direct and societal costs for various EVD cases can be determined using Table 2. For example, the total direct cost for an extensive supportive care EVD case 15–44 years old that dies in Sierra Leone would be $342 (treatment and PPE plus personnel costs), while the total societal costs would be $15 595 (treatment and PPE cost plus personnel costs plus productivity losses). The median cost for an EVD case that recovers ranged from $480 to $912 (societal perspective). Total costs for EVD patients that die varied by country and age ($5929–$18 989), with younger persons incurring higher productivity losses.

Extrapolating these supportive care costs and productivity losses to the number of reported probable and confirmed cases and deaths estimates the total economic burden for each country by age group. In all three countries, the economic burden was the highest for 15–44 year olds (Table 2). This reflects the severity of the epidemic across age groups. The total economic burden of reported cases was the lowest in Guinea (which had the fewest reported cases and deaths of the three) and ranged from $16.0 million to $11.2 million. In Liberia, where the highest number of cases has been reported, the burden ranged from $33.6 million to $36.7 million.

As the number of reported cases and deaths are most likely under estimates,[32] we also determined the total burden when accounting for underreporting. The total burden of EVD in all three countries cost

Table 1 Model input parameters, values, and sources

Parameter	Mean or median	Standard deviation or range	Source (ref. no.)
Gross national income (GNI) per capita (USD)			30
Guinea	474		
Liberia	422		
Sierra Leone	700		
Personal protective equipment (PPE) costs (per unit)			46
Coveralls	2.60	0.17	
Face shields	0.57	0.48	
Gloves (each)	0.08	0.05	
Gowns	0.74	0.30	
Mask	0.07	0.03	
N95 respirators	0.70	0.39	
Shoe covers (each)	0.66	0.02	
Surgical hoods	0.21	0.02	
Cost of body bag	25		27
Supportive care costs (per unit)			47
Ceftriaxone (1 g injection)	0.836	0.614	
Diazepam (5 mg/ml injection)	0.0942	0.0646	
Metoclopramide (10 mg tablet)	0.00895	0.01093	
Morphine (10 mg)	0.2679	0.2107	
Oral rehydration salts (ORS) (1 packet/1 l)	0.1584	0.1894	
Oral rehydration salts (ORS) (1 packet/500 ml)	0.0715	0.0175	
Paracetamol (100 mg tablet)	0.00301	0.00239	
Ringers lactate (RL) (1000 ml bott)	1.0758	0.2476	
Ringers lactate (RL) (500 ml bott)	0.6767	0.2221	
Weight $<$15 years old (kg)	24.1		48, 49
Weight $\geq$15 years old (kg)	60.7		50
Duration of treatment			25
Discharged/recovered	11.8	7.2	
Died	4.2	6.4	
Ratio of doctors annual wage to GNI*	36.25		51–53
Ratio of nurse annual wage to GNI*	6.43		51–53
Age distribution of recovered cases in West Africa			25
$<$15 years old	12.6		
15–44 years old	73.1		
$\geq$45 years old	14.3		
Age distribution of cases who died in West Africa			25
$<$15 years old	14.2		
15–44 years old	56.5		
$\geq$45 years old	29.3		

Note: *Ratio estimated using data from Senegal, Benin, Niger, Ghana, Burkina Faso, Zambia, and Nigeria (Senegal data from personal communication with PATH and project Optimize).

≥$164 million with an underreporting factor of 2 and ≥$328 million for an underreporting factor of 4.

Discussion

Our model estimates that the median cost of an EVD case (direct costs plus productivity losses) ranges from $480 to $18 929 depending on the severity and outcome. As expected, the major driver of costs per case is mortality and the resulting productivity losses.

How does this cost per case estimate compare to that of other diseases? One challenge is the variability in methodologies and locations used to generate the cost per case for other diseases. Our estimated cost per EVD case is higher than those reported for measles ($369–$451 in 2014 USD), but these measles estimates do not include productivity losses due to death, which is less common for measles versus EVD.[33] Across Ghana, Tanzania, and Kenya, the total cost per malaria episode (direct and indirect household and health system costs) in children ranges from $6 to $334 (discounted to 2014 USD).[34] These costs are substantially lower than our Ebola estimate and may be due to the difference in productivity losses from mortality. The reported mean cost per cholera case in Zanzibar, as determined by patient interviews, was $50 (2014 USD).[35] This is also substantially lower than our estimate for EVD. However, the average cost per person with cholera in 2007 across the WHO African region is a reported $771 (discounted to 2014 USD).[36] During the 2006–2007 outbreak of meningococcal meningitis in Burkina Faso, the total cost of case management per cases was $143 (in 2014 USD), of which $32 was direct medical cost.[37] Of note, although some evidence suggests that convalescent EVD patients may have serious long term sequelae such as chronic myalgias, blindness, and deafness,[38–41] our estimates did not include these due to a current lack of long-term data

Table 2 Median (95% range) costs (in USD 2014) of Ebola cases

	Guinea	Liberia	Sierra Leone
Supportive care EVD treatment and PPE costs per case			
Recover			
<15 years old	431 (413–450)	431 (413–450)	431 (413–450)
15–44 years old	446 (428–466)	446 (428–466)	446 (428–466)
≥45 years old	447 (428–464)	447 (428–464)	447 (428–464)
Die			
<15 years old	178 (163–195)	178 (163–195)	178 (163–195)
15–44 years old	185 (169–202)	185 (169–202)	185 (169–202)
≥45 years old	185 (168–202)	185 (168–202)	185 (168–202)
Extensive supportive care EVD treatment and PPE costs per case			
Recover			
<15 years old	598 (576–622)	598 (576–622)	598 (576–622)
15–44 years old	830 (800–862)	830 (800–862)	830 (800–862)
≥45 years old	830 (801–859)	830 (801–859)	830 (801–859)
Die			
<15 years old	238 (217–259)	238 (217–259)	238 (217–259)
15–44 years old	321 (292–351)	321 (292–351)	321 (292–351)
≥45 years old	322 (291–351)	322 (291–351)	322 (291–351)
Personnel costs			
Recover	40 (39–41)	36 (34–37)	59 (57–61)
Die	14 (13–16)	13 (11–14)	21 (19–23)
Productivity losses due to absenteeism and mortality			
Recover	15 (15–16)	14 (13–14)	23 (22–24)
Die			
<15 years old	13 511 (13 511–13 512)	12 252 (12 251–12 252)	18 730 (18 729–18 731)
15–44 years old	11 285 (11 285–11 286)	10 189 (10 188–10 189)	15 253 (15 252–15 254)
≥45 years old	6430 (6430–6431)	5732 (5731–5732)	8157 (8156–8158)
Total outbreak costs			
Number of reported cases (31)	2292	7719	7897
Number of reported deaths (31)	1428	3177	1768
Total cost of recovered cases*			
<15 years old	140 370–188 566	466 836–629 118	509 885–675 909
15–44 years old	840 774–1 483 708	2 797 310–4 961 908	3 049 148–5 263 661
≥45 years old	164 491–290 127	547 272–970 388	596 547–1 029 421
Total cost of deaths*			
<15 years old	2 778 786–2 790 866	4 980 782–5 004 629	4 216 800–4 230 070
15–44 years old	9 265 724–9 375 915	24 120 519–24 437 696	19 978 885–20 155 394
≥45 years old	2 773 780–2 831 034	2 693 729–2 755 897	2 114 329–2 148 926
Total costs, reported	15 963 926–16 960 005	35 ,606 448–38 759 635	30 465 594–33 503 381
Total costs, underreporting factor of 2	31 927 852–33 920 011	71 212 896–77 519 271	60 931 189–67 006 762
Total costs, underreporting factor of 4	63 855 703–67 840 022	142 425 793–155 038 542	121 862 378–134 013 525

Note: *Range represents costs across EVD severity (i.e. total cost of supportive care cases to total cost of extensive supportive care cases).

on the frequency, exact symptomology, and disability effects of such chronic EVD conditions.

Another way to place these estimates in context is to compare the to-date cost of the current epidemic: in Liberia alone, our estimates of $143–$155 million outstrip their allocated annual health budget ($49 million for 2011–2012) in that country, which is over three times higher.[42]

In general, our model aimed to be conservative. Our model does not include secondary or indirect costs such as the impact on those people around a case (e.g. how their work patterns may be affected by proximity to a known EVD case). We did not incorporate costs incurred outside patients' time in Ebola care centers (i.e. costs incurred before or after seeking care are not accounted for) or those associated with infection control practices beyond PPE. Our model did not account for the full spectrum of sociodemographic and clinical heterogeneity among EVD patients; likewise, for simplicity, we relied on median ages and weights for each of the three age groups, rather than age and weight distributions. The model also did not consider other costs associated with patient treatment and epidemic response, such as those associated with setup and management of temporary field hospitals.

Nevertheless, determining the provider and societal costs of an EVD case is an important starting point to help understand the economic burden of EVD and ultimately the cost impact and cost–effectiveness of interventions. Estimating the cost of an EVD case is important in budgeting and planning for not only future epidemics, but also individual cases and periodic smaller outbreaks. Without cost of case estimates, decision makers may not plan and budget as well for responses, policies, treatments, surveillance, and other interventions. The cost per case can serve as a cornerstone for future analyses such as the cost–effectiveness of current and new Ebola interventions — which are being rapidly developed in response to the current situation in West Africa.[43,44]

Just accounting for direct costs and productivity losses due to death and acute treatment gives us a conservative estimate of over $82 million for the current West Africa epidemic to date. This is a conservative benchmark to compare the investments into the Ebola epidemic control to date, such as the World Bank disbursements of $117 million.[45] Of course, the actual epidemic costs likely exceed our estimate due to the elements mentioned earlier and because the WHO estimates the number of actual cases may be two to four times higher than those reported.[32]

Conclusion

Our model of the provider and societal costs of EVD is one of the first attempts at quantifying the cost of an EVD case. Extrapolating suggests that the current epidemic to date has cost over $82 million in total costs from the societal perspective in Guinea, Liberia, and Sierra Leone. Determining the direct and productivity costs of an EVD case is an important starting point to help understand the economic burden of EVD and ultimately the cost impact and cost–effectiveness of interventions.

Disclaimer Statements

Contributors SMB and BYL contributed to the study concept, design, data collection, analysis, manuscript preparation and approval. KG contributed to data collection, analysis, and manuscript preparation and approval.

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Conflicts of interest None.

Ethics approval None.

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