



# How should we overcome the threat by the pandemic of 2019-nCoV? Epidemic simulation using the SIRS model

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Since the first identification in December 2019 in Wuhan, China, a number of cases of novel coronavirus (2019-nCoV)-infected patients is increasing around the world. It has been reported that there are high-risk populations with high mortality, such as elderly people and those with comorbidities [1]. However, no specific treatment has been developed yet. Historically, humans have overcome the pandemics of viral infection by preventing secondary infection. Several studies have simulated the spread of 2019-nCoV, and the basic reproduction number ( $R_0$ ) ranges from 2.2 to 3.6 [2, 3]. On the other hand, patients treated with disease-modifying antirheumatic drugs may have insufficient antibody response, implying the possibility of reinfection [4].

Here, to simulate the efficacy of preventing secondary infection in population with consideration of reinfection, I simulated a scenario of one person with 2019-CoV infection entering into a population of 1000 people with the hypothesis that a part of them lose immunity. I used the SIRS model which is composed of different categories within a population; the susceptible ( $S$ ), infected ( $I$ ), recovered ( $R$ ), and returned-susceptible ( $S$ ) compartments, respectively. The model can be written as the following ordinary differential equation:

$$\begin{aligned}\frac{dS}{dt} &= -\frac{\beta SI}{N} + \xi R \\ \frac{dI}{dt} &= \frac{\beta SI}{N} - \gamma I \\ \frac{dR}{dt} &= \gamma I - \xi R \\ R_0 &= \frac{\beta}{\gamma}\end{aligned}$$

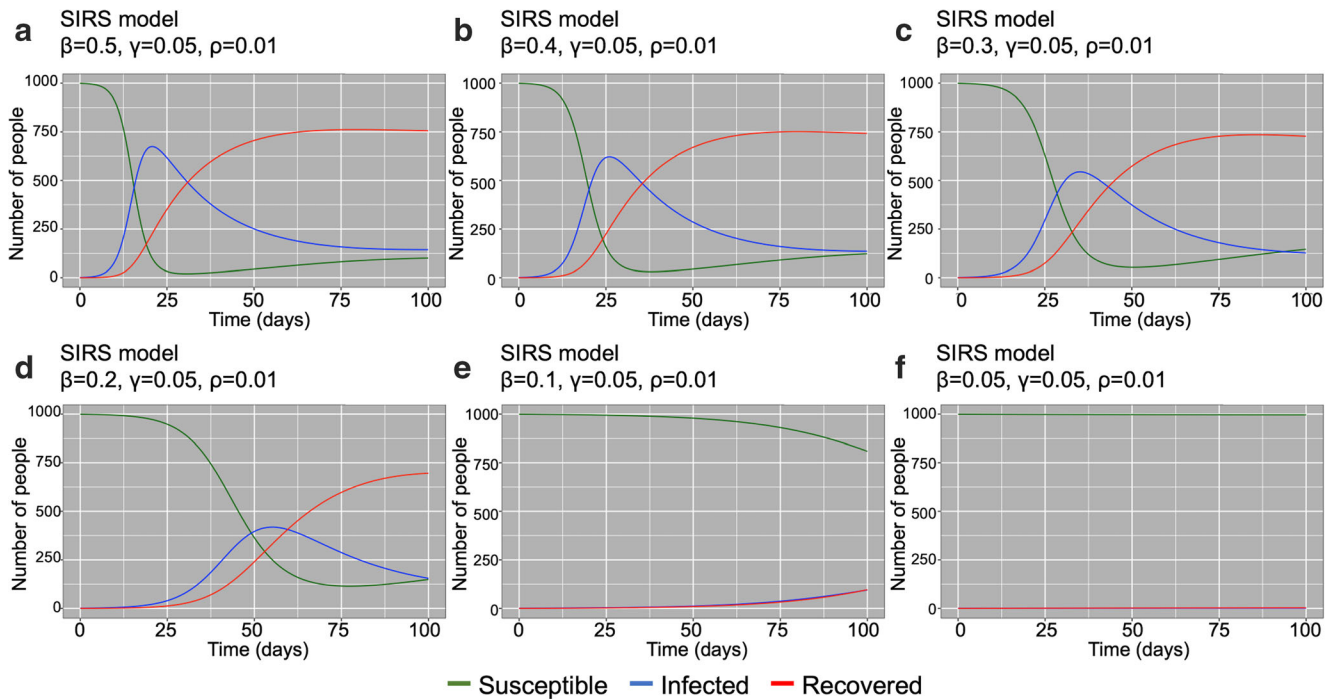
where  $S$ ,  $I$ , and  $R$  are proportions of susceptible, infected, and recovered individuals, respectively,  $\beta$  is the transmission rate of infection,  $\gamma$  is recovery rate (inverse of the infectious period), and  $\xi$  is returning rate of recovered individuals to the susceptible statue due to loss of immunity.  $N$  ( $= S + I + R$ ) is the total population. The simulation was started with  $S=999$ ,  $I=1$ , and  $R=0$  for the following 100 days after the entry of one person with 2019-nCoV. Considering the uncertainty of parameters in the real-world outside China, I combined parameters based on considerable circumstances. Analyses were performed by R software.

First, parameters were set as  $(\beta, \gamma, \xi) = (0.5, 1/20, 0.01)$  based on assumption that infectious duration is 20 days [5] and 1% of recovered individuals return to the susceptible statue due to loss of immunity. As  $\beta$  decreased 0.5, 0.4, 0.3, 0.1, and 0.05 (Fig. 1 a, b, c, d, e, and f, respectively), the maximum number of infected people decreased and the peak delayed, suggesting the effectivity of decreasing transmission rate by standard precautions. When  $\beta$  was 0.05, the secondary infection did not occur.  $R_0$  in each situation was 10, 8, 6, 4, 2, and 1, respectively. Next, to evaluate the efficacy of prompt isolation of infected patients,  $\gamma$  was stratified with 1/20, 1/16, 1/12, 1/8, 1/4, and 1/1 with keeping  $\beta N$  and  $\xi$  the same. As a result, the maximum number of infected people decreased as  $\gamma$  increased (Fig. 2 a, b, c, d, e, and f, respectively). The secondary infection did not occur in the case of  $\gamma=1/1$ .  $R_0$  in each situation was 10, 8, 6, 4, 2, and 1, respectively. These trends were the same as the case  $\xi=0$  (Supplementary

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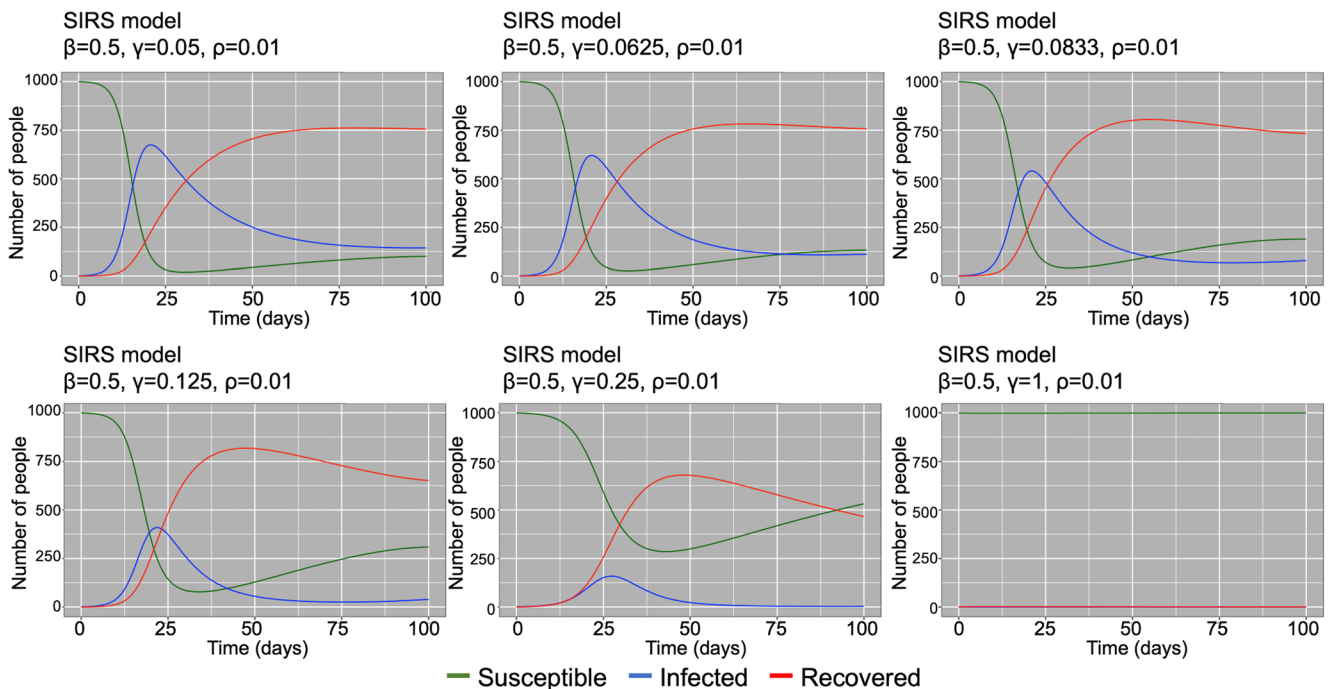


**Figure 1** SIRS model for assessing impact of transmission rate ( $\beta$ ). Transmission rate were stratified with 0.5 (a), 0.4 (b), 0.3 (c), 0.2 (d), 0.1 (e), and 0.05 (f) with keeping recovery rate ( $\gamma$ ) and returning rate ( $\xi$ ) as 1/20 and 0.01, respectively

Figs. 1 and 2; when 2019-nCoV infection would lead to long-lasting immunity).

This study suffers from several limitations. First, since the clinical characteristics of 2019-nCoV are largely unknown, the value of parameters used in this simulation may not be proper. Second, the SIRS model is a simple model based on some

assumptions; the population is closed (no vital dynamics such as birth and death) and the course of the infection is short (emergent outbreak). Also, the possibility that asymptomatic patients could be infectious to others is not considered in this model [6]. Third, because the SIR model assumes a homogeneous infection network between individuals, the



**Fig. 2** SIRS model for assessing impact of recovery rate ( $\gamma$ ). Recovery rates were stratified with 1/20 (a), 1/16 (b), 1/12 (c), 1/8 (d), 1/4 (e), and 1 (f) with keeping transmission rate ( $\beta$ ) and returning rate ( $\xi$ ) as 0.5 and 0.01, respectively

heterogeneity of individuals such as disease status was not considered. Forth, other than standard precautions,  $\beta$  is also affected by virologic characteristics and factors of hosts. Therefore, the result of this study cannot apply to data in the real-world directly. However, this study demonstrated that outbreaks can be prevented by performing appropriate precautionary measures even in populations with consideration of the possibility of reinfection.

**Author's contributions** Conceptualization, formal analysis, and writing were conducted by the author.

**Data availability** All custom computer codes in the generation or processing of the described data are available in the supplementary file.

## Compliance with ethical standards

**Ethics approval and consent to participate** Ethical approval or individual consent was not applicable.

**Consent for publication** Not applicable.

**Disclosures** None.

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