Report – modeling the infectious disease Diphtheria

1. Research on Diphtheria outbreak

Background of Diphtheria

Diphtheria is an infectious disease caused by *Corynebacterium*, a toxigenic bacteria genus. There are more than 100 species of aerobic, Gram-positive rods from which are mostly *C. diphtheriae* but also *C. ulcerans*, and *C. pseudotuberculosis* known to produce the diphtheria toxin, encoded by *tox*. C. diphtheriae can be divided into the four biotypes gravis, mitis, intermedius, and belfanti based on morphology and biochemical reactions. While belfanti is not described as toxigenic, mitis is associated with mild, intermedius with intermediate, and gravis with serious disease severity The disease increased childhood morbidity and mortality before vaccinations were established and affected the respiratory, cutaneous, and ocular compartments [1].

The outbreak in the European region

The European region suffered from an acute diphtheria outbreak in the late 20. century to the early 21. century. The World Health Organization (WHO) provides information about reported cases and incidence rate per one million total population from 1980 to 2021. A minor outbreak reached its peak in 1983 with an incidence rate of 0.9 before it started to decrease to 0 in 1988. The severest epidemic outbreak in European took place between 1989 and 2008 (Figure 1). The all-time high was reached in 1995 with 50433 reported cases and an incidence rate of 58.7 [2].

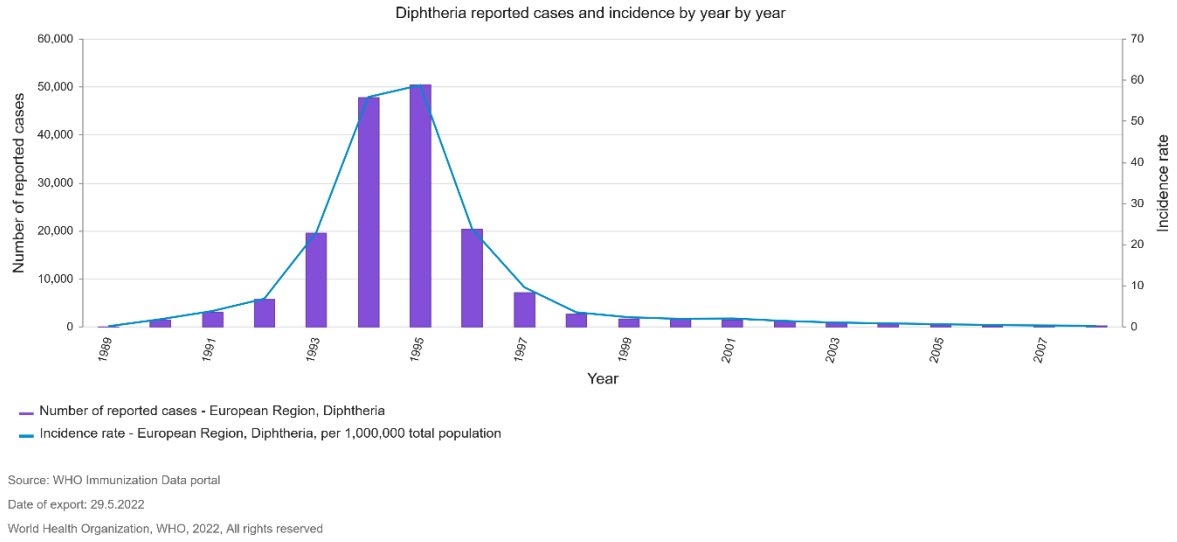

Figure 1 Diphtheria outbreak in Europe from 1989 to 2008 [2]

2. Definition of scenarios

General Set up

The population number N was set with 726352883 to the population number in Europe back in 2000 when the outbreak occurred. Unfortunately, no references regarding the contact rate were found and the value was therefore estimated to be 0.3. The average recovery rate of diphtheria lies between 7 and 14 days and was set to the mean value of 10.5. The model was calculated for 200 data points (days).

The diphtheria infection divides the population into susceptible, infectious, and recovered. Several sources were identified that claim the possibility of reinfection after a first infection [3]. However, they always lacked any values, and therefore, this compartment was not included in the model.

Influencing factors

Influencing factors are financial (government, funding, community), human (organizations, agencies), and physical (facilities, equipment) resources. Additionally, there are non-resource-related factors including education and training (knowledge about the disease before it occurs), leadership, intergovernmental relationships, and communication (information sharing, appropriate allocation of resources, and cooperation between organizations and countries). Other factors are disease characteristics, and environmental and legislative factors [4].

Intervention

Reported cases in Europe have been reduced due to effective vaccination and mass immunization [5]. For this model, vaccination was used as an intervention with a vaccination rate of 0.1% of the European population per day which equals 726352.883 people. The vaccination rate will be represented in the model with the variable delta = 0.001.

Definition of R_0 and R_e

R_0 is the basic reproduction number that is used to measure the transmissibility of infectious agents. The variable is composed of the duration of infectivity of an infected patient, the likelihood of transmission of infection per contact between a susceptible and an infectious person, and the contact rate. R_0 is estimated either retrospectively using contact-tracing data or with mathematical models using ordinary differentiation equations [6].

R_e is the effective reproduction number and states the number of people in a population that can be infected by an individual at any specific time. The value alters over time since the population will experience an immunization due to individual immunity after infection, vaccination, and mortality. The variable is affected by the number of people with infection, the number of contacts between susceptible and infected people, and general behavior like social distancing [6].

3. Analyzing the impact of the intervention

Figure 2 depicts the diphtheria outbreak model without interventions. The structure represents a one-time acute outbreak with a peak after 105 days including around 230 million infected patients. After 155 days, the disease nearly vanished.

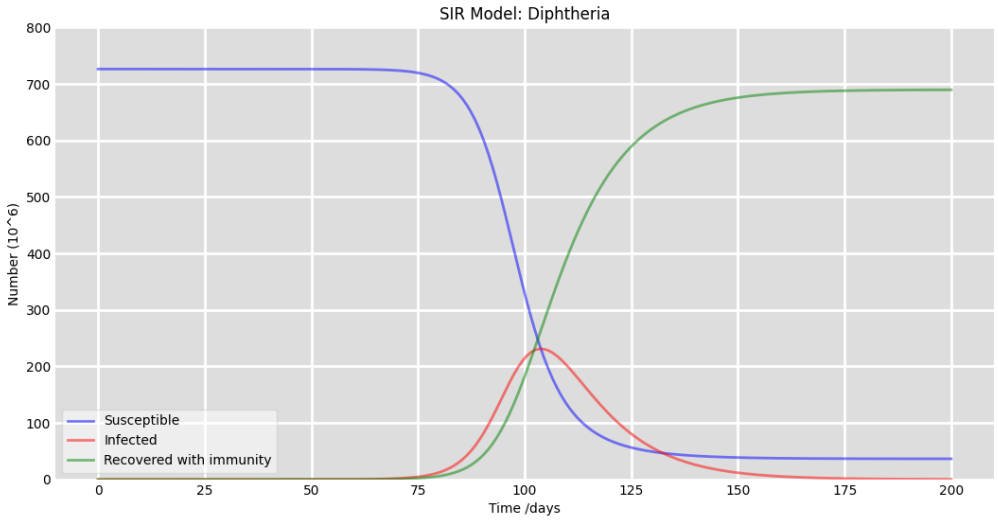

Figure 2 Model of a diphtheria outbreak without interventions.

Figure 3 depicts the diphtheria model with vaccination as an intervention. Since the vaccination rate and the population number are both constants, the number of vaccinated people rises continually. The peak of infected patients is reached after 110 days with 180 simultaneously infected individuals. Since the vaccination starts on day 0, the number of susceptible and recovered people immediately decreases and increases, respectively.

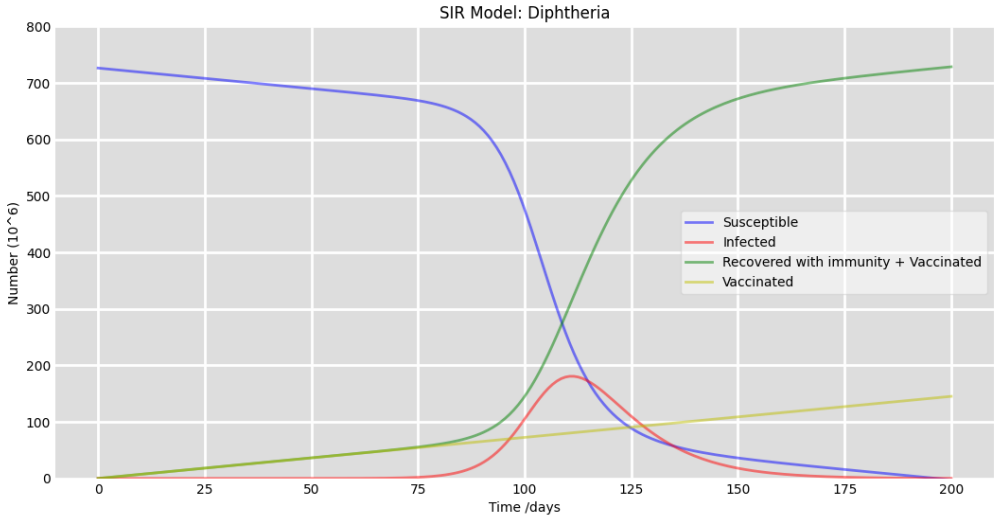

Figure 3 Model of a diphtheria outbreak with vaccination as an intervention

When we compare the outbreak without intervention to the outbreak with vaccination, we can see that the peak number of simultaneously infected individuals is reduced by 50 million. In addition, the timepoint for the peak and before the infection vanishes is delayed by 5 days. With this setup, the usage of a vaccine against diphtheria can be seen as beneficial.

The way the vaccination was modeled has some unrealistic characteristics. Vaccination begins on day 1 although the outbreak is not yet known at this time. Furthermore, the same number of people are vaccinated every day, so it is not taken into account that the logistics for the vaccination must first be set up and the vaccination numbers will only increase from 0 to 0.1%. As mentioned above, people can be infected again after initial infection, but values have never been mentioned in the literature and were therefore not included in the model.

References

[1] https://pubmed.ncbi.nlm.nih.gov/31804499/

[2] https://immunizationdata.who.int/pages/incidence/DIPHTHERIA.html?CODE=eur&YEAR=

[3] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC1489558/

[4] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6518241/pdf/ijerph-16-01432.pdf

[5] https://www.ecdc.europa.eu/en/diphtheria

[6] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7751056/