Osong Public Health Res Perspect 2016 7(1), 43—48
http://dx.doi.org/10.1016/j.phrp.2015.12.012
pISSN 2210-9099 eISSN 2233-6052

ORIGINAL ARTICLE

Modeling the Spread of Ebola

Tae Sug Do [a], Young S. Lee [b,*]

[a]*Department of Mathematics Education, Catholic Kwandong University, Kangleung, Korea.*
[b]*Department of Mathematics and Computer Science, Manchester University, North Manchester, IN, USA.*

Received: October 1, 2015
Revised: October 29, 2015
Accepted: December 28, 2015

KEYWORDS:
basic reproductive number,
Ebola,
epidemiological model,
Nigeria,
stability analysis

Abstract

Objectives: This study aims to create a mathematical model to better understand the spread of Ebola, the mathematical dynamics of the disease, and preventative behaviors.

Methods: An epidemiological model is created with a system of nonlinear differential equations, and the model examines the disease transmission dynamics with isolation through stability analysis. All parameters are approximated, and results are also exploited by simulations. Sensitivity analysis is used to discuss the effect of intervention strategies.

Results: The system has only one equilibrium point, which is the disease-free state $(S,L,I,R,D) = (N,0,0,0,0)$. If traditional burials of Ebola victims are allowed, the possible end state is never stable. Provided that safe burial practices with no traditional rituals are followed, the endemic-free state is stable if the basic reproductive number, R_0, is less than 1. Model behaviors correspond to empirical facts. The model simulation agrees with the data of the Nigeria outbreak in 2004: 12 recoveries, eight deaths, Ebola free in about 3 months, and an R_0 value of about 2.6 initially, which signifies swift spread of the infection. The best way to reduce R_0 is achieving the speedy net effect of intervention strategies. One day's delay in full compliance with building rings around the virus with isolation, close observation, and clear education may double the number of infected cases.

Conclusion: The model can predict the total number of infected cases, number of deaths, and duration of outbreaks among others. The model can be used to better understand the spread of Ebola, educate about prophylactic behaviors, and develop strategies that alter environment to achieve a disease-free state. A future work is to incorporate vaccination in the model when the vaccines are developed and the effects of vaccines are known better.

1. Introduction

The Ebola virus was first identified in 1976 near the Ebola River infecting at least 280 people, and there were several outbreaks of Ebola virus disease (EVD) over the years. However, none of those were as serious as the current outbreak in West Africa, which started in March 2014 and is affecting the whole world.

Multiple species have been identified, but the present outbreak was caused by the Zaire species. The Centers for Disease Control and Prevention say that only mammals have shown the ability to spread and become

*Corresponding author.
E-mail: yslee@manchester.edu (Y.S. Lee).

infected with Ebola. The current outbreak in West Africa was started from a 2-year-old boy who was infected by a bat, and then Ebola has spread through human-to-human transmission via direct contact with bodily fluids of infected people, and with surfaces and materials contaminated with these fluids. That is why health care workers have frequently been infected while treating patients with suspected or confirmed EVD. It has not been proved that Ebola can spread among humans via airborne transmission, although Ebola goes airborne from pigs to monkeys [1].

Diagnosis of EVD without a laboratory test can be difficult. Since the symptoms start with fever, severe headache, muscle pain, and fatigue, the onset appears to be similar to that of flu. Progressed symptoms also cause misdiagnosis as malaria or typhoid, because diarrhea, vomiting, abdominal pain, and unexplained hemorrhage follow. The delay in laboratory tests for EVD multiplies secondary infections, slows quarantine or isolation, and increases fatality. Once infected, the incubation period is anywhere between 2 days and 21 days, but the average is 8−10 days [2]. The average fatality rate is around 50%, and case fatality rates vary from 25% to 90% [3].

Epidemiologists build rings around the virus to stop the spread of Ebola, which starts with the circle of people in direct contact with the patient. All the people in the circle are asked about their own circle of close contacts. With close observation and clear education, such as monitoring the symptoms and avoiding crowded public spaces among others, these rings are usually sufficient to stop the spread of EVD [4]. Isolation is absolutely necessary to bring an end to the spread of Ebola. However, it is not easy to decide whether to quarantine a person or not. According to Sankarankutty and Mekaru [5], quarantine is the separation and restriction of movement of healthy people who may have been exposed to an infected person, and isolation is the separation and restriction of movement of already infected individuals. Quarantine is a strong control strategy, but is excessive and can be counterproductive because many quarantined persons may turn out to be not infectious at all. Along the analogous reasoning, the World Health Organization does not recommend any ban on international travel or trade. Closing borders hinders the international community's ability to fight EVD. The World Health Organization and Centers for Disease Control and Prevention recommend isolation of the infected persons and self-monitoring of exposed individuals, on which our model is based.

Our objective is to better understand the spread of the Ebola virus, the mathematical dynamics of the disease, and preventative behaviors by creating a mathematical model. We create an epidemiological model with a system of nonlinear differential equations, and the model examines the dynamics of the system analytically and numerically. To see how closely our model describes an outbreak of EVD, we approximate all parameter values of the system. Since the model is applied to the recent outbreak in Nigeria, the data set from Nigeria is used to estimate parameter values. The first Ebola case in Nigeria appeared in July 2014, and Nigeria was declared Ebola free in October 2014 [6]. Discussions and conclusions follow with the combination of analytical stability analysis and simulation of the model in the last section.

2. Materials and methods

Our model is composed of five compartments, dividing the population studied into the following classes: S, L, I, R, and D; $S(t)$ is the number of susceptible individuals at time t; the class L is consisted of latent individuals, who are infected but not infectious yet, or individuals with symptoms but misdiagnosed by a doctor or the patient; I denotes the class of infected, infectious, and isolated individuals; R is the group of recovered individuals; and $D(t)$ represents the number of individuals who died of EVD at time t. Since the outbreaks and durations of the EVD epidemics are usually short time periods, we assume that the total population:

$$N(t) = S(t) + L(t) + I(t) + R(t) + D(t)$$

is constant, i.e., the number of births and deaths due to factors that are unrelated to Ebola is negligible in our study.

Transmission rates are expressed as the mass action terms:

$$\beta(1-p)S/N$$

where p denotes the proportion of susceptible professional health care workers to general susceptible individuals;

$$\beta = (p_\beta)(c_\beta),$$

where p_β is the probability of getting successfully infected when contacted with an infected person and c_β is the per capita contact rate. Once an Ebola patient is confirmed, the spread can be stopped systematically by activating control strategies such as identifying and following up contacts, setting up isolation units, training health care providers, providing protective clothing and gear, educating public about how Ebola spreads, prohibiting traditional burials of Ebola victims among others. Since the intervention takes time, the transmission rates are reduced gradually; hence, β is defined as a piecewise function of time. The contagion from latent individuals and isolated patients often occurs to health care providers. In the expression:

$$(\alpha_L L + \alpha_I I)pS/N,$$

α_L and α_I are the probabilities of getting positively infected when a healthcare provider comes into contact