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Critical Factors of Infection Wavy Curve Oscillation of COVID-19 and Future Predictions in Japan

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Abstract

A novel model based on the macromolecule diffusion theory predicted the oscillation of the number of coronavirus disease 2019 infections. In this model, the diffusion coefficient, which depends on population density, determines the wavy oscillation frequency. The recovery rate of infected individuals determines the wavy amplitude. These two factors are critical factors beyond which the value of the infection phase abruptly changes, such as the phase transition. Therefore, we must ensure that the values remain within the critical values of social and medical preventive measures. The number of new infections was expected to peak around the 200-day serial intervals.

Keywords: Infection wavy curve oscillation; Nonlinear kinetics; Diffusion coefficient; Recovery rate

About the Study

We recently reported a nonlinear mathematical model to explain the wavy oscillation curve [1]. The purpose was to determine the critical factors that affect the increase in the number of new infections, the threshold factor, and the dynamics of the explosion in the number of new infections, which we call phase transition [2-4]. In infection propagation, the diffusion process of a population is a rate-limiting step and depends on the population density 1. Importantly, this diffusion dependency on the population density yields nonlinearity of the infection kinetics that causes infectious wavy oscillation [5-9]. Nonlinearity causes oscillation of the infectious number. Unlike previous models, we set the "cluster", which can detect contagious people. We have added the growth steps for this cluster.

Infection transmission models, such as the SEIR model, consist of three or four types of individuals: susceptible (S), exposed (E), Infectious (I), and Recovered (R). Our model consists of three types of populations: X (non-infectious), Z (infectious), and W (cluster). The presence of the cluster was based on the dispersal data of the infection. First, X can irreversibly be involved in the cluster $X+X+W \leftrightarrow W$. Subsequently, *Z* leaves the cluster $W \to Z$.

Furthermore, *Z* is treated to recover to $X : Z + P \to X$. In addition, the population interactions increased the infection risk: $X+Z \to X+Z$ and $X+Z \to 2Z$.

$$\frac{dX}{dt} = -h_1(\mathrm{X})\,\mathrm{WX} + \mathrm{h}_3\, pZ - h_4(X)X^2 - h_5(X,Z)X \tag{1}$$

$$\frac{dZ}{dt} = h_2\,\mathrm{W} - \mathrm{h}_3\, pZ - h_4(X)X^2 + h_5(X,Z)XZ \tag{2}$$

h1, *h4*, and *h5* are proportional to the diffusion coefficients of populations X and Z. These are the basic equations. indicates the recovery rate. We set a metapopulation model based on the kinetics by combining the above equation applicable to areas with daily transportation. In the Kansai area, local governments cooperated to prevent infectious propagation. Each person obeyed the guidelines for preventing infection, for example, wearing a mask, performed healthy hygiene practices, and other non-pharmaceutical interventions. Transmission during transportation was not considered in this study. The infection wavy oscillation was well simulated, and the peak in the number of infections increased by approximately 2.0 times at each infectious wave. In past infections, the predicted serial interval with wavy oscillation was approximately 200 days ± 10 days.

Using the above simulation, we predicted the threshold of the recovery rate p_c . When $p - p_c < 0$, an infection explosion occurs; however, when $p - p_c > 0$, an infection explosion is suppressed, and the infection number may exhibit a wavy oscillation. Notable, the following relation between $\in = p - p_c$ and the wavy oscillation frequency *f* period was observed as a logarithmic function $f = a \log \in + b$, where a and b are arbitrary coefficients. The simulation predicts that the wave amplitude nearly approaches a plateau after the wavy oscillation.

Another simulation result showed that individual diffusion control was critical for the suppression of infection control. There are two critical values for diffusion: h_{1c} and h_{2c} . At $h_1 < h_{1c}$, no new wave of infection was observed. At $h_1 > h_{2c}$, a wavy oscillation was observed, and the amplitude approached a plateau when h_1 was near . Thus, suppressing the diffusion of infected individuals is critical for infection control. The oscillating model of infection waves proposed here can clearly explain the importance of limiting human flow, detecting cluster outbreaks, and securing medical resources to recover infected individuals. The thresholds for the diffusion coefficient and recovery rate can be calculated by simulation; thus, it is possible to judge whether the current infection state will transition to a "phase transition" state in which infections increase or whether the number of infections will oscillate. In addition, the data that the peak value of the wavy oscillation of infected people number has increased by about double may be related to the primary and effective reproduction numbers, which are indicators of "contagiousness." However, from the perspective of

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nonlinear dynamics, this doubling of the peak value requires further theoretical analysis. A plot of new infections in the Kansai area from January 16, 2022, and a simulated curve (green line) are shown in Figure 1. The cumulative number of infected people is expected to reach more than 25% of the Japanese population. The cumulative number of infected people exceeds 50% of the total population when the infection peaks the next time.

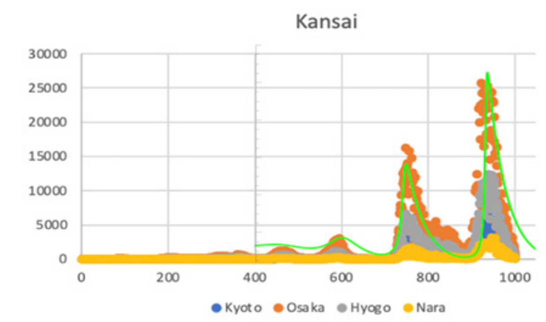

Figure 1: Numerical simulation of the new infection. Simulation of the newly infected population in the Kansai area. The theoretical simulated curve of the number of new infections in Osaka is shown in green. The plots show the infection numbers in the Kansai district (Osaka, Kyoto, Nara, and Hyogo) of Japan (https://www.mhlw.go.jp/stf/covid-19/open-data.html). The horizontal x-axis represents the date from January 2022, and the vertical y-axis represents the infectious number. The theoretical plot was fitted to the maximum and minimum numbers of infections in the plot. The simulation was performed using Mathematical, version 10 (Wolfram, IL, USA). **Note:** (●) Kyoto, (●) Osaka, (●) Hyogo, (●) Nara

Conclusion

Therefore, there is a possibility that herd immunity will be established by infecting almost the entire population at the next infection peak, and the infection may converge. However, as the flow of people recovers, the peak of infection accelerates, and it is expected that the peak of infection will occur earlier. In conclusion, the new infectious number model based on nonlinear diffusion kinetics can reasonably predict the infection number. This model may provide essential insights into similar transmissions in the future.

Conflict of Interest Statement

There is no conflict.

Funding

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