Inferring outbreak characteristics from a short observation period of symptomatic patients

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Objective

This paper presents a method that infers the number of infected people, the time of infection and the dose received from an aerosol release of a pathogen during a bioterrorism incident. Inputs into the inference process are the number of new diagnosed patients showing symptoms each day as observed over a short duration (3–4 days) during the early epoch of the outbreak.

Background

The aerosol release of a pathogen during a bioterrorist incident may not always be caught on environmental sensors—it may be too small, may consist of a preparation that is coarse and heavy (and consequently precipitates quickly) or may simply have occurred in an uninstrumented location. In such a case, the first intimation of an event is the first definitive diagnosis of a patient. Being able to infer the size of the attack, its time, and the dose received has important ramifications for planning a response. Estimates drawn from such a short observation period will have limited accuracy, and hence establishing confidence levels (i.e., error bounds) on these estimates is an major concern. These estimates of outbreak characteristics can be also be used as initial conditions for epidemic models to predict the evolution of disease (along with error bounds in the predictions), in particular, communicable diseases in which the contagious period starts soon after infection (e.g., plague).

In this paper, we will consider anthrax and smallpox as our model pathogens. Since the contagious period of smallpox usually starts after the long incubation period (7–17 days), and the early epoch will consist only of index cases, we will model it as a non-contagious disease. Inputs will be obtained from simulated outbreaks as well as from the Sverdlovsk anthrax outbreak of 1979 [1].

Methods

We employ a Bayesian approach to develop probability density functions (PDFs) for the number of people infected (N), the time of infection (τ) and the dose received (D), conditioned on the data. The likelihood function is analytically derived [2] from the expression for the incubation period distribution; for anthrax, this expression is dose-dependent [3]. The problem of estimating a dose is novel and specific to bioterrorism incidents. Uniform distributions are used as priors.

Results

Presently, we have tested our approach using outbreaks where N varied between 10^2 and 10^4 and D between 1 and 10^4. Small outbreaks (N < 100) are difficult to infer, given the paucity of the symptomatic patient stream. Dosage is the most difficult parameter to estimate, though matters are considerably improved if the observation period is lengthened or *if the frequency of observations in a given period is increased*, e.g., by collecting data over 6 hour intervals instead of daily. We also applied this approach to data from the Sverdlovsk outbreak where 70 people died.

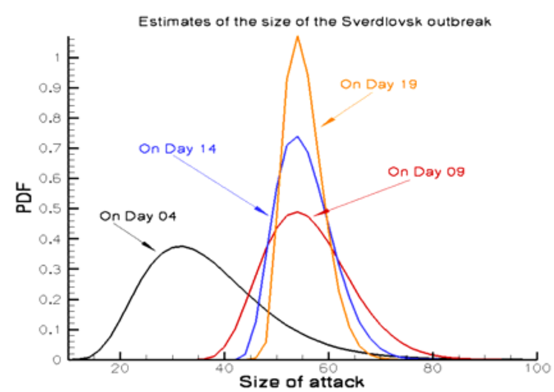

Figure 1 Estimates of the size of outbreak for the Sverdlovsk problem developed using our Bayesian approach. Estimates improve as more data becomes available.

Conclusions

We have a prototypical approach for estimating the characteristics of an outbreak resulting from inhalational infection. It is currently being extended, using sophisticated mathematical techniques, for robustness and is being investigated as an input for predictive forward simulations.

References

[1] Meselson et al, *Science*, 266:1202-1208, 1994

[2] Ray et al, Sandia National Laboratories Technical Report SAND2006-1491.

[3] D. Wilkening, *PNAS*, 103(20):7589-7594, 2006.

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