Risk Management and Preparedness: Use of Stochastic Modeling and Risk Analytics to Estimate Frequency and Severity of Filovirus Epidemics

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<td>Filovirus epidemics pose a significant risk for human and economic losses. Historically, epidemic risk has been challenging to quantify. Current methods for risk management and preparedness planning typically rely on a limited set of scenarios based on often sparse and incomplete observational data. These methods suffer from the limitations that the historical record represents only a small subset of the plausible epidemics that could occur, and that the likelihood that a future epidemic would be of a similar size as the events used for scenario-based preparedness planning is often not estimated. This means that the scenarios used for preparedness planning may be too mild or too severe in comparison to the level of planning that an organization or government may actually need. Models of infectious disease spread allow for global simulations of spatiotemporal dynamics of hypothetical epidemic scenarios. These models can help fill in the gaps in observational data, and with the appropriate probabilistic weightings, can provide a clearer picture of the expected frequency and severity of epidemics. This in turn can enable more informed approaches to preparedness planning and risk management.</td>
<td>We evaluated model outputs of cases, hospitalizations, and deaths due to filovirus epidemics. The countries that are predicted to most commonly experience filovirus epidemics (at least one infection that either originated in the country or was imported) were Democratic Republic of the Congo, Guinea, Liberia, and Uganda. We estimate that Democratic Republic of the Congo has a 31% annual probability of having at least one filovirus infection in any given year. The number of filovirus-associated deaths in modeled outbreaks ranged from one death in small events to over 250,000 global deaths in one extreme scenario, with the greatest estimated average annual mortality rates observed in West and Central Africa (Figure 4). We estimate that there is an approximately 1.5% probability that the global number of cases within a year meets or exceeds the number of cases reported for the 2014 West Africa Ebola epidemic (Figure 5).</td>
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Materials & Methods
We used a stochastic epidemic model (Figure 1) to simulate over 200,000 filovirus epidemics, with varying initial parameters and differing availability and efficacy of intervention measures. Vaccine availability and ring vaccination are considered. Probability distributions of model parameters such as spark location, transmissibility, time from onset to hospitalization, and case-fatality ratio were derived from analysis of primary literature and historic case data (Figure 2). We constructed an event catalog by selecting simulated events using a sampling algorithm that accounted for the joint probability of each parameter combination for each scenario and the inter-arrival time distribution between filovirus epidemics (Figure 3). The event catalog was then used to generate exceedance probability metrics, which estimate the likelihood of observing an event of a given severity (e.g., expected deaths), or worse, in any given year.

Discussion
Constructing an event catalog allows us to estimate the relative likelihood of filovirus events in different regions, which can help guide preparedness planning and epidemic risk management towards an objective severity benchmark (e.g., 1 in 20 year event), rather than utilizing a benchmark scenario based solely on historical experience. These model outputs can be used to fill analytical gaps in managing epidemic risk, for example, to support decision-making around disaster risk financing mechanisms to cover filovirus outbreak response costs.

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Figure 1. Filovirus model structure

Figure 2. Meta-analysis of time from onset to hospitalization

Figure 3. Event catalog generation process

Figure 4. Average annual mortality rates for modeled filovirus events

Figure 5. Global filovirus exceedance probability curve