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Research Article

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Effect of Reinfection on the Spread of COVID-19 Evaluated by a Flexible Compartment Model

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Abstract

Infection-induced immunity in recovered individuals decreases gradually, and when it decreases to below a certain threshold, recovered individuals substantially get back to susceptible individuals and can be infected with reinfections, which are infections that occur in individuals who have been infected once and have recovered from infection. The increase in susceptible individuals due to getting back to susceptible individuals from recovered individuals can increase not only the number of individuals who could be infected but also the contact rate between infected individuals and susceptible individuals, resulting in a marked increase in the number of infected individuals.

Using a flexible compartment model specific to COVID-19, the duration of infection-induced immunity required for reinfection to occur was examined and the changes in the number of reinfected individuals were calculated. The model includes the duration of infection-induced immunity, which indicates the validity period of the effectiveness of infection-induced immunity, and the 'back to rate', which indicates the ratio of the number of individuals who get back to susceptible individuals from recovered individuals as independent variables in the equations. Change in the number of infected individuals was examined in relation to the duration of infection-induced immunity.

Even if infection-induced immunity has a duration of effectiveness, if the duration is long, reinfection might not occur. The duration of infection-induced immunity required for reinfection to occur varies depending on symptomatic rate and potential infectious capacity of coronavirus. When reinfection occurs, not only reinfections but also 'normal infections', which are the first-time infections occurring in the 'original' susceptible individuals, occur. As a result, the number of infected individuals increases significantly, and the duration of infection becomes significantly longer. It is necessary to reduce the occurrence of reinfection in the early stages of infection through vaccination, PCR testing, and other medical and policy care.

Keywords: *Back-to-rate, Compartment model, COVID-19, Duration of infection, Duration of infection-induced immunity, Infection during the latent period, Isolation, Recovered, Reinfection, Susceptible, Symptomatic rate.*

1. Introduction

Individuals infected with COVID-19 are isolated from the community when they become symptomatic after the latent period ends, and when the isolation period ends, they become 'recovered' individuals who have infection-induced immunity (disease-induced immunity) and then return to the community. In a community mixed with infected individuals, susceptible individuals and recovered individuals, the contact rate between infected individuals and susceptible individuals is reduced by the contact of infected individuals with recovered individuals when the number of recovered individuals increases, resulting in a decrease in the number of infected individuals.

Infection-induced immunity through infection with COVID-19 has been confirmed to protect against 'reinfection'. However, when the validity of infection-induced immunity decreases below a certain threshold, an individual who has been infected once, has infection-induced immunity and has recovered from the infection will become infected again, a 'second-time infection'. This second-time infection is usually referred to as 'reinfection', and it occurs in an individual when his/her infection-induced immune effectiveness falls below a certain threshold.

The duration of infection-induced immunity, which indicates the 'validity period of effectiveness of immunity against SARS-CoV-2 infection and/or COVID-19 disease', has been examined and reported as follows: "Both SARS-CoV-2-specific T cells and antibodies could be detected for a period of more than 1 year after infection, indicating that the immune protection established during initial infection is maintained and might possibly protect from severe disease in case of reinfection or infection with novel emerging variants [1]", and/or "Reinfection by SARS-CoV-2 under endemic conditions would likely occur between 3 months and 5·1 years after peak antibody response, with a median of 16 months [2]", and/or "The weighted average risk reduction against reinfection was 90.4%. Protection against SARS-CoV-2 reinfection was observed for up to 10 months [3]" and/or "Overall protection of previous infection was 85.7% (95% CI, 82.2-88.5) and lasted up to 13 months [4]", and/or "The shortest duration between the first infection and reinfection was 19 days and the longest was 293 days [5]", and/or "The number of cases of SARS-CoV-2 infection per 100,000 person-days at risk (adjusted rate) increased with the time that had elapsed since vaccination with BNT162b2 or since previous infection. Among unvaccinated persons who had recovered from infection, this rate increased from 10.5 among those who had been infected 4 to less than 6 months previously to 30.2 among those who had been infected 1 year or more previously [6]", and/or "National surveys covering 2020-2021 documented that a previous SARS-CoV-2 infection is associated with a significantly reduced risk of reinfections with efficacy lasting for at least one year and only relatively moderate waning immunity [7]", and/or "The incremental immunity acquired from past infections waned within 1 year [8]" and/or "Protection from re-infection from ancestral, alpha, and delta variants declined over time but remained at 78·6% at 40 weeks. Protection against re-infection by the omicron BA.1 variant declined more rapidly and was estimated at 36·1% (24·4–51·3) at 40 weeks [9]", and/or "Published meta-analyses show consistently high levels of protection (81.0–87.0%) provided by prior infection, even over 7 months post-initial infection [10]", and/or "The duration of protection against reinfection was stable over the median 5 months and up to 1-year follow-up interval [11]", and/or "The effectiveness of previous infection against reinfection waned to 24·7% (95% CI 16·4–35·5) at 12 months [12]", and/or "In infected–unvaccinated participants, neutralising antibody titers continually declined from 6-month to 2-year follow-up visits, with a half-life of about 141·2 days [13]". It is also pointed that "Before Omicron, natural infection provided strong and durable protection against reinfection, with minimal waning over time. However, during the Omicron era, protection was robust only for those recently infected, declining rapidly over time and diminishing within a year. This shift in patterns suggests a change in evolutionary pressures, with intrinsic transmissibility driving adaptation pre-Omicron and immune escape becoming dominant post-Omicron [14]". As shown in the above studies, protection against reinfection can last for months or more than a year.

However, it is sure that the effectiveness of infection-induced immunity wanes over time. In other words, the effectiveness of the immunity acquired through infection does not continue permanently but decreases gradually until it is below a certain threshold, which indicates a loss of effectiveness. The reinfection rate (and/or 'reinfection incidence rate') has been investigated and reported as follows: "Of 906 records retrieved and reviewed, 11 studies and 11 case reports were included in the meta-analysis and the systematic review, respectively. The pooled SARS-CoV-2 reinfection incidence rate was 0.70 per 10,000 person-days. The incidence of reinfection was lower than the incidence of new infection (HR = 0.12) [15]", and/or "During the Delta and Omicron waves, both infection-induced and hybrid immunities were associated with a trend of equal or greater decrease of occurrence than vaccine-induced immunity in hospitalizations, intensive care unit admissions, and deaths in comparison to those without pre-existing immunity, with hybrid immunity often trending with the greatest decrease [16]", and/or "A total of 23,231 reinfected patients were included, with pooled estimated reinfection rates ranging from 0.1 to 6.8%. Reinfections were more prevalent during the Omicron variant period [17]", and/or "All notified cases were extracted from the Japanese national COVID-19 surveillance database including 20,297,335 records up to 25 September 2022." "Among 19,830,548 SARS-CoV-2 first infections, 233,424 (1.2%) were reinfected with BA.5. The protective effect against BA.5 reinfection of prior infection with Wuhan strain was 46%, Alpha variant was 35%, Delta variant was 41%, and BA.1/BA.2 subvariant was 74%. The reduced risk of BA.5 reinfection by 7%, 33%, and 66% was associated with two, three, and four doses of vaccination, respectively, compared with one-dose vaccination." "Increased frequency of vaccination led to more protection from reinfection with BA.5 [18]", and/or "in the Delta wave, D614G nAbs mediate 37% of the total protection against infection conferred by prior exposure to SARS-CoV-2, and that protection decreases with waning immunity. In contrast, Omicron BA.1 nAbs mediate 11% of the total protection against Omicron BA.1 or BA.2 infections, due to Omicron's neutralization escape [19]", and/or "Once you have had COVID-19, your immune system responds in several ways. This immune response can protect you against another infection for several months, but this protection decreases over time. People with weakened immune systems who get an infection may have a limited immune response or none at all [20]". The reinfection rate (the number of infected individuals/the number of prior infected individuals) is reported to be as low as a few percent or less than 10%.

Most of the articles above also discuss the relationship between infection-induced immunity and hybrid immunity, which is immunity provided by a combination of infection and vaccination, for example, "The protective effect of prior SARS-CoV-2 infection on re-infection is high and similar to the protective effect of vaccination [3]", and/or "Among persons who had received a single dose of vaccine after previous infection, the adjusted rate, which is the number of cases of SARS-CoV-2 infection per 100,000 person-days at risk, was low (3.7) among those who had been vaccinated less than 2 months previously but increased to 11.6 among those who had been vaccinated at least 6 months previously. Among previously uninfected persons who had received two doses of vaccine, the adjusted rate increased from 21.1 among those who had been vaccinated less than 2 months previously to 88.9 among those who had been vaccinated at least 6 months previously [6]", and/or "The effectiveness of hybrid immunity against hospital admission or severe disease was 97·4% at 12 months with primary series vaccination and 95·3% at 6 months with the first booster vaccination after the most recent infection or vaccination. Against reinfection, the effectiveness of hybrid immunity following primary series vaccination waned to 41·8% at 12 months, whereas the effectiveness of hybrid immunity following first booster vaccination waned to 46·5% at 6 months [12]" and/or "infection-induced immunity is as or more effective than vaccination in reducing the severity of reinfection from the Delta or Omicron variants [16]" and/or "The reduced risk of BA.5 reinfection by 7%, 33%, and 66% was associated with two, three, and four doses of vaccination, respectively, compared with one-dose vaccination." "Increased frequency of vaccination led to more protection from reinfection with BA.5. Up-to-date vaccination may be encouraged to prevent future reinfection among the previously infected population [17]" and/or "Protection conferred by hybrid immunity was more durable than that from either vaccination or prior infection alone, but protection against Omicron reinfection was only 50.1 % at 26 weeks following vaccination. Individuals with hybrid immunity had 80.6 % protection following booster doses declining to 36.9 % after 16 weeks [21]". Vaccinations are reported to not only be protective against first-time infection for individuals who are not infected but also significantly increase the effectiveness of infection-induced immunity against reinfection, such as hybrid immunity. At the same time, the effectiveness of infection-induced immunity has been certainly confirmed to wane over time together with vaccine-induced immunity.

As shown above, the duration of infection-induced immunity (the validity period of the effectiveness of infection-induced immunity) has been discussed in relation to the level of effectiveness of infection-induced immunity. However, even if the effectiveness of infection-induced immunity falls below a certain threshold, it does not necessarily mean that reinfection will occur. In other words, even if infection-induced immunity has a duration of effectiveness, if the duration is long, an epidemic of reinfection might not occur. How long is the duration of immunity necessary if reinfection does not occur? How long is the duration of immunity required for reinfection to occur? The essential effect of reinfection on the spread of COVID-19 is obscured behind the actual/phenomenal processes that have been influenced by hospital care, vaccination, wearing a mask, seasonal changes in virus activity and so on.

As noted previously, the effectiveness of infection-induced immunity wanes over time. For recovered individuals, their infection-induced immunity eventually decreases to below a threshold, and they realistically get back to susceptible individuals and can be infected with reinfections. The number of susceptible individuals is affected not only by the change in the number of infected individuals but also by the change in the number of individuals who get back to susceptible individuals from recovered individuals. With an increase in the number of susceptible individuals due to getting back to susceptible individuals from recovered individuals, the number of infected individuals must increase. Additionally, since the contact rate between infected individuals and susceptible individuals also increases, a marked increase in the number of infected individuals could be induced.

Since infections usually continue almost every day after the start of infection, the number of infected individuals increases daily. In response to changes in the number of infected individuals, the number of individuals who recover from disease after having acquired infection-induced immunity and then get back to susceptible individuals after their immunity wanes to below a certain threshold also changes daily. Although all susceptible individuals who have got back from recovered individuals will not always become infected, since they would join the number of existing 'original' susceptible individuals, a long duration of infection could be induced, accompanied by a serious increase in the number of infected individuals. How do reinfections affect the spread of COVID-19? The essential characteristics of reinfection, which are obscured by current infection processes complicated by vaccination, medical care, seasonal changes in virus activity and other factors, should be examined to understand the spreading processes of COVID-19 and to consider medical/social/political plans to mitigate the pandemic.

The model used here for calculating the number of infected individuals is the flexible compartment model specific to COVID-19 proposed by Ohmori (2022) [22]. Since the model uses the duration of infection-induced immunity, which indicates the validity period of the effectiveness of infection-induced immunity and can be given as an independent variable, when and how many individuals whose infection-induced immunity decreases to below a certain threshold can be calculated. With this model, the duration of infection-induced immunity required for reinfection to occur can be revealed. The number of individuals, including not only individuals who were infected with reinfections but also individuals who were infected with 'normal infections', can also be calculated.

The change in the number of infected individuals was calculated in cases with different durations of infection-induced immunity, revealing the relationship between the duration of infection-induced immunity and the occurrence of reinfection. The effect of reinfection was assessed by comparing the differences in the number of infected individuals if reinfection occurred and if reinfection did not occur. Although the duration of infection-induced immunity varies depending on the characteristics of the virus and its mutants, the revealed conditions for outbreaks of reinfections could offer reference materials for medical and/or political measures.

2. Framework of the flexible compartment model used here

The flexible compartment model proposed by Ohmori [22] consists of six categories: 'susceptible (remainder): *RM*'; 'vaccinated: *V*'; 'recovered: *RI*, *RT*, *RAS*'; 'infected ('infectious', 'patient'): *P*'; 'isolated: *I*, *PI*'; and 'death: *DAS*, *DTI*, *DT*', as shown in Figure 1. 'Susceptible' refers to susceptible individuals who are not infected but could become infected. 'Vaccinated' refers to vaccinated individuals who have been vaccinated, who have immunity and who live and work in the real community, as shown in Figure 1. 'Recovered' refers to individuals who were isolated from the real community to the isolation community when they were symptomatic after the end of the latent period and returned to the real community after the infectious period (the recovery period/isolation period) ended. These individuals recover from the disease and have immunity. 'Infected' refers to individuals who have been infected and are capable of infecting susceptible individuals. 'Isolated' refers to individuals kept in isolation, indicating individuals who have been isolated and kept in the 'isolation community' until the recovery period (isolation period) ends. After the end of the isolation period, they become 'recovered' and have immunity and return to the community. 'Death' refers to individuals who died from infection after the latent period.

'Back to' indicates "getting back (and/or returning) to susceptible individuals (*RM*) from vaccinated individuals (*V*) after the end of duration (validity period) of vaccine-induced immunity" for vaccinated individuals and/or "getting back (and/or returning) to susceptible individuals (*RM*) from recovered individuals (*RI*, *RT* and *RAS*) after the end of duration (validity period) of infection-induced immunity" for recovered individuals.

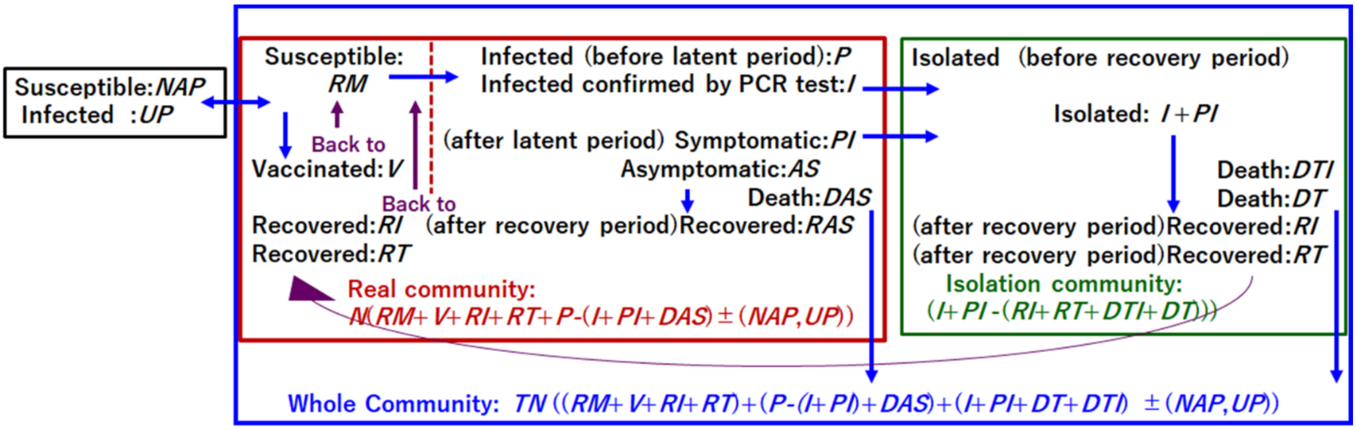

Figure 1: Flow of individuals: 'susceptible; *RM*, *NAP*', 'vaccinated; *V*', 'recovered; *RI*, *RT*, *RAS*', 'infected; *P*(*I*, *PI*, *AS*'), *UP*', 'isolated; *I*, *Pl* and 'death; *DAS*, *DTI*, *DT*'. (after Ohmori (2022[22], 2023[23], 2024a, b [24, 25]).

The compartment on the left side, containing 'susceptible', 'vaccinated', 'recovered', 'infected' and 'death', is the 'real community'. Its population, *N*, is changed by subtracting the number of isolated individuals (*I*, *PI*) and dead individuals (*DAS*) and by adding the number of recovered individuals (*RI*, *RT*). Another compartment on the right side, containing 'isolated', 'recovered' and 'death', is the 'isolation community', whose population, that is, the number of individuals kept in isolation, is also changed by subtracting the number of recovered individuals (*RI*, *RT*) returning to the real community and of the death (*DTI*, *DT*). The large compartment consisting of the two compartments mentioned above is the 'whole community', the population of which is referred to as *TN*(*n*). *TN*(*n*) includes the number of individuals living in the two compartments and the toll of death (*DAS*, *DTI*, *DT*) occurring at the fatality rate in the two compartments. *TN*(*n*) and *N*(*n*) are changed due to the number of 'susceptible (*NAP*(*n*))' and/or 'infected (*UP*(*n*))' individuals coming in and/or going out of the community. As shown above, each compartment contains individuals belonging to different categories, and its population changes by interacting with another compartment and with the outside.

The infected individuals in the community, *P*(*n*), were separated into three groups: those (*I*(*n*)) who were confirmed to be infected because they tested positive, those (*PI*(*n*)) who became symptomatic after the latent period and those (*AS*(*n*)) who were asymptomatic through the recovery period. The isolated individuals were divided into two groups: those (*I*(*n*)) who were confirmed to be infected because they tested positive and were then isolated and those (*PI*(*n*)) who became symptomatic in the community and were subsequently isolated. Each of these parameters needs to be calculated differently depending on the coefficients for test positive rate and symptomatic rate.

The recovered individuals were divided into two groups. One group includes recovered individuals in the right compartment, which are divided into two subgroups: one subgroup comprises those (*RI*(*n*')) who were isolated because they tested positive (*I*(*n*)) but have since recovered, and the other subgroup comprises those (*RT*(*n*')) who were isolated because they were symptomatic in the community (*PI*(*n*)) but have since recovered. The recovered individuals returned to the community after the isolation period ended. The date (*n*') of returning to the community must be calculated in a different manner according to the duration of isolation. The total number of these recovered individuals (*RI*(*n*') + *RT* (*n*')) is not always equal to that of isolated individuals (*I*(n) + *PI*(*n*)) because *RI*(*n*') + *RT*(*n*') is the number obtained by subtracting the total number of deaths (*DTI*(*n*) + *DT*(*n*)) from (*I*(*n*)+*PI*(*n*). The other group includes individuals who recovered from asymptomatic disease in the left compartment (*RAS*(*n*'); they were not isolated, remained in the community and recovered from the disease after the recovery period. The number of recovered individuals (*RAS*(*n*')) is not always equal to the number of asymptomatic infected individuals (*AS*(*n*)) because *RAS*(*n*') is the number after subtracting the number of deaths (*DAS*(*n*)) from *AS*(*n*).

The dead individuals (Death) who died from infection were also divided into two groups: those (*DAS*(*n*)) who were asymptomatic and died from infection after the latent period in the community and those (*DTI*(*n*) and *DT*(*n*)) who died during the isolation period. Each of these variables needs to be calculated in a different manner according to the fatality rate. The vaccinated individuals *V*(*n*) have immunity and live and work in the community. Vaccination decreases the number of susceptible individuals and reduces the contact rate between infected individuals and susceptible individuals.

3. Calculation process of the flexible compartment model

3.1. Contact rate in the community mixed with infected, susceptible, recovered and vaccinated individuals

Infection is caused by contact between infected individuals and susceptible individuals. It actually occurs in a community mixed with infected, susceptible and recovered individuals. Thus, infected individuals contact not only susceptible individuals but also recovered individuals. From a physical point of view, contact between infected individuals and recovered individuals must reduce the contact rate between infected individuals and susceptible individuals when the number of recovered individuals increases. Accounting for the reduction effect of recovered individuals on the contact rate, the contact rate should be given by the following equation:

$cr(n)=(S(n)/N(n))(1-\delta*(R(n)/N(n)))$ (1)

where '$cr(n)$' is the contact rate, n is the date starting from 1 when the infection begins, $S(n)$ is the number of susceptible individuals in the community, $R(n)$ is the number of recovered individuals who returned to the community from isolation, and $N(n)$ is the population that includes susceptible individuals, vaccinated individuals, infected individuals who are not yet isolated and recovered individuals who returned to the real community from the isolation community but excludes individuals who are kept in isolation and dead individuals. The term '$-\delta(R(n)/N(n))$' represents the reduction effect of the recovered individuals on the contact rate between infected individuals and susceptible individuals, and the term '$1-\delta(R(n)/N(n)$' represents the 'reduction rate' of the contact rate. The reduction effect increases with decreasing value of $(1-\delta(R(n)/\mathrm{N}(n))$, indicating that the contact rate decreases with increasing number of recovered individuals. 'δ' is a coefficient that expresses the activity level of the recovered individuals living in the community. When the value of δ is given by 1, the activity is the same as that of the susceptible individuals, and when the value of δ is given by 0, the recovered individuals are not active, meaning a similar condition as they are kept in isolation, although the number of recovered individuals is added to the population.

The reduction in the contact rate is caused not only by the recovered individuals but also by the vaccinated individuals who have been vaccinated, have immunity and are living and working in the community. The reduction effect of vaccination should be taken into account in the simulation, as expressed by Eq. (1'):

$cr(n) =(S(n)/N(n))* (1-(alI(n)* CRT(n)+alV(n)*V(n))/N(n))$ (1')

where $CRT(n) =\Sigma RT(n)$ and $RT(n)$ is the number of recovered individuals who were once isolated because they were symptomatic and had returned to the community when the isolation period ended and where the coefficient $alI(n)$ is the activity level of the recovered individuals who returned to the community from isolation. $V(n)$ is the number of vaccinated individuals who have immunity and are living and working in the community, and $alV(n)$ is the activity level of the vaccinated individuals. The '$(alI(n)* CRT(n)+alV(n)*V(n))$' conceptually refers to the sum of the activities of recovered individuals and vaccinated individuals, and '$(1-(alI(n)* CRT(n)+alV(n)*V(n))$' is equivalent to $(1-\delta(R(n))$ of Eq. (1). The contact rate, $cr(n)$, expressed in Eq. (1'), is used for the calculation of the number of infected individuals, as shown by Eq. (2). However, the contact rate of Eq. (2) reflects the reduction effect on all recovered individuals, including not only the recovered individuals who were once isolated and had returned to the community but also the individuals who had recovered from asymptomatic individuals and were living in the community. The contact rate decreases with increasing trial time (days) because of an increase in the sum of the number of recovered individuals and the number of vaccinated individuals, $R+V$.

3.2. Calculation of the number of infected individuals, the number of individuals newly infected a day and the increment/decrement in the number of infected individuals

The number of infected individuals $P(n)$ should not equal the number of individuals infected each day $AP(n)$, which is usually announced. The former is the total number of infected individuals existing in the community, that is, the sum of the number of infected individuals during the latent period and/or the recovery period, whereas the latter is the number of individuals newly infected for one day. However, P (1), the initial number of infected individuals, is arbitrarily set for simulation. The increment and/or decrement in the number of infected individuals on date n in the community, $\Delta P(n)$, can be calculated by subtracting the number of individuals isolated on date n from the number of individuals newly infected on date n.

For the simulation, an Excel file is used, and the calculation is performed via Eq. (2). The Excel files and the meanings of the individual terms/variables are explained in the supplementary files. The independent variables of twenty-four terms can be specified arbitrarily, and the values of the dependent variables of ninety-nine terms are uniquely determined based on the independent values, which are given arbitrarily.

The number of individuals who are newly infected on day n, $AP(n)$, that is, the number of new infected individuals at night on day n, $\mathrm{AP}(n(\mathrm{night}))$, is given by the following equation:

$$AP(n)=AP(n(\mathrm{night}))=(pfc(n)/lp(n))*icf(n)*cr(n)*(RP(n)/N(n))*RM(n)$$
$$=(pfc(n)/lp(n))*icf(n)*(RM(n)/N(n))*(1-(alI(n)*(CRI(n)+CRT(n))+al(n)*CRAS(n)+alV(n)*V(n))/N(n))*(RP(n)/N(n))*RM(n) \quad (2)$$

where the coefficient $pfc(n)$ is the potential (biological) infectious capacity of coronavirus, which is an approximate value indicating the number of susceptible individuals infected during the latent period, $lp(n)$. The latent period, $lp(n)$, is the time interval between when an individual is infected and when he/she is symptomatic. '$pfc(n)/lp(n)$' is the number of susceptible individuals infected by an infected individual a day, and its value, including decimal places, is used in the calculation. The coefficient $icf(n)$ is the infection reduction rate caused by infection control measures preventing the spread of the virus, such as facemasks, partitions and disinfectants.

The coefficient '$cr(n)$' is the contact rate, and instead of Eq. (1'), it is realistically given by:

$$cr(n) =(RM(n)/N(n))* (1-(alI(n)*(CRI(n)+CRT(n))+al(n)*CRAS(n)+alV(n)*V(n))/N(n)) \quad (1'')$$

The coefficient $alI(n)$ is the activity level of the individuals $CRI(n)+CRT(n)$ who returned from isolation to the community, where $CRI(n)$ is $\Sigma RI(n)$ and $RI(n)$ is the number of individuals who were isolated due to being test positive and had returned to the community and $CRT(n)$ is $\Sigma RT(n)$ and $RT(n)$ is the number of recovered individuals who were once isolated due to being symptomatic and had returned to the community; these are all the recovered individuals who returned from isolation to the community. The coefficient $al(n)$ is the activity level of the individuals *CRAS*(*n*) who have recovered from the asymptomatic individuals and are living in the community. *CRAS*(*n*) is Σ*RAS*(*n*), and *RAS*(*n*) is the number of recovered individuals who were infected but were not symptomatic, were asymptomatic, were not isolated, were staying in the community, had continued to infect until the recovery period ended and then became 'recovered individuals'.

alV(*n*) is the activity level of the individuals *V*(*n*) who were vaccinated. The term '*alI*(*n*)*(*CRI*(n) +*CRT*(*n*)) +*al*(*n*)**CRAS*(*n*)' is equivalent to *CRT*(*n*) in Eq. (1'), and '1-(*alI*(*n*)*(*CRI*(*n*)+*CRT*(*n*))+*al*(*n*)**CRAS*(*n*) +*alV*(*n*)**V*(*n*))' is equivalent to '1-δ(*R*(*n*)' of Eq. (1).

In a strict sense, since an infection occurs during the day from the morning to the evening in the model, for the purpose of calculation, the *AP* (*n*(night)), which is the value of *AP*(*n*) at night, is the correct number of individuals newly infected a day. This number increases/decreases from the *AP*(*n*) in the morning, which is equal to the *AP*(*n*) of the previous night, that is, *AP*(*n*-1(night)).

RM(*n*) is the number of susceptible individuals in the community, which is equivalent to *S*(*n*) in Eqs. (1) and (1'). As its calculation process is explained in section **4.3. 'Change in the number of susceptible individuals'**, the number of susceptible individuals (*RM*(*n*)) is calculated not only by subtracting from the total population *TN* of the community the cumulative number *CI* of individuals who were confirmed to be infected due to being test positive and then were isolated, the cumulative number *CAP* of infected individuals, including both recovered individuals and dead individuals, and the cumulative number *V* of vaccinated individuals but also by adding the total cumulative number of susceptible individuals having got back from recovered individuals (*JCReRec*(*n*)). This total of the cumulative number of susceptible individuals who get back from recovered individuals (*JCReRec*(*n*)) is explained by Eq. (38) in section **4.2. 'Change in the number of individuals getting back to susceptible individuals from recovered individuals'**.

Therefore, the number of susceptible individuals (*RM*(*n*) in the community at night (after the occurrence of 'Breakthrough Infection' and/or 'Reinfection'), is given by

$$RM(n)= TN(\mathrm{n})-(CI(n)+CAP(n)+V(n))+JCReRec(n) +CTAPReRec(n-1) \quad (3)$$

where *TN*(*n*) is the total population of the whole community, such as a city. *TN*(1) is the initial population of the community arbitrarily given in the simulation, and *TN*(*n*) is changed by coming in/going out of the susceptible individuals *NAP*(*n*) and/or the infected individuals *UP*(*n*).

CI(*n*)=Σ*I*(*n*), where *I*(*n*) is the number of individuals isolated because they test positive. Since all the individuals confirmed to be infected due to test positivity are not always isolated and the individuals who are decided to be isolated are isolated on the day next to the day when they are confirmed to be infected, in the actual calculation, *I*(*n*) is given by:

$$I(n)= CP(n-1)*\ i(n-1) \quad (4)$$

where the coefficient *i*(*n*) is the isolation rate for individuals who are confirmed to be infected because they test positive. *CP*(*n*) is the number of individuals confirmed to be infected because they tested positive. The individuals who are required to be isolated are isolated the following day for the purpose of calculation. Conversely, the individuals confirmed to be infected on the previous day, date (*n*-1), are isolated on date *n*. Thus, *I*(*n*) is given by Eq. (4).

CP(*n*) is given by:

$$CP(n)=T(n)*bp(\mathrm{n})*ir(n) \quad (5)$$

where *T*(*n*) is the number of individuals who underwent PCR and/or antibody testing, which can be set arbitrarily on any day when tests are performed, and the coefficient *bp*(*n*) is the magnification of the incidence rate for the test to the incidence rate, *ir*(*n*), in the community. The incidence rate, *ir*(*n*), is given by:

$$ir(n)=P(n)/TN(n) \quad (6)$$

where *P*(*n*) is the number of infected individuals already living in the community and *P* (1) is the initial number of infected individuals in the community and is arbitrarily given by you. *TN*(*n*) is the total population of the whole community. Since individuals who have the test are mainly close contacts, the incidence rate for the test would be biased to be higher than *ir*(*n*). The incidence rate for the test is given by the magnification with respect to *ir*(*n*). The value of *bp*(*n*)**ir*(*n*) indicates the percentage of positive results for the PCR and/or antibody test, that is, the 'positive rate' in the test, *tir*(*n*). The positive rate, *tir*(*n*), is given by:

$$tir(n)=bp(n)*ir(n) \quad (7)$$

CAP(*n*) is the cumulative number of individuals newly infected a day up to the morning of date *n*; this value is equal to the cumulative number of infected individuals up to the night date (*n*-1). *CAP*(*n*) includes the number of individuals who were infected but had recovered.

$$CAP(n) =\Sigma AP(n) \quad (8)$$

V(*n*) in Eq. (3) is the number of vaccinated individuals on date *n*, which represents the cumulative number of currently existing vaccinated individuals, excluding individuals who have got back to susceptible individuals.

$$V(n) = JCV0(n)-CReVac(n) \quad (9)$$

where *CReVac*(*n*) is Σ*ReVac*(*n*), and *ReVac*(*n*) is the number of individuals who have got back from vaccinated individuals to susceptible individuals on date *n*. *JCV*0(*n*) is the 'adjusted *CV*0(*n*)', and *CV*0(*n*) is the cumulative (total) number of vaccinated individuals up to day *n*:

$$CV0(n)=\Sigma V0(n)= \Sigma(TN(1)*vd(n)) \quad (10)$$

Eq. (9) indicates that the number of currently existing vaccinated individuals (*V*(*n*)) is calculated by subtracting the number of individuals having got back to susceptible individuals *CReVac*(*n*) from the (adjusted) total number of vaccinated individuals *JCV*0(*n*). *JCV*0(*n*) is calculated as follows:

$$JCV0(n)=\mathrm{IF}(CV0(n)< (TN(n)+RM00(n)), (TN(n)+RM00(n)), (TN(n)+RM00(n))) \quad (11)$$

where $RM00(n)$ is the number of currently existing susceptible individuals in the community and is given by:

$$RM00(n)= TN(n)+JCReRec(n)-(CI(n)+CAP(n)) \quad (=(TN(n)-(CI(n)+CAP(n))) +JCReRec(n)) \quad (12)$$

where $TN(n)$ is the total population of the community and $JCReRec(n)$ is the cumulative number of susceptible individuals who got back from recovered individuals, excluding the number of individuals who got reinfected, that is, the number of currently existing susceptible individuals who got back from recovered individuals, and is given by Eq. (38). $CI(n)$ is the cumulative number of individuals isolated because they tested positive, and $CAP(n)$ is the cumulative number of individuals up to the n^{th} day, including the number of individuals who tested positive but were not isolated and were staying in the community. Eq. (12) represents the sum of the number of 'remaining original' susceptible individuals (TN(n)-(CI(n)+CAP(n))) and the number of currently existing susceptible individuals who got back from recovered individuals ($JCReRec(n)$).

The total number of currently existing vaccinated individuals ($CV0(n)$) must be less than or equal to the total number of the community's population ($TN(n)$) and the number of susceptible individuals in the community ($RM00(n)$). Specifically, ($TN(n)+RM00(n)-CV0(n)$) should be greater than or equal to 0; that is, $(TN(n)+ RM00(n)-CV0(n))\geqq 0$. Thus, $CV0(n)$ should be less than or equal to the value of $(TN(n)+RM00(n))$; that is, $CV0(n))\leqq(TN(n) +RM00(n))$. Therefore, if $CV0$(n) calculated via Eq. (10) becomes larger than $(TN(n) +RM00(n))$, $CV0$(n) should be set to $(TN(n) +RM00(n))$; otherwise, $CV0$(n) is given by Eq. (10). In other words, Formula (11) indicates that:

'If $CV0(n) < (TN(n) +RM00(n))$, then $JCV0(n)= CV0(n)$; otherwise, $JCV0(n)= (TN(n) +RM00(n))$'

$RP(n)$ in Eq. (2) is the number of infected individuals excluding the individuals kept in isolation and the dead, that is, the number of infected individuals living and working in the community, for example, the number of infected individuals during the latent period and/or asymptomatic infected individuals even after the latent period. Thus, $RP(n)$ could be called the 'Spreader' who continues to infect susceptible individuals in the community. When n is 1, which indicates the first day of simulation, $RP(1)$ is equal to $P(1)$, which is the initial number of infected individuals in the community and is arbitrarily given by you. Since $RP(n)$ is the number of infected individuals minus the number of isolated individuals ($PI(n)$), the number of dead individuals ($DAS(n)$) and the number of recovered individuals living in the community ($RAS(n)$) from the total number of infected individuals up to day n, $RP(n)$ is given by the following equation:

$$RP(n)=\Sigma(AP(n)-PI(n-1)-DAS(n-1)-RAS(n)) = \Sigma AP(n)- \Sigma PI(n-1)- \Sigma DAS(n-1)- \Sigma RAS(n) \quad (13)$$

where $PI(n)$ is the number of symptomatic individuals who became symptomatic on the day after the end of the latent period in the real community and were isolated the next day. $PI(n)$ is given by:

$$PI(n)= AP(n-(lp+1))* syr(n-(lp+1)) \quad (14)$$

where $lp(n)$ is the latent period and $(n-(lp+1))$ indicates the 'latent period+1' before date n, meaning the day after the end of the latent period, because the infected individuals become symptomatic and are isolated on the day after the end of the latent period. The value of $AP(n-(lp+1))$ is the number of infected individuals who were newly infected on date $(n-(lp+1))$, which is the day after the end of the latent period. The coefficient $syr(n)$ is the symptomatic rate on day n. When $syr(n)$ is 1, all the infected individuals become symptomatic and isolated. Conversely, therefore, the number of asymptomatic infected individuals, $AS(n)$, is given by

$$AS(n) = AP(n-(lp+1)) - PI(n) \quad (15)$$

$DAS(n)$ is the number of individuals who are asymptomatic and die of infection after the latent period in the community, that is, the death toll in the community. It is given by:

$$DAS(n)= AS(n-\mathrm{trunc}((rp-lp)/2))*fr(n-\mathrm{trunc}((rp-lp)/2)) \quad (16)$$

where the coefficient $rp(n)$ is the recovery period, which is the time interval between when an individual is infected and when he/she recovers from the disease and is not capable of infection. '$(rp-lp)$' is equivalent to the isolation period. $AS(n-\mathrm{trunc}((rp-lp)/2))$ is the number of asymptomatic infected individuals who were not isolated and were staying in the community on the day 'trunc((rp-lp)/2) days' before day n. $AS(n)$ *is* the number of infected individuals subtracting the PI from the AP, as shown by Eq. (15); the coefficient $fr(n)$ is the fatality rate for the asymptomatic infected individuals in the community. The 'death' of infected individuals occurs in the middle of the isolation period, that is, 'trunc((rp-lp)/2)'. Specifically, some of the infected individuals who have been isolated on day n die on day $(n+\mathrm{trunc}((rp-lp)/2))$. For asymptomatic individuals, the same procedure was used. When the number of asymptomatic individuals infected on date n is $AS(n)$, an $AS(n)* fr(n)$ number of individuals will also die on day $(n+\mathrm{trunc}((rp-lp)/2))$. Conversely, the death toll of asymptomatic individuals on date n, $DAS(n)$, is given by Eq. (16).

$RAS(n)$ is the number of recovered individuals who were infected but were asymptomatic and not isolated; these individuals continued to infect susceptible individuals in the community until the recovery period ended, after which they became recovered individuals. In the actual calculation, $RAS(n)$ is the number of asymptomatic infected individuals excluding the death toll, and it is given by:

$$RAS(n)=AS(n-(rp-lp))-DAS(n-(1+\mathrm{trunc}((rp-lp)/2))) = AS(n-(rp-lp))-AS(n-(rp-lp))*fr(n-(rp-lp)) \quad (17)$$

$CRI(n)$ in Eq. (1'') is $\Sigma RI(n)$, where $RI(n)$ is the number of recovered individuals who were isolated because they tested positive. $RI(n)$ is given by:

$$RI(n)=I(n-rpI)-DTI(n-(1+\mathrm{trunc}(rpI/2))) \quad (18)$$

where $I(n)$ is the number of individuals isolated because they test positive and is given by Eq. (4). $DTI(n)$ is the death toll among individuals isolated because they test positive and is given by:

$$DTI(n)= I(n\text{-trunc}(rpI/2))*frI(n\text{-trunc}(rpI/2)) \quad (19)$$

where $frI(n)$ is the fatality rate for the isolated individuals and $rpI(n)$ is the isolation period for the isolated individual due to a positive test result, which is less than or equal to rp. The deaths of isolated individuals occurred during the middle of the isolation period. When the number of individuals isolated on day n is $I(n)$, $I(n)* frI(n)$, the number of individuals will die on the day '($n+rpI/2$) days' after day n. Conversely, for the death toll on day n, the day of death among I is (n-trunc(rpI/2)).

$CRT(n) = \Sigma RT(n)$, where $RT(n)$ is the number of recovered individuals who were isolated because they were symptomatic in the community. $RT(n)$ is given by:

$$RT(n)=PI(n-(rp-lp))-DT(n-(1+\text{trunc}((rp-lp)/2))) \quad (20)$$

where $DT(n)$ is the death toll among the individuals isolated due to being symptomatic and is given by Eq. (21); '(n-(rp-lp))' indicates the time lag in days between the 'n^{th} day' and 'isolation'; and '(n-(1+trunc((rp-lp)/2)))' indicates the time lag in days between the 'n^{th} day' and the 'death date'.

$$DT(n)=PI(n\text{-trunc}((rp-lp)/2))*frI(n\text{-trunc}((rp-lp)/2)) \quad (21)$$

Where $PI(n)$ is the number of symptomatic infected individuals given by Eq. (14) and $frI(n)$ is the fatality rate for the isolated individuals. '(rp-lp)' is the isolation period for the individuals isolated because they are symptomatic.
For calculation, Eq. (2) is transformed into the following equation:

$$AP(n(\text{night}))= p(n)* RM(n) \quad (22)$$

where $p(n)$ is the infection coefficient, which is the infectious capacity and includes the contact rate that changes with the number of susceptible individuals, infected individuals, recovered individuals and vaccinated individuals in the (real) community:

$$p(n)= (pfc(n)/lp(n)) * icf(n) *(RM(n)/N(n))* (1-(AL(n)/N(n)))*(RP(n)/N(n)) \quad (23)$$

where $AL(n)$ is the sum of the activity levels of the recovered individuals and vaccinated individuals:

$$AL(n)=alI(n)*(CRI(n)+CRT(n))+al(n)*CRAS(n)+alV(n)*V(n) \quad (24)$$

The term $AL(n)/N(n)$ is equivalent to the term $\delta(R(n)/N(n))$, and the term '1-($AL(n)/N(n)$)' is equivalent to the term (1-$\delta(R(n)/N(n))$ of Eq. (1). When the value of $alI(n)$ is given a value of 1, the activity of recovered individuals who returned from isolation to the community is the same as that of the susceptible individuals, and when the value of $alI(n)$ is given a value of 0, the recovered individuals are not active, meaning a similar condition as they are kept in isolation, although the number of recovered individuals who have returned to the community is added to the population. For $al(n)$ and $alV(n)$, similar things can be said. When the value of $AL(n)$ is 1, the activity of recovered individuals and vaccinated individuals is the same as that of susceptible individuals. If the value of $AL(n)$ is 0, neither the recovered individuals nor the vaccinated individuals are active. This means that the community resembles a situation consisting only of infected and susceptible individuals, although the number of recovered individuals who have returned to the community and of vaccinated individuals is added to the population.

The value of $pfc(n)/lp(n)$ is the infection rate (persons/person/day) for an infected individual, and ($RP(n)/N(n)$) indicates the ratio of the number of infected individuals living in the community. Thus, the value of ($pfc(n)/lp(n)$)*($RP(n)/N(n)$) indicates the probability of occurrence of infection by the total number of infected individuals in the community. The term ($RM(n)/N(n)$)* (1-($AL(n)/N(n)$)) indicates the contact rate, that is, the probability of contact occurring between susceptible individuals and an infected individual. Therefore, the coefficient $p(n)$ indicates the possibility of infection of susceptible individuals per day in the community with mixed infected, susceptible and recovered individuals.
The number of infected individuals in the morning on day n, $P(n)$, is given by the following equation:

$$P(n)= P(n\text{-}1(\text{night}))=RP(n-1)+AP(n\text{-}1(\text{night})) =RP(n-1)+p(n-1)*RM(n-1) \quad (25)$$

where $P(n$-1(night)) is the number of infected individuals on the previous night.

Considering the number of isolated individuals, the rate of change in the number of infected individuals, $\Delta P(n)$, that is, the increment and/or decrement in the number of infected individuals a day in the community, can be calculated by subtracting the number of individuals isolated on day n due to being symptomatic from the number of individuals newly infected on day n. $\Delta P(n)$ is given by the following difference equation:

$$\Delta P(n) = AP(n) - PI(n) = AP(n) - syr(n')*AP(n') \quad (26)$$

where the date n' indicates the day before day n by the 'latent period'. Thus, $PI(n)$ is the number of individuals who were newly infected on day n', were symptomatic on the day after the end of the latent period and were subsequently isolated on day n.

As previously mentioned, $N(n)$ is the population excluding isolated individuals and dead individuals but including the recovered individuals who returned to the community; that is, $N(n)$ is the total number of individuals living and working in the community and is given by the following equation:

$$N(n)=TN(n-1)-(CI(n-1)+CPI(n-1)+CDAS(n-1)+CDT(n-1))+CRI(n-1)+CRT(n-1) \quad (27)$$

where $TN(n)$ is the total population of the community. For Eq. (27), when n is 1, i.e., the first day of simulation, N(1) is TN(1), which is the initial population of the community, and the other terms are 0. The use of '(n-1)' means that the population on the previous night becomes the population on the morning of day n.

As previously noted, $TN(n)$ is changed by the number of susceptible individuals ($NAP(n)$) and/or infected individuals ($UP(n)$) who come in and/or leave the community. $CI(n)$ is $\Sigma I(n)$, $CPI(n)$ is $\Sigma PI(n)$, $CDAS(n)$ is $\Sigma DAS(n)$, $CDT(n)$ is $\Sigma DT(n)$, $CRI(n)$ is $\Sigma RI(n)$ and $CRT(n)$ is $\Sigma RT(n)$.

For the simulation using Eq. (2) or Eq. (22), when n is 1, i.e., the first day of simulation, N (1) is equal to TN (1), which is the initial population of the community and can be arbitrarily set. RP (1) is equal to P (1), which is the initial number of infected individuals. P (1) can also be set arbitrarily. RM (1) is the initial number of susceptible individuals in the community and is inevitably determined by subtracting P (1) from N (1).

4. Method

4.1. A visualized 'simple mathematical/statistical process of reinfection'

The term ‘reinfection’ here refers to a second infection caused by COVID-19 that occurs in individuals who have previously been infected and recovered from COVID-19 because of the loss of infection-induced immune effectiveness. In other words, 'reinfection' refers to an infection that occurs in a susceptible individual who has got back from one who has recovered from the first-time infection (first infection and/or initial infection and/or normal infection).

However, infections also occur among susceptible individuals who have got back from individuals who have recovered from ‘reinfection’. Some individuals would get ‘reinfection’ multiple times: first-time infection (initial infection, normal infection), second-time infection (reinfection in a narrow definition), third-time infection, fourth-time infection and more times. In this article, therefore, the term ‘reinfection’ is used in a broad sense to refer to any infection that occurs due to loss of infection-induced immune effectiveness, indicating all infections after first-time infection; second-time infection, third-time infection, fourth-time infection, and so on. In the model calculations, this applies regardless of the interval between infections.

The changes in the number of infected individuals (AP (n)) and the number of susceptible individuals (Sus(n)) in a reinfection process simplified from the mathematical/statistical reinfection process used in this study are shown in Figure 2. Consider a community with an initial population of 256. The community's population of 256 consists entirely of susceptible individuals (Original susceptible individuals (OS)). When the infection rate is set at 1/4 (25%), by the end of the first epidemic (Epidemic 1), among the 256 susceptible individuals, 64 will become infected individuals (N1: first-time infected individuals), and 192 will remain susceptible individuals (OS). If reinfection does not occur, the epidemic comes to an end. All the infected individuals (N1) should become recovered individuals and eventually get back to susceptible individuals.

When reinfection occurs, among the remaining susceptible individuals (192), by the end of the second epidemic (Epidemic 2), 48 will become infected individuals. They are all ‘First infected individuals (first-time infected individuals: N1)’. The remaining 144 will remain susceptible individuals (OS). By the end of the third epidemic (Epidemic 3), among the remaining susceptible individuals (144), 36 will become 'newly infected individuals'. They are all also 'First infected individuals (N1)’. The remaining 108 will remain susceptible individuals (OS). Furthermore, by the end of the fourth epidemic (Epidemic 4), 27 of the remaining susceptible individuals (108) will become infected individuals (N1), and 81 will remain susceptible individuals (OS). This process will continue into the fifth epidemic and beyond.

As examined above, if reinfection occurs, multiple epidemics will occur, not only two epidemics but also three or more epidemics, including the ‘first epidemic’, which consists of only the first-time infected individuals. Additionally, the individuals infected with first-time infection (normal infection) occur in every epidemic period. However, as the number of epidemic outbreaks progresses, both the number of original susceptible individuals (OS) and the number of first-time infected individuals (N1) decrease.

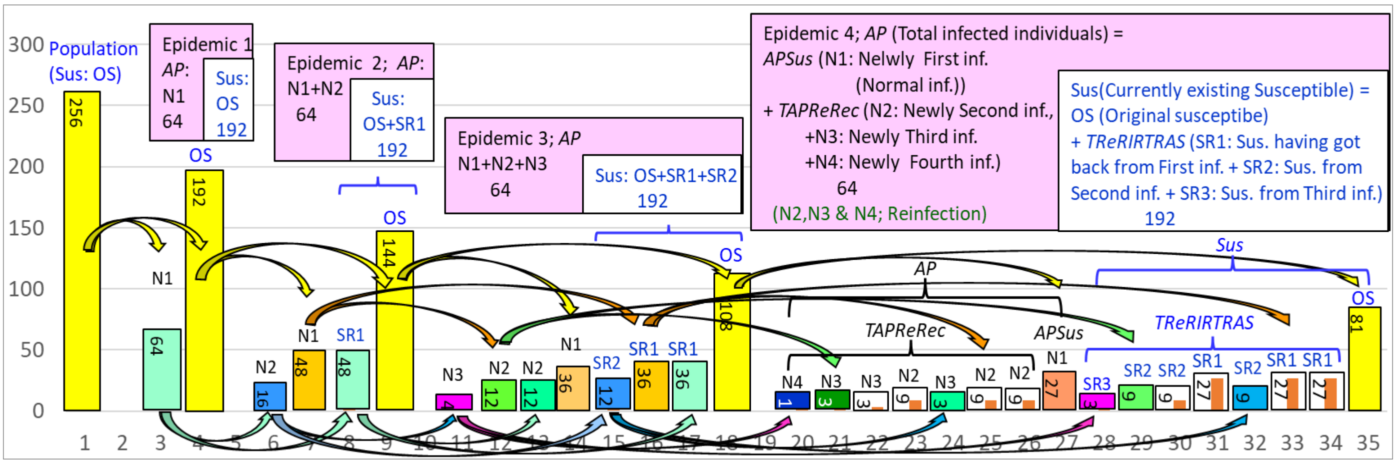

Figure 2: Changes in the number of susceptible individuals and infected individuals in a simple process of reinfection. Sus: Currently existing susceptible individuals (represented as *RM* in the calculations) (= OS (Original susceptible individuals) + *TReRIRTRAS* (SR1 (Sus. having got back from First inf. (first-time infection)) + SR2 (Sus. from Second inf.) + SR3 (Sus. from Third inf.), AP: Total infected individuals (= *APSus* (N1: Newly First inf. (Normal inf.) + *TAPReRec* (N2: Newly Second inf.+ N3: Newly Third inf. + N4: Newly Fourth inf.) (N2, N3 & N4: reinfection). The initial population of the community is 256, and the infection rate is 1/4 (25%).

On the other hand, for infected individuals, after the duration (the validity period) of infection-induced immunity has expired, by the end of the second epidemic (Epidemic 2), 16 out of the 64 first-time infected individuals in the first epidemic (Epidemic 1) will become reinfected individuals (Second infection (second-time infection): N2). The remaining 48 first-time infected individuals will not be reinfected this time and become 'susceptible individuals (SR1)' who have got back from the recovered individuals of the 'First-time infection (N1)'. After that, by the end of the third epidemic (Epidemic 3), out of the 16 second infected individuals in the second epidemic (Epidemic 2), 4 will become reinfected individuals (Third infection (third-time infection): N3). The remaining 12 second-infected individuals will not get reinfected and become susceptible individuals (SR2), who have got back from the recovered individuals of 'Second infection (N2)'. Furthermore, by the end of the fourth epidemic (Epidemic 4), out of the 4 third infected individuals in the third epidemic (Epidemic 3), 1 will become a reinfected individual (Fourth infection (fourth-time infection): N4). The remaining 3 will not be reinfected for this time and become susceptible individuals (SR3), who have got back from the recovered individuals of 'Third infection (N3)'.

In the above process, as mentioned above, 48 out of the 64 individuals who were first-time infected during the first epidemic were not reinfected during the second epidemic and became susceptible individuals at the end of the second epidemic (Epidemic 2). However, during the third epidemic and after, they are also exposed to the wave of the infection outbreak. Specifically, by the end of the third epidemic (Epidemic 3), 12 out of the 48 susceptible individuals will become reinfected (N2: Second infection). The remaining 36 'first-time' infected individuals will not be reinfected for this time, too, and become the susceptible individuals (SR1) who have got back from the recovered individuals of the 'First-time infection (N1)'. This process will be repeated in the same way that it was observed in the original susceptible individual (OS).

As explained above, for infected individuals, these processes will be repeated. Therefore, as the number of epidemic outbreaks increases, individuals who get reinfected multiple times will appear in accordance with the number of outbreaks. In other words, reinfection occurs multiple times in the same individuals. In reality, as will be examined in section **4.2. 'Change in the number of individuals getting back to susceptible individuals from recovered individuals' 4.3. 'Change in the number of susceptible individuals'** and **4.4. 'Reinfection'**, the number of susceptible, infected and recovered individuals changes from day to day, so the infection rate also varies from day to day, and the number of susceptible and infected individuals changes in a more complex manner. However, similar to the decrease in the number of first-time infected individuals among original susceptible individuals, the number of individuals with high-frequency reinfection decreases.

The total number of infected individuals (*AP*(*n*)) is the sum of the number of individuals in these two groups: the first-time infected individuals (N1) among the currently existing original susceptible individuals and the reinfected individuals (N2, N3, etc.) among the susceptible individuals who got back from recovered individuals. As the number of epidemic outbreaks increases, the number of each N1, N2, etc., also decreases.

Similarly, the total number of currently existing susceptible individuals (Sus: represented as *RM* in the calculations) is the sum of the number of individuals in two groups: the remaining original susceptible individuals (OS) and the susceptible individuals who got back from recovered individuals (SR1, SR2, SR3, etc.). As the number of epidemic outbreaks increases, the number of each SR1, SR2, etc., also decreases.

As examined above, the remaining original number of susceptible individuals (OS) and the number of susceptible individuals having got back from recovered individuals of each of SR1, SR2, SR3, etc., decreases. These decreases suggest that, eventually, reinfection will no longer occur, and ultimately, the epidemic will come to an end, because the number of reinfected individuals in each OS, SR1, SR2, etc. should be less than the number of susceptible individuals of OS, SR1, SR2, etc.

4.2. Change in the number of individuals getting back to susceptible individuals from recovered individuals

As mentioned previously, the effectiveness of the immunity acquired through COVID-19 infection does not continue permanently but decreases gradually and finally reaches below a certain threshold, which varies mainly according to the properties/sensitivity of the COVID-19 virus/strain. This means that infection-induced immunity has a duration that indicates the 'validity period of effectiveness of infection-induced immunity'. In the present work, the duration of infection-induced immunity (the validity period of infection-induced immunity) indicates the time interval between when an individual becomes a 'recovered individual' after he/she was once infected with COVID-19 and when his/her immunity acquired through infection decreases below a certain threshold of immunity level at which infection could occur. However, it should be noted that all individuals whose immunity acquired through infection decreases below a certain threshold are not always infected with COVID-19 again. Specifically, individuals whose duration of infection-induced immunity ends substantially get back to 'susceptible individuals' who could be infected, and some of them should become reinfected. The duration of infection-induced immunity is determined by the fact that several weeks and/or several months after individuals recover, infection-induced immunity decreases to below a certain threshold. Although the duration of infection-induced immunity varies from person to person, from a statistical point of view, the average duration (*dii*) is used in the calculation.

The number of individuals $ReRT(n)$ who got back to susceptible individuals from recovered individuals who were isolated because they were symptomatic:

$$ReRT(n)=CRT(n-dii)*bii(n-dii) \quad (28)$$

where $CRT(n)$ is $\Sigma RT(n)$, and $RT(n)$ is the number of recovered individuals who were isolated because they were symptomatic in the community. $RT(n)$ is the number of recovered individuals excluding the death toll given by Eq. (20). The variable *dii* is the duration of infection-induced immunity (the validity period of infection-induced immunity), and the coefficient $bii(n)$ is the 'back to rate' at which recovered individuals with infection-induced immunity get back to susceptible individuals a day.

In the calculation, recovered individuals get back to susceptible individuals on day 'dii' days after they return to the community, and on and after the day, they can become infected again. Since the infected individuals recover and return to the community on the 'rp +2' day after infection, the recovered individuals get back to susceptible individuals on the 'rp+2+dii' day after infection.

Specifically, for example, when the recovery period (rp) is set to 14 and dii is set to 150, the individuals infected on the first day of simulation recover on day 16 and get back to susceptible individuals on day 166 (=14+2+150), which is the day 150 days after the isolated-recovered individuals return to the community. Conversely, the number of individuals 'getting back to susceptible individuals from isolated-recovered individuals' on day 166, $ReRT$ (166), is given by:

$$ReRT(166)= RT(16)*bii(16)= RT(166 - 150)*bii(166 -150) \quad (29)$$

By replacing 166 with n and 150 with dii, Eq. (29) can be rewritten as Eq. (28).

On the other hand, the number of individuals ($ReRT(n)$) who got back to susceptible individuals from recovered individuals (RT) who were isolated because they were symptomatic decreased with increasing number of individuals ($APReRT(n)$) who were reinfected among $ReRT(n)$. Thus, the cumulative number of susceptible individuals ($JCReRT(n)$) who got back from recovered individuals (RT) who were isolated due to being symptomatic is given by Eq. (28). $JCReRT(n)$ is called the 'adjusted $CReRT(n)$'.

$$JCReRT(n)= CReRT(n)-CAPReRT(n-1) \quad (30)$$

where $CReRT(n)$ is $\Sigma\ ReRT(n)$. $CAPReRT(n)=\Sigma APReRT(n)$, and $APReRT(n)$ is the number of reinfected individuals among susceptible individuals ($ReRT$) who got back from recovered individuals who were isolated because they were symptomatic. $APReRT(n)$ is given by:

$$APReRT(n)=AP(n)*(JCReRT(n)/RM(n)) \quad (31)$$

Similarly, the number of individuals $ReRI(n)$ who got back to susceptible individuals from recovered individuals (RI) who were isolated because they tested positive is given by:

$$ReRI(n)=CRI(n-dii)*bii(n-dii) \quad (32)$$

where CRI(n)=$\Sigma RI(n)$, and $RI(n)$ is the number of recovered individuals who were isolated because they tested positive and returned to the community after the isolation period ended. $RI(n)$ is the number of recovered individuals excluding the death toll given by Eq. (18).

The 'adjusted $ReRI(n)$', that is, $JCReRI(n)$, is the cumulative number of susceptible individuals who got back from recovered individuals (RI) who got back from recovered individuals who were isolated because they tested positive. As in Eq. (28) for $JCReRT(n)$, $JCReRI(n)$ is given by:

$$JCReRI(n)= CReRI(n)-CAPReRI(n-1) \quad (33)$$

where $CReRI(n)=\Sigma\ ReRI(n)$. $CAPReRI(n)=\Sigma APReRI(n)$, and $APReRI(n)$ is the number of reinfected individuals among susceptible individuals, $ReRI(n)$, who got back from recovered individuals who were isolated because they tested positive and is given by:

$$APReRI(n)=AP(n)*(JCReRI(n)/RM(n)) \quad (34)$$

Similarly, the number of individuals $ReRAS(n)$ who got back to susceptible individuals from recovered individuals (RAS; asymptomatic-recovered individuals) who were asymptomatic and were not isolated, lived in the community and recovered was as follows:

$$ReRAS(n)=CRAS(n-dii)*bii(n-dii) \quad (35)$$

where $CRAS(n)$ is $\Sigma RAS(n)$, and $RAS(n)$ is the number of recovered individuals who were infected once but did not become symptomatic, were asymptomatic, were not isolated, were living in the community, continued to infect susceptible individuals until the recovery period ended, and subsequently recovered. $RAS(n)$ is the number of recovered individuals excluding the death toll given by Eq. (17).

The 'adjusted $ReRAS(n)$' ($JCReRAS(n)$), which is the cumulative number of susceptible individuals who got back from asymptomatic-recovered individuals ($ReRAS$):

$$JCReRAS(n)= CReRAS(n)-CAPReRAS(n-1) \quad (36)$$

where $CReRAS(n)= \Sigma ReRAS(n)$. $CAPReRAS(n)=\Sigma APReRAS(n)$, and $APReRAS(n)$ is the number of reinfected individuals among susceptible individuals, $ReRAS(n)$, who got back from asymptomatic-recovered individuals and is given by:

$$APReRAS(n)=AP(n)*(JCReRAS(n)/RM(n)) \quad (37)$$

Therefore, the total cumulative number of susceptible individuals ($JCReRec(n)$) who got back from recovered individuals, excluding the number of individuals who were reinfected (and/or who were infected multiple times), is the 'adjusted total number of susceptible individuals who got back from recovered individuals' and is given by:

$$JCReRec(n)=JCReRI(n)+JCReRT(n)+JCReRAS(n) \quad (38)$$

As explained above, since the number of individuals $ReRI(n)$ is the number of individuals who got back to susceptible individuals from the recovered individuals (RI) who were isolated because they tested positive, $ReRT(n)$ is the number of individuals who got back to susceptible individuals from the recovered individuals (RT) who were isolated because they were symptomatic, the number of individuals, and $ReRAS(n)$ is the number of individuals who got back to susceptible individuals from the recovered individuals (RAS) who were asymptomatic and were not isolated and lived in the community. The total number of susceptible individuals who got back to susceptible individuals from recovered individuals a day (*TReRIRTRAS*(*n*)) is as follows:

$$TReRIRTRAS(n) = ReRI(n) + ReRT(n) + ReRAS(n) \quad (39)$$

Instead of (*ReRI*(*n*)+ *ReRT*(*n*)+*ReRAS*(*n*)), using *AP*(n), *TReRIRTRAS*(*n*) is expressed as

$$TReRIRTRAS(n) = AP(n-((rp+1)+dii)) \quad (40)$$

For example, when the recovery period (*rp*) is set to 14 and *dii* is set to 200, the individuals who get infected on the first day (on day 1) of simulation should get back to susceptible individuals on day 216 (=1+(14+1)+200), which is the day 200 days after the day when the infected individuals returned to the community after the recovery period, that is, on (14+1) day. Conversely, the individuals 'getting back to susceptible individuals from recovered individuals on day 216 are the same individuals who got infected on day 1, that is, day '216-((14+1)+200). Thus, *TReRIRTRAS*(216) is given by:

$$TReRIRTRAS\ (216) = AP\ (216-((14+1)+200)) = AP\ (1) \quad (41)$$

By replacing 216 with *n*, 14 with *rp* and 200 with *dii*, Eq. (41) can be rewritten as Eq. (40).

Now, consider a case where the community population is 1,000,000 and where the potential (biological) infectious capacity of coronavirus (*pfc*) is 1.0, the symptomatic rate (*s*) is 1.0, and the vaccination rate (*v*) is 0 (indicating that vaccination was not performed).

When the effectiveness of infection-induced immunity (*dii*) is permanent, that is, when the duration of infection-induced immunity (*dii*) has no time limit, the number of individuals infected a day (*AP*) increases to a peak of 2,135 on days 191 and 192 and then decreases to 0 on day 326, with a cumulative number of infected individuals of 141,782. The number of infected individuals (*P*) increases to a peak of 14,895 on day 194 and then decreases to 0 on day 342, with a total number of infected individuals of 141,785. Reinfection never occurs.

If the duration of infection-induced immunity (*dii*) is 200 days, the number of individuals infected a day (*AP*) increases to a peak of 2,135 on days 191 and 192 and then decreases to 0 on day 326, with a cumulative number of infected individuals of 141,786. The number of infected individuals (*P*) increases to a peak of 14,895 on day 194 and then decreases to 0 on day 343, with a cumulative number of infected individuals of 141,790. The number of susceptible individuals (*RM*), which is represented as 'Sus' in Figure 2, increases from a minimum of 858,566 on day 284 to 863,067 on day 343, when *P* (343) becomes 0. The number of *RM* just before day 343 is too small to cause reinfection. Therefore, even if there is a limit to the duration of infection-induced immunity (*dii*), if it is 200 days, reinfection will not occur.

The total number of susceptible individuals who get back from recovered individuals (*TReRIRTRAS*(*n*)) shows the same pattern of change, with a delay of 215 days as the number of individuals infected a day (*AP*). Specifically, *TReRIRTRAS*(*n*) increases to a peak of 2,135 on days 406 and 407 and then decreases to 0 on day 541. The total cumulative number of susceptible individuals who have got back from recovered individuals (*JCReRec*) eventually increases to a number equal to the cumulative number of infected individuals (*CAP*) (Figure 3).

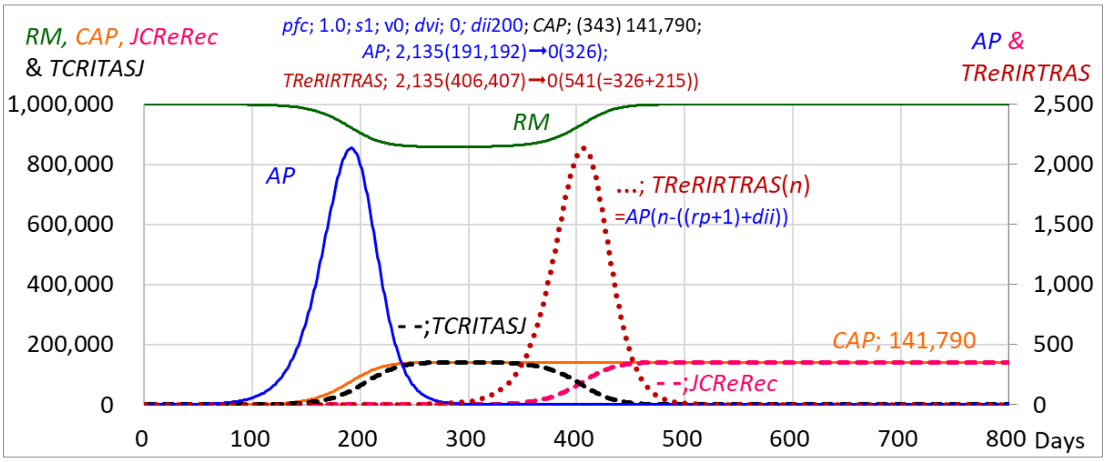

Figure 3: Change in *AP* (the number of infected individuals a day) and in *TReRIRTRAS* (the number of susceptible individuals getting back from recovered individuals a day). *RM*: the number of susceptible individuals; *CAP*: the cumulative number of infected individuals; *JCReRec*: the cumulative number of susceptible individuals getting back from recovered individuals; *TCRITASJ*: the total number of recovered individuals in the community. The potential (biological) infectious capacity of coronavirus (*pfc*) is 1.0, the symptomatic rate (*syr*) is 1.0, the vaccination rate (*v*) is 0 (indicating that vaccination was not performed), the duration of vaccine-induced immunity (*dvi*) is 0, and the duration of infection-induced immunity (*dii*) is 200 (days).

In addition, the sum of the number of recovered individuals in all groups, *TCRITASJ*(*n*), is given by:

$$TCRITASJ(n) = CRIJ(n) + CRTJ(n) + CRASJ(n) - CTAPReRec(n) \quad (42)$$

where *CRIJ*(*n*) is the number of remaining recovered individuals who were isolated because they tested positive:

$$CRIJ(n) = CRI(n) - JCReRI(n) \quad (43)$$

CRTJ(*n*) is the number of remaining recovered individuals who were isolated because they were symptomatic:

$$CRTJ(n)=CRT(n)-JCReRT(n) \quad (44)$$

CRASJ(n) is the number of remaining recovered individuals who were asymptomatic, not isolated and remained in the community:

$$CRASJ(n)=CRAS(n)-JCReRAS(n) \quad (45)$$

CTAPReRec(*n*) in Eq. (42) indicates the cumulative number of 'newly reinfected (newly multiple time infected) individuals' who get reinfected among the susceptible individuals who got back from recovered individuals and can be explained by Eq. (52) in section **4.4. 'Reinfection'**; Some susceptible individuals who have got back from recovered individuals become infected repeatedly (a second, third, or more multiple infections).

The total number of remaining recovered individuals (*TCRITASJ*(*n*)) reaches a peak of 141,216 on day 293. As some *TCRITASJ*(*n*) get back to susceptible individuals, *TCRITASJ*(*n*) decreases daily, eventually reaching 0 on day 551. *TCRITASJ*(*n*) also indicates the total number of currently existing recovered individuals in the community who have infection-induced immunity just before getting back to susceptible individuals. Thus, the following equation holds:

$$TN(n)=TCRIRTRAS(n)+RM(n)+I2(n)+RP(n) \quad (46)$$

where *TN*(*n*) is the total population of the community, *I*2(*n*) is the number of individuals kept in isolation and *RP*(*n*) is the number of infected individuals in the community ("Spreaders"). On day 293, the sum of 141,216 *TCRITASJ* (293) individuals, 858,625 susceptible individuals (*RM* (293)), 116 individuals kept in isolation (*I*2 (293)), and 43 infected individuals in the community (*RP* (293)) equals the community population (*TN*) of 1,000,000. The number of susceptible individuals (*RM*) decreases to the bottom (the minimum) of 858,566 on day 284 and returns to 1,000,000 on day 551. *RM* (*n*) varies almost inversely with *TCRITASJ*(*n*), as shown in Figure 3.

The relationship between the number of susceptible individuals *RM*(*n*) and the number of individuals infected a day *AP*(*n*) is shown in Figure 4-A & 4-B.

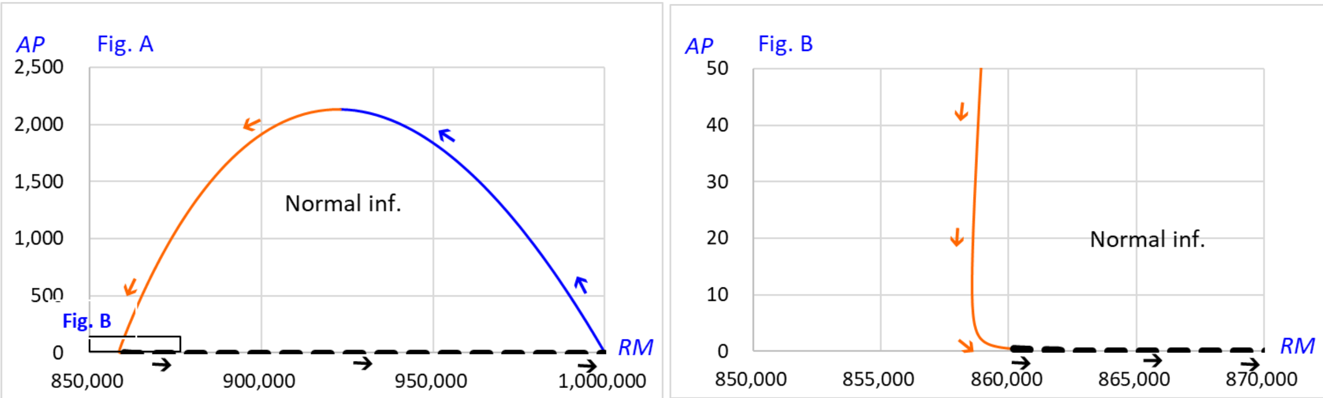

Figure 4-A & B: Relationships between the number of susceptible individuals (*RM*) and the number of individuals infected a day (*AP*). *RM*(*n*) decreases with the occurrence of infection and reaches the minimum value of 858,566 before *AP*(*n*) reaches 0. *RM*(n) increases due to the addition of susceptible individuals, who got back from recovered individuals, and reaches 1,000,000 on day 551.

RM(*n*) decreases to 923,039 on day 191 when the *AP* (191) becomes the peak of 2,135, to the minimum of 858,566 on day 284 when the *AP* (284) is 12. Then, *RM*(*n*) increases to 860,208 on day 326 when *AP* (326) becomes 0. This means that *RM*(*n*) starts to increase due to the addition of susceptible individuals who got back from recovered individuals before *AP*(*n*) reaches 0 (Figure 4-B). *RM*(*n*) increases further but without reinfection during that time and reaches 1,000,000 on day 551 because of the addition of susceptible individuals who get back from recovered individuals.

The relationship between the number of infected individuals in the community (Spreaders; *RP*(*n*)), excluding the individuals kept in isolation and the dead individuals, and the number of individuals infected a day (*AP*) is shown in Figure 5.

AP(*n*) changes approximately proportionally to changes in *RP*(*n*). However, the rate of change (increase rate and/or decrease rate) differs when there is an increase and when there is a decrease, mainly due to the changes in the ratios of *RP*(*n*)/*N*(*n*) and/or *RM*(*n*)/*N*(*n*). When *AP* (191) increases to the peak of 2,135, *RP*(*n*) reaches 12,695 on day 191. However, *RP*(*n*) increases further and reaches a maximum of 12,780 on day 194 when the *AP* (194) is 2,122. *RP*(*n*) decreases to 4 on day 326 when *AP* (326) becomes 0. *RP*(*n*) further decreases and reaches 0 on day 342 in the calculation.

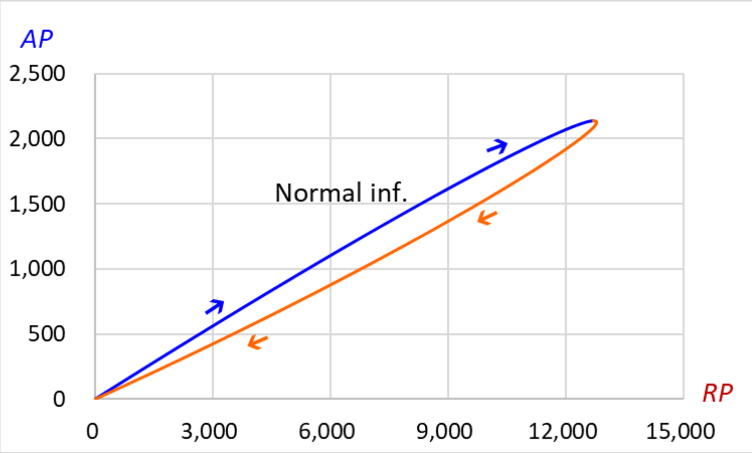

Figure 5: Relationship between the number of infected individuals in the community ("Spreaders"; *RP*(*n*)), excluding the individuals kept in isolation and the number of dead individuals, and the number of individuals infected a day (*AP*). *AP*(*n*) changes approximately proportionally to changes in *RP*(*n*). However, the rate of change (increase rate and/or decrease rate) differs when there is an increase and when there is a decrease.

4.3. Change in the number of susceptible individuals

The number of susceptible individuals in the community *RM*(*n*) is affected not only by the change in the number of infected individuals (*CI*(*n*)+*CAP*(*n*)) but also by the change in the number of vaccinated individuals (*V*(*n*)) and the number of susceptible individuals (*JCReRec*(*n*)) who got back from recovered individuals and, furthermore, the number of reinfected individuals (*CTAPReRec*(*n*-1)), as shown in Figure 3. Thus, the number of susceptible individuals in the community, *RM*(*n*), is given by:

$$RM(n)= TN(n)-(CI(n)+CAP(n)+V(n)) +JCReRec(n)+CTAPReRec(n\text{-}1) \quad (47)(=3)$$

where *TN*(*n*) is the total population of the community, *CI*(*n*) is Σ*I*(*n*), *CAP*(*n*) is Σ*AP*(*n*), and *V*(*n*) is given by Eq. (9).

As explained previously by Eq. (38), the '*JCReRec*(*n*)' in Eq. (47) is the 'adjusted total number of individuals who get back from recovered individuals,' which excludes the number of individuals who were reinfected and have returned to the category of 'Infection'. Therefore, since '*JCReRec*(*n*)' realistically indicates the number of currently existing susceptible individuals who got back from recovered individuals, *RM*(*n*) decreases as the number of infected individuals (*AP*(*n*)) increases and increases as *JCReRec*(*n*) increases.

CTAPReRec(*n*-1) in Eq. (47) is the cumulative number up to the (n-1)th day of the 'newly reinfected individuals' among the susceptible individuals who got back from recovered individuals. *CAP* (*n*) in Eq. (47) is the cumulative number of infected individuals, including those who have been reinfected, and the same individuals (reinfected individuals) are counted twice (or more). Since these reinfected individuals are subtracted twice (or more), *RM* (*n*) needs to be adjusted by returning the 'same cumulative number of reinfected individuals' up to the previous day, that is, *CTAPReRec*(*n*-1). The calculation of '*CTAPReRec*(*n*)' is explained by Eq. (52) in the following section **4.4. 'Reinfection'**.

Eq. (47) suggests that as the number of infected individuals increases with the occurrence of reinfection, the number of susceptible individuals (*JCReRec*) who get back from recovered individuals increases and that, since the total number of susceptible individuals (*RM*) also increases, the number of reinfected individuals will inevitably increase, and the duration of infection will also become longer.

4.4. Reinfection

As previously explained, 'reinfection' refers to not only the second-time infection occurring among susceptible individuals who have got back from recovered individuals with 'first-time infection' but also the infection (third-time infection, fourth, etc.) occurring among susceptible individuals who have got back from recovered individuals with multiple-time infections.

The susceptible individuals who got back from recovered individuals can be divided into three categories. For each category, the cumulative number of susceptible individuals is given as follows: The cumulative number of susceptible individuals (*JCReRI*(*n*)) who got back from recovered individuals (*RI*), who were isolated because they tested positive, is given by Eq. (33). The cumulative number of susceptible individuals (*JCReRT*(*n*)) who got back from recovered individuals (*RT*) who were isolated due to being symptomatic is given by Eq. (30), and the cumulative number of susceptible individuals (*JCReRAS*(*n*)) who got back from asymptomatic-recovered individuals (*ReRAS*) is given by Eq. (36). When reinfection occurs, some of these susceptible individuals are reinfected. Therefore, the number of newly reinfected individuals among each of *JCReRI*, *JCReRT*, and *JCReRAS* needs to be calculated multiple times lagged by the duration of infection-induced immunity.

The number of newly reinfected individuals (*APReRI*(*n*)) in *JCReRI*(*n*) is given by:

$$APReRI(n)=AP1(n)*(JCReRI(n)/RM(n)) \quad (48)(=34)$$

where *AP*1(*n*) is the number of individuals who were newly infected on the n^{th} day, which is equal to *AP*(*n*(night)) and is given by Eq. (22). It is noted here that *AP*1(*n*) is calculated using

RM(*n*), which is the number of currently existing susceptible individuals, including not only the 'original' susceptible individuals but also the susceptible individuals who got back from recovered individuals who recovered from 'reinfection'.

Similarly, the number of newly reinfected individuals (*APReRT*(*n*)) for *JCReRT*(*n*) is given by:

$$APReRT(n)=AP1(n)*(JCReRT(n)/RM(n)) \quad (49)(=31)$$

Similarly, the number of newly reinfected individuals (*APReRAS*(*n*)) for *JCReRAS*(*n*) is given by:

$$APReRAS(n)=AP1(n)*(JCReRAS(n)/RM(n)) \quad (50)(=37)$$

Thus, the total (*TAPReRec*(*n*) of the number of individuals who were newly reinfected on the n^{th} day among the susceptible individuals who got back from recovered individuals is given by:

$$TAPReRec(n)=APReRI(n)+APReRT(n)+APReRAS(n) \quad (51)$$

The cumulative number of newly reinfected individuals in the susceptible individuals who got back from recovered individuals (*CTAPReRec*(*n*)) is given by:

$$CTAPReRec(n) =\Sigma TAPReRec(n) \quad (52)$$

On the other hand, for the original susceptible individuals (OS), the number of newly infected individuals, *APSus*(*n*), among the currently existing original susceptible individuals is given by:

$$APSus(n)=AP1(n)*((RM(n)-(CJCReRI(n)+JCReRT(n)+JCReRAS(n)+JCReVacJ(n)))/RM(n)) \quad (53)$$

This *APSus* (*n*) represents the number of individuals who were 'normal infected' individuals, that is, the 'first-time infected' individuals (individuals infected for the first time), among the remaining original susceptible individuals. The cumulative number (*CAPSus*(*n*)) of *APSus*(*n*) is given by:

$$CAPSus(n) =\Sigma APSus(n) \quad (54)$$

This infection process in the remaining original susceptible individuals is repeated. Thus, the number of newly infected individuals among the remaining original susceptible individuals also needs to be calculated multiple times lagged by the duration of infection-induced immunity.

As shown in Figure 2, the total number of individuals infected a day, *AP*(*n*) (= *AP*1(*n*), which is given by Eq. (2) or Eq. (22)), is the sum of the number of individuals reinfected a day among susceptible individuals who got back from recovered individuals (*TAPReRec*(*n*)) and the number of individuals infected a day among the remaining original susceptible individuals (*APSus*(*n*)).

5. Results and Discussion

5.1. Change in the number of infected individuals if reinfection occurs when *pfc* is 1.0

When the potential (biological) infectious capacity of coronavirus (*pfc*) is 1.0, the symptomatic rate (*s*; *syr*) is 1.0, and the vaccination rate (*v*) is 0 (indicating that vaccination was not performed), if the duration of infection-induced immunity (*dii*) is set to 200 days, as mentioned previously (**4.2. Change in the number of individuals getting back to susceptible individuals from recovered individuals**), reinfection does not occur. However, if the duration of infection-induced immunity (*dii*) is set to 150 days, the number of infected individuals (*P*(*n*)) never becomes 0 for a long period. During this period, the total number of susceptible individuals (*RM*(*n*)), which is represented as 'Sus' in Figure 2, increases from a minimum of 859,857 on day 264 to 980,834 on day 382. This number is sufficient to cause reinfection, and as a result, reinfection (epidemic 2) starts on day 282. Namely, when the duration of infection-induced immunity (*dii*) is 150 days, reinfection (a second infection, a third infection, etc.) occurs.

The number of individuals infected a day (*AP*), the number of infected individuals (*P*), and the cumulative number of infected individuals (*CAP*) when *dii* is set to 150 days are shown in Table 1. The date of the peak differed slightly between *AP* and *P*. The duration of each epidemic differed slightly between *AP* and *P*, resulting in differences in the total number of infected individuals during each epidemic. The number of individuals at the peak of both *AP* and *P* steadily decreases. As shown in Figure 8-B, on day 2,982, when the seventh epidemic reached a 'temporary calm,' the *AP* (2,982) was 54, and the *RM* (2,982) was 990,992. This day is recognized as the end of the seventh epidemic when compared to other epidemics. When the seventh epidemic ends on day 2,982, the total number of infected individuals of the seventh epidemic by *AP* (2,982) is 45,241, and that by *P* (2,982) is 45,600, indicating that the total number of infected individuals of each epidemic also steadily decreases (Table 1).

Table 1: The number of individuals infected a day (*AP*) at peak and trough, the number of infected individuals (*P*) at peak and trough, and the cumulative number of infected individuals (*CAP*). The "*CAP*" indicates the total number of infected individuals for each epidemic. The duration of infection-induced immunity (*dii*) is 150 days.

syr 1.0		Epidemic 1		Epidemic 2		Epidemic 3		Epidemic 4		Epidemic 5		Epidemic 6		Epidemic 7	
dii 150		Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	End
AP	Date	191	336-381	566	712-757	957	1,109-1,146	1,353-1,354	1,521-1,532	1,745-1,749	1,919-1,936	2,139-2,147	2,331-2,358	2,552-2,556	7,206
	Number	2,136	0	1,999	0	1,474	1	905	6	490	24	238	51	107	0
	"*CAP*"	141,920		133,835		112,054		86,427		64,527		48,644		(2,982; 45,241)	94,095
	CAP		141,920		275,755		387,809		474,236		538,763		587,407	(632,648)	681,502
P	Date	194	349-372	569	727-746	960	1,127-1,132	1,356	1,524-1,535	1,750	1,927-1,933	2,144-2,148	2,344-2,351	2,556-2,559	8,029
	Number	14,898	2	13,942	2	10,288	8	6,324	45	3,429	169	1,665	356	746	0
	"*CAP*"	141,917		133,833		112,040		86,466		64,434		48,358		(2,982; 45,600)	94,721
	CAP		141,917		275,750		387,790		474,256		538,690		587,048	(632,648)	681,769

The changes in the number of individuals infected a day (*AP*), the number of infected individuals (*P*) and the number of susceptible individuals who have got back from recovered individuals to susceptible individuals a day (*TReRIRTRAS*) are shown in Figure 6.

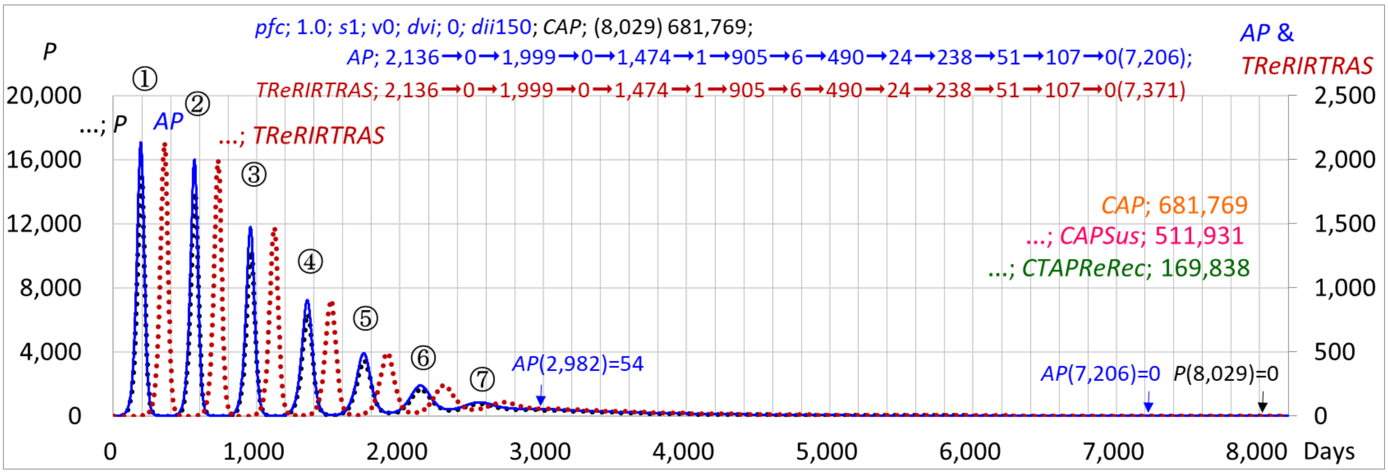

Figure 6: Changes in the number of individuals infected a day (*AP*) and the number of susceptible individuals who have got back from recovered individuals to susceptible individuals a day (*TReRIRTRAS*). The *dii* is 150 days.

The number of individuals infected a day (*AP*) increases to the first peak of 2,135 on day 191 and on day 192 during the first epidemic (①), decreases to 0 and keeps 0 from day 336 to day 381, increases to the second peak of 1,999 on day 566 during the second epidemic (②), decreases to 0 and keeps 0 from day 712 to day 757, increases to the third peak of 1,474 on day 957 during the third epidemic (③), decreases to 1 and keeps 1 from day 1,109 to 1,146, increases to the fourth peak of 905 on day 1,353 and on day 1,354 during the fourth epidemic (④), decreases to 6 and keeps 6 from 1,521 to 1,532, increases to the fifth peak of 490 from day 1,745 to day 1,749 during the fifth epidemic (⑤), decreases to 24 and keeps 24 from day 1,919 to day 1,936, increases to the sixth peak of 238 from day 2,139 to day 2,147 during the sixth epidemic (⑥), decreases to 51 and keeps 51 from day 2,331 to day 2,358, and then increases to the seventh peak of 107 from day 2,552 to day 2,556 during the seventh epidemic (⑦), and decreases to 0 on day 7,206. Day 7,206, when the *AP* becomes 0, does not indicate a 'true end day of infection', just as has been seen in the previous epidemics as 'interruption of epidemic' when *AP* showed 0 in the first epidemic. The number of individuals infected a day (*AP*(*n*) and/or *AP*1(*n*)) at the peak also declines with the epidemic.

The number of infected individuals (*P*) increases to the first peak of 14,898 on day 194 during the first epidemic (①), decreases to 2 and keeps 2 from day 349 to day 372, increases to the second peak of 13,942 on day 569 during the second epidemic (②), decreases to 2 and keeps 2 from day 727 to day 746, increases to the third peak of 10,288 on day 960 during the third epidemic (③), decreases to 8 and keeps 8 from day 1,127 to 1,132, increases to the fourth peak of 6,324 on day 1,356 during the fourth epidemic (④), decreases to 45 and keeps 45 from 1,524 to 1,535, increases to the fifth peak of 3,429 on day 1,750 during the fifth epidemic (⑤), decreases to 169 and keeps 169 from day 1,927 to day 1,933, increases to the sixth peak of 1,665 from day 2,144 to day 2,148 during the sixth epidemic (⑥), decreases to 356 and keeps 356 from day 2,344 to day 2,351, increases to the seventh peak of 746 from day 2,556 to day 2,559 during the seventh epidemic (⑦), and decreases to 0 on day 8,029. Day 8,029, when *P* reaches 0, marks the 'true end of infection,' since no infections will occur after this date. The number of infected individuals (*P*(*n*)) at the peak declines with the epidemic.

As shown in Figure 6, the date of the peak and the duration of each epidemic differ slightly between the *AP* and *P*. However, the curves of increase/decrease are so similar that it is difficult to distinguish them clearly in the graph. The number of susceptible individuals who got back from recovered individuals a day (*TReRIRTRAS*(*n*)) shows the exact same curve as AP(*n*), with a lag of 165 (= (14+1)+150; (*rp*+1)+*dii*) days.

On the other hand, the number of susceptible individuals (*RM*: the total number of susceptible individuals in the community) varies almost inversely with the total number of remaining recovered individuals (*TCRITASJ*), which is given by Eq. (42), as shown in Figure 7. The total number of individuals who got back from recovered individuals (*JCReRec*) increases and decreases repeatedly in sync with *TCRITASJ* and eventually becomes equal to 511,931, which is the final value of *CAPSus*, which is the cumulative number of 'first-time infected' individuals (individuals infected for the first time) among the remaining original susceptible individuals.

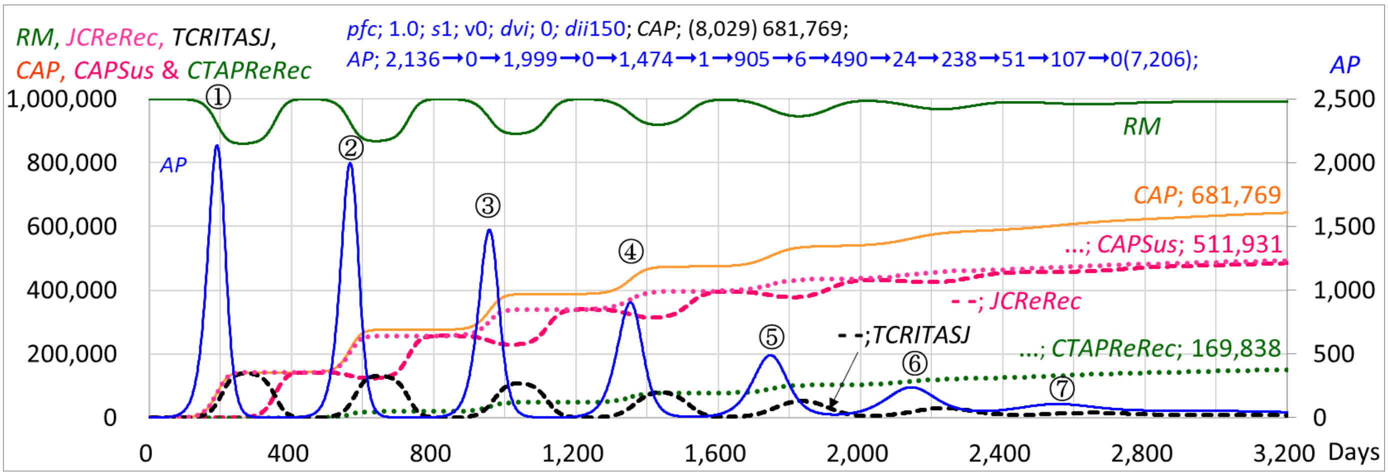

Figure 7: Changes in the number of individuals infected a day (*AP*), the number of susceptible individuals in the community (*RM*), the total number of individuals who got back from recovered individuals (*JCReRec*), the total number of remaining recovered individuals (*TCRITASJ*), the cumulative number of infected individuals (*CAP*), the cumulative number of the 'first-time infected individuals' among the remaining original susceptible individuals (*CAPSus*) and the cumulative number of 'newly reinfected individuals' who get reinfected among the susceptible individuals who have got back from recovered individuals (*CTAPReRec*).

It is suggested that even if reinfection occurs, as long as no new strains or variants emerge, the number of infected and reinfected individuals will decrease, and the epidemic will eventually end. However, according to the calculation in the example case with a *dii* of 150 days, the number of individuals infected a day (*AP*(*n*)) will be 0 on the 7,206th day (in longer than 19 years), and the day when the number of infected individuals (*P*(*n*)) will decrease to 0, meaning "the day when the epidemic will end completely", is the 8,029th day (after approximately 22 years). If reinfection occurs, it may take a seriously long time for the epidemic to subside. Moreover, even if the number of individuals newly infected a day (*AP*(*n*)) is kept at 0 for a relatively long period of time, such as several tens of days, reinfection, that is, the next epidemic, may occur.

The relationship between the number of susceptible individuals in the community (*RM*) and the number of individuals infected a day (*AP*) is shown in Figure 8 (A and B). The circles representing the outbreaks of individual epidemics shrink as the outbreaks progress. The number of susceptible individuals in the community decreases with the occurrence of infections. However, when *AP*(*n*) becomes relatively small during the latest stage of each epidemic, since the number of susceptible individuals who got back from recovered individuals overcomes *AP*(*n*), *RM*(*n*) starts to increase before *AP*(*n*) reaches 0 or the minimum number of each epidemic. As *RM*(*n*) continues to increase and approaches 1,000,000, reinfection will occur, and the next epidemic will begin.

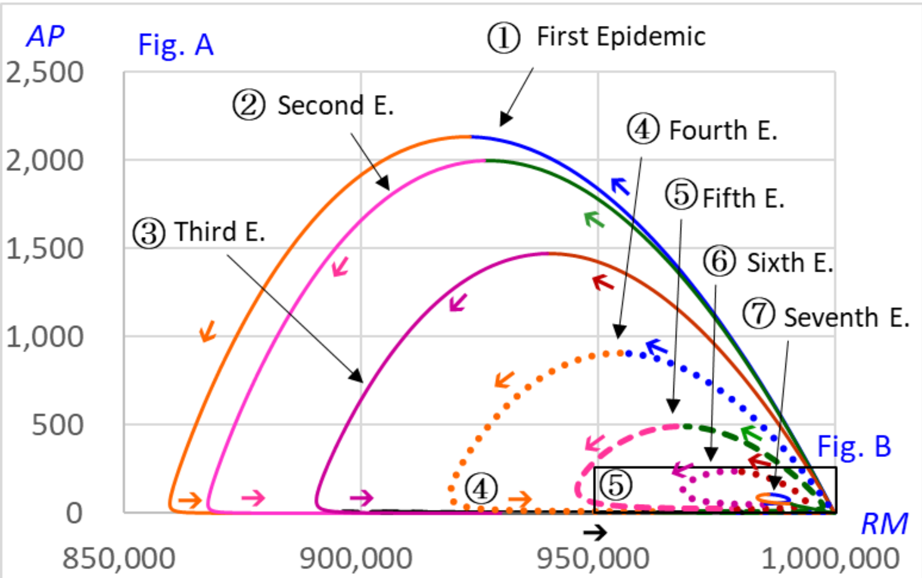

Figure 8-A: Relationships between the number of susceptible individuals in the community (*RM*) and the number of individuals infected a day (*AP*). *RM* decreases with the occurrence of infection. The circles representing the outbreaks of individual epidemics shrink as the outbreaks progress. *RM*(*n*) starts to increase before *AP*(*n*) reaches 0 or the minimum number of each epidemic.

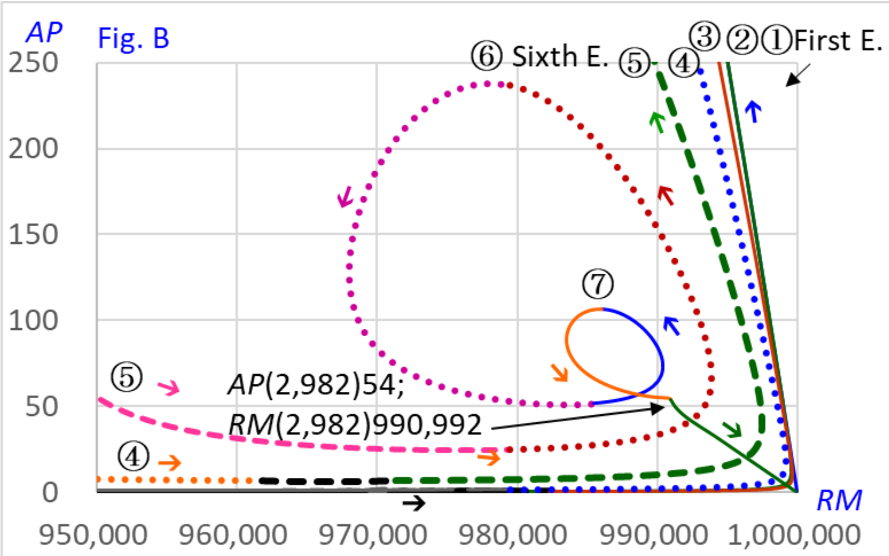

Figure 8-B: Relationships between *RM* and *AP* in the cases of the sixth and seventh epidemics. When *AP*(*n*) becomes significantly small during the latest stage of each epidemic, *RM*(*n*) starts to increase before *AP*(*n*) reaches 0 or the minimum number of each epidemic. On day 2,982, the lull (the inflection point in the trend) in the seventh epidemic, *AP* (2,982) becomes 54, and *RM* (2,982) becomes 990,992. On day 7,206, when *AP* (7,206) reaches 0, *RM* (7,206) reaches 999,909. After *AP*(*n*) becomes 0, *RM*(n) continues to increase and reaches 1,000,000 on day 8,187.

On day 2,982, the lull in the seventh epidemic, *AP* (2,982) is 54, and *RM* (2,982) is 990,992 (Figure 8-B). After that, *AP*(*n*) simply decreases, and *RM*(*n*) increases. At the end of the seventh epidemic, on day 7,206, *AP* (7,206) reaches 0 and *RM* (7,206) reaches 999,909. Even after *AP*(*n*) reaches 0, as recovered individuals continue to get back to susceptible individuals, *RM*(*n*) continues to increase and reaches 1,000,000 on day 8,187, in the calculation, including decimal points.

The relationships between the number of infected individuals in the community (‘Spreaders’, *RP*), excluding the individuals kept in isolation and the number of dead individuals, and the number of individuals infected a day (*AP*) are shown in Figure 9 (A and B). As the number of epidemic outbreaks progresses, the maximum number of *RP* of each epidemic decreases.

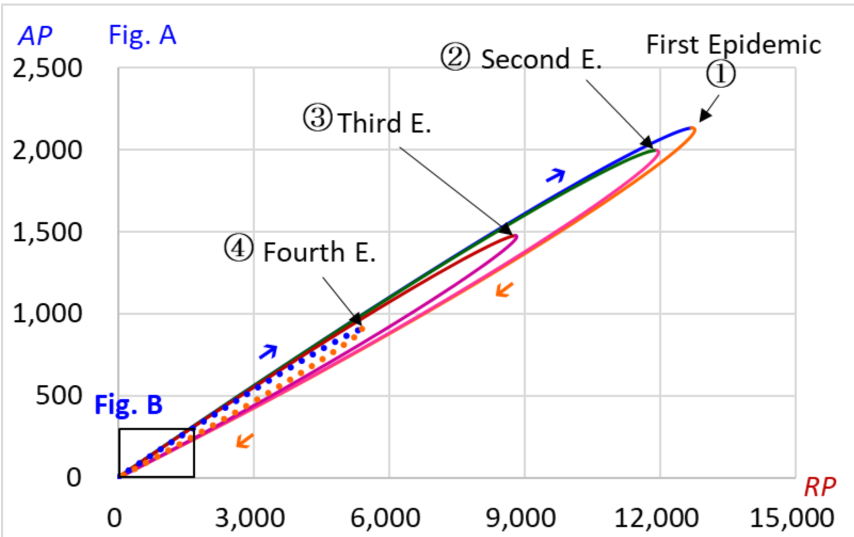

Figure 9-A: Relationships between the number of infected individuals in the community (‘Spreaders’, *RP*), excluding the individuals kept in isolation and the number of dead individuals, and the number of individuals infected a day (*AP*).

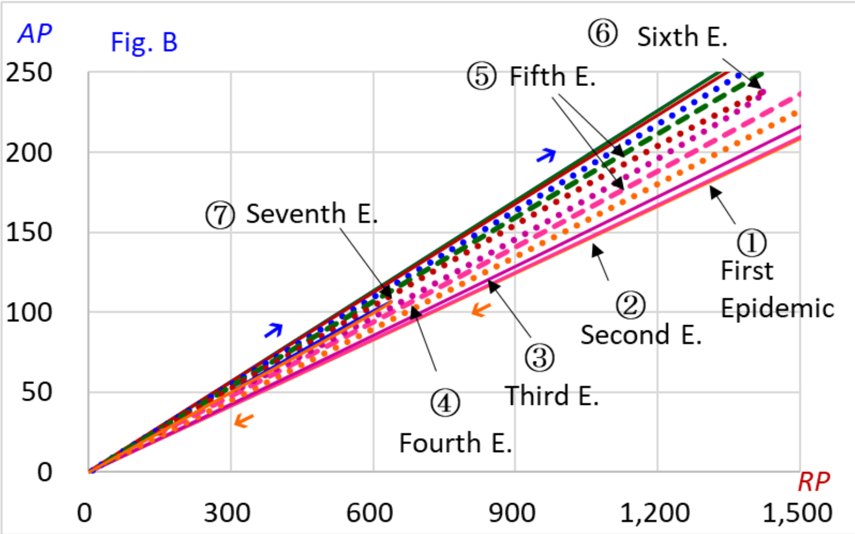

Figure 9-B: Relationship between the number of infected individuals in the community ("Spreaders", *RP*) and the number of individuals infected a day (*AP*) in the case of the sixth epidemic and the seventh epidemic. As the number of epidemic outbreaks progresses, the maximum number of *RP* of each epidemic decreases, and infection (reinfection) eventually never occurs because the number of *RP* is too small.

5.2. Changes in the composition of the number of first-time infected individuals and the number of reinfected individuals

When 'reinfection' occurs multiple times among the same individuals, the '*TAPReRec*(*n*)' given by Eq. (51) indicates the total number of individuals who were newly reinfected a day among the susceptible individuals who got back from the recovered individuals. As previously explained, the number of newly infected individuals, *APSus*(*n*), among the currently existing original susceptible individuals is the number of individuals who are 'normal infected' individuals, that is, the 'first-time infected' individuals, among the remaining original susceptible individuals.

As explained in section **4.1. 'A simple mathematical/statistical process of reinfection'** and shown in Figure 2, the total number of individuals infected a day, *AP*(*n*) (= *AP*1(*n*), which is given by Eq. (2) or Eq. (22)), is the sum of *TAPReRec*(*n*) and *APSus*(*n*). The changes in the compositions of *TAPReRec*(*n*) and *APSus*(*n*) are shown in Figure 10.

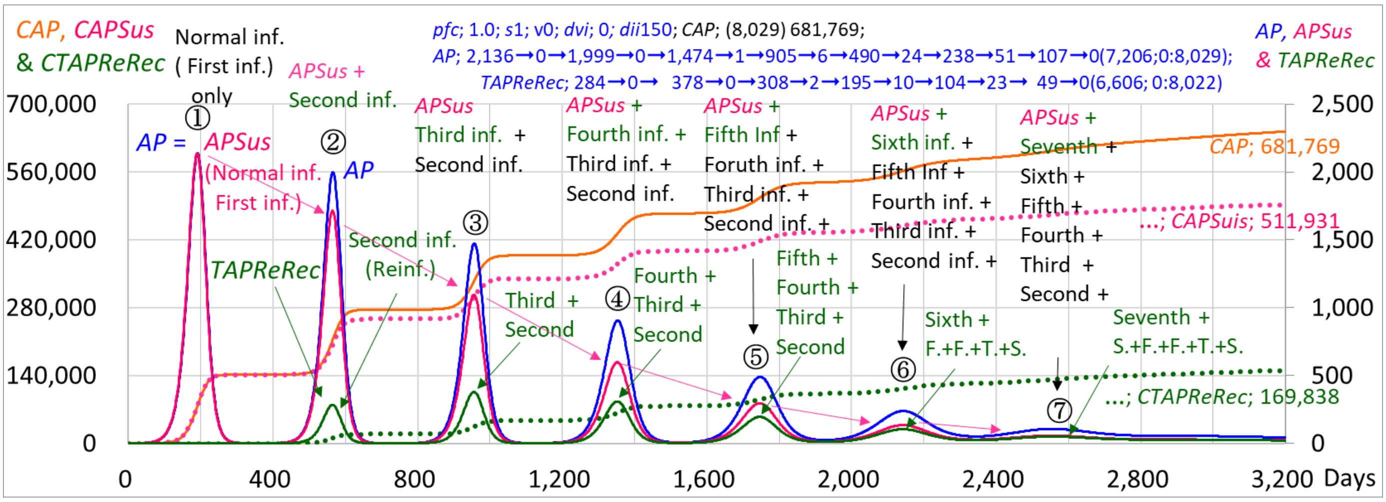

Figure 10: The changes in the composition of *TAPReRec*(*n*), which is the total number of newly reinfected individuals among the susceptible individuals who got back from the recovered individuals, and *APSus*(*n*), which is the number of infected individuals (First-time infected individuals; normal infected individuals) among the currently existing original susceptible individuals. *CAP* is the cumulative number of infected individuals, *CAPSus* is the cumulative number of 'first-time infected individuals' among the remaining original susceptible individuals, and *CTAPReRec* is the cumulative number of 'newly reinfected individuals' who get reinfected among the susceptible individuals who have got back from recovered individuals.

As previously explained, *APSus* indicates the number of infected individuals among the remaining original susceptible individuals. During the first epidemic (①), the 'remaining' original susceptible individuals indicate the 'initial' original susceptible individuals. Therefore, *AP*(*n*) changes exactly the same as does *APSus*(*n*) during the first epidemic (①).

The *APSus* (Normal inf.) during the second epidemic(②) indicates the number of infected individuals among the remaining original susceptible individuals, excluding the number of normal infected individuals (the first-time infected individuals) during the first epidemic. This, therefore, indicates a first-time infection in the case of the remaining original susceptible individuals. 'Second inf. (Reinf.)' indicates the number of infected individuals among the susceptible individuals who got back from the recovered individuals who recovered from the first-time infection (normal infection) during the first epidemic. Thus, the 'Second infection' is the 'reinfection' in a narrow sense. *AP* is the sum of the *APSus* and Second inf.

For the third epidemic (③), *APSus* indicates the number of newly (first-) infected individuals among the remaining original susceptible individuals, excluding the number of first-time infected individuals during the first epidemic. 'Second inf. (second-time infected individuals)' indicates the number of individuals newly infected among susceptible individuals who got back from recovered individuals who were first-time infected during the first epidemic. 'Third inf.' indicates the number of newly (third-time) infected individuals among the susceptible individuals who got already second infected during the second epidemic and had recovered. The *AP* is the sum of the *APSus*, Third inf and Second inf. The total number of 'reinfected individuals' is the sum of the Third inf. and Second inf.

Similarly, for the seventh epidemic (⑦), the *APSus* indicates the number of newly (first-time) infected individuals during the seventh epidemic among the remaining original susceptible individuals. The total number of newly 'reinfected' individuals (*TAPReRec*) is the sum of 'Seventh inf.' (seventh-time infected individuals during the seventh epidemic among susceptible individuals who got back from recovered individuals who were sixth-time infected during the sixth epidemic), 'Sixth inf.' (sixth-time infected individuals during the seventh epidemic among susceptible individuals who got back from recovered individuals who were fifth-time infected during the sixth epidemic), 'Fifth inf.' (fifth-time infected individuals during the seventh epidemic among susceptible individuals who got back from recovered individuals who were fourth-time infected during the sixth epidemic), 'Fourth inf.' (fourth-time infected individuals during the seventh epidemic among susceptible individuals who got back from recovered individuals who were third-time infected during the sixth epidemic), 'Third inf.' (third-time infected individuals during the seventh epidemic among susceptible individuals who got back from recovered individuals who were second-time infected during the sixth epidemic) and 'Second inf.' (second-time infected individuals during the seventh epidemic among susceptible individuals who got back from recovered individuals who were first-time infected during the sixth epidemic). The total number of infected individuals a day (*AP*(*n*)) during the seventh epidemic is the sum of *APSus* (First inf.) and *TAPReRec* (Seventh inf. + Sixth inf. + Fifth inf. + Fourth inf. + Third inf. + Second inf.) (Figure 11).

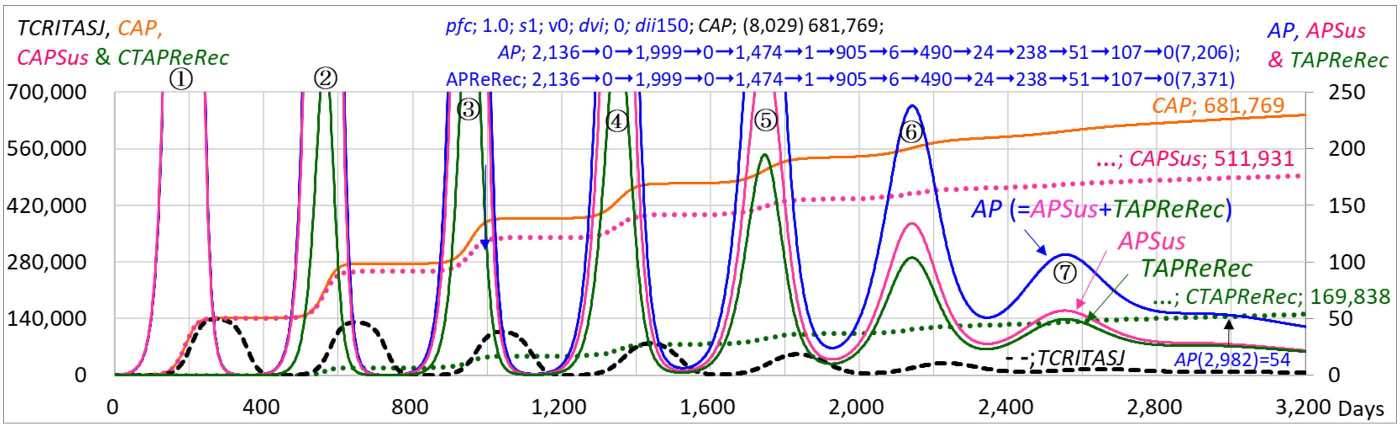

Figure 11: Changes in the composition of *TAPReRec*(*n*) and *APSus*(*n*) in *AP*(*n*), especially during the sixth and seventh epidemics. *AP*(*n*): total number of infected individuals a day; *TAPReRec*(*n*): the total number of newly reinfected individuals among the susceptible individuals who got back from the recovered individuals; *APSus*(*n*): the number of infected individuals (First-time infected individuals; normal infected individuals) among the currently existing original susceptible individuals; *TCRITASJ*: the total number of remaining recovered individuals.

The change in the ratio of the number of newly first-time infected individuals (*APSus*(*n*)) and the number of newly reinfected individuals (*TAPReRec* (*n*)) to the total number of individuals infected a day (*AP*(*n*)) is shown in Figure 12. When *AP*(*n*) becomes 0, that is, when the value of *AP*(*n*) becomes less than 0.5, the ratio is still calculated using decimal values. Thus, the ratio never becomes 0 and represents a ratio between decimal values.

As the number of epidemic outbreaks increases, the total number of individuals infected a day (*AP*(*n*)) decreases. The ratio of the number of 'newly first-time infected individuals (*APSus*(*n*))' among the remaining original susceptible individuals decreases toward 0.5. On the other hand, the ratio of the number of 'newly reinfected individuals (*TAPReRec* (*n*))' among the susceptible individuals who got back from recovered individuals increases toward 0.5. Therefore, even in the epidemics caused by 'reinfection', the individuals who become infected for the first time among the remaining original susceptible individuals constitute the majority of infected individuals.

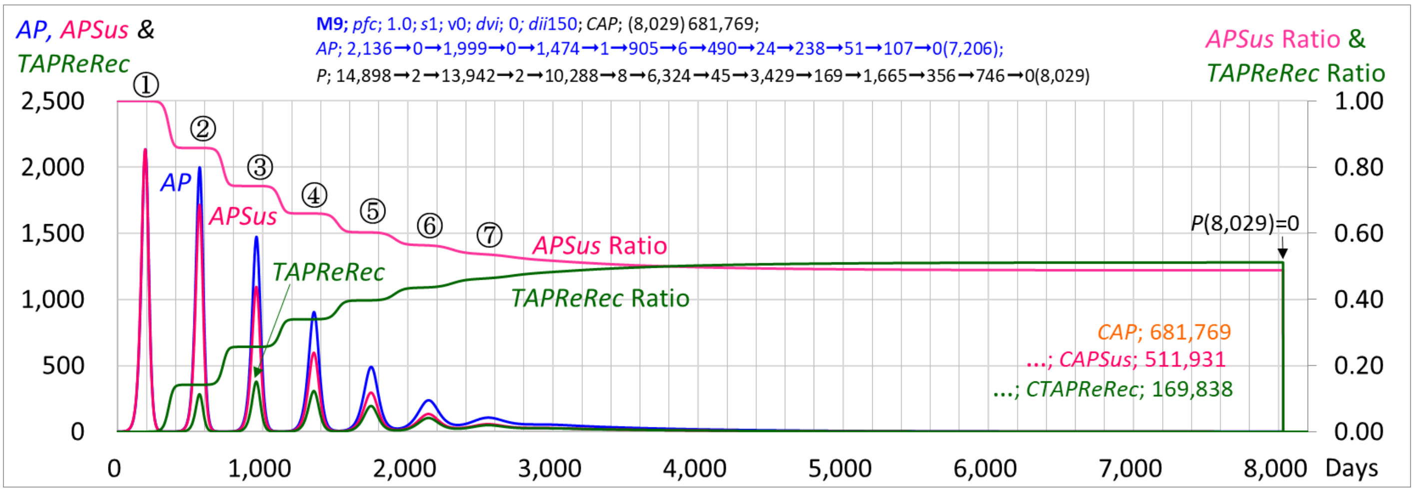

Figure 12: Changes in the ratios of *TAPReRec*(*n*) and *APSus*(*n*) to *AP*(*n*). After around day 4,000, the number of individuals infected a day (*AP*(*n*)) becomes less than 18, and the number of each of *APSus* and *TAPReRec* is less than 9, indicating that the ratios are almost the same.

On the day of the 6,224th, *AP* (6,224) becomes 1, and the calculations show that the ratio of *APSus* (6,224) is 0.49 and that the ratio of *TAPReRec* (6,224) is 0.51. Furthermore, on the day of the 8,028th, the last day of infection, the *AP* (8,028) is still 1, the ratio of *APSus* (8,028) is 0.49, and the ratio of *TAPReRec* (8,028) is 0.51. After around the 4,000th day, the number of individuals infected a day (*AP*(*n*)) becomes less than 18, and both *APSus*(*n*) and *TAPReRec*(*n*) are less than 9, indicating that the ratios are almost the same.

5.3. Relationship between the duration of infection-induced immunity required for reinfection to occur and the symptomatic rate

The symptomatic rate, *syr*, is the ratio of the number of individuals who become symptomatic to the total number of individuals newly infected a day. This symptomatic rate practically refers to the 'isolation rate', which indicates the ratio of the number of isolated individuals to the total number of individuals newly infected a day. And it is known that the symptomatic rate has a serious effect on the number of infections [23].

As noted previously, when the potential (biological) infectious capacity of coronavirus (*pfc*) is 1.0, the vaccination rate (*v*) is 0 (indicating that vaccination was not performed), and the symptomatic rate (*syr*) is 1.0; if the duration of infection-induced immunity (*dii*) is 200 days, reinfection will not occur, but if *dii* is 150 days, reinfection will occur. Here, the relationship between the duration of infection-induced immunity required for reinfection to occur and the symptomatic rate will be examined.

The duration of infection-induced immunity required for reinfection to occur differs according to the symptomatic rate (*syr*) (Table 2). For example, when the symptomatic rate (*syr*) is 1.0, if the duration of infection-induced immunity (*dii*) is 156 days, reinfection will never occur. However, if *dii* is 155 days, reinfection occurs. Thus, the duration of infection-induced immunity required for reinfection to occur can be said to be 155 days (Table 2-A).

Specifically, if the duration of infection-induced immunity (*dii*) is 156 days, the number of individuals infected a day (*AP*) increases to 2,136 at the peak on days 191 and 193 and then decreases to 0. The infection ends on day 364, the day when the number of infected individuals (*P*) becomes 0. The total number of infected individuals is 141,874. On the other hand, if *dii* is 155 days, as explained in the case where *dii* is 150 days, reinfection occurs accompanying 7 breakouts of the epidemic. The first epidemic shows roughly the same pattern as the case of a *dii* of 156 days where no reinfections occur. The infection ends on day 8,254, and the total number of infected individuals (*CAP*) is 681,562. Thus, the duration of infection becomes extremely long, and the total number of infected individuals also greatly increases.

Table 2-A: Duration of infection-induced immunity required for reinfection to occur (*dii*) depending on the symptomatic rate (*syr*; 1.0~0.7). *AP* indicates the number of individuals infected a day, "*CAP*" indicates the total number of infected individuals for each epidemic, and *CAP* indicates the cumulative number of infected individuals. 'End' indicates the day when the number of infected individuals *P*(*n*) becomes 0. When *syr* is 1.0, if *dii* is 156, reinfection never occurs, but if *dii* is 155, reinfection with 7 epidemics occurs. If reinfection occurs, when *syr* is 0.9 and 0.8, 6 epidemics occur, and when *syr* is 0.7, 5 epidemics occur. However, as the symptomatic rate decreases, the total number of infected individuals (*CAP*) increases. When the value of *syr* is equal to or less than 0.8, if reinfection occurs, *CAP* exceeds the community population of 1,000,000.

			Epidemic 1		Epidemic 2		Epidemic 3		Epidemic 4		Epidemic 5		Epidemic 6		Epidemic 7	
syr	*dii*		Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	End
		Date	191	332-395	578	721-784	981-982	1,128-1,188	1,390-1,392	1,555-1,583	1,795-1,800	1,967-1,997	2,201-2,208	2,396-2,422	2,612-2,641	8,254
	155	*AP*	2,136	0	1,999	0	1,474	1	905	5	491	21	240	46	107	0
		"*CAP*"	141,890		133,811		112,016		86,333		64,358		48,110		(3,079; 46,100)	95,044
1.0		*CAP*		141,890		275,701		387,717		474,050		538,408		586,518	(632,611)	681,562
			Peak	End												
		Date	191-192	364												
	156	*AP*	2,135	0												
		CAP	141,874													
			Epidemic 1		Epidemic 2		Epidemic 3		Epidemic 4		Epidemic 5		Epidemic 6			
syr	*dii*		Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	End		
		Date	145	254-298	435	547-589	749	868-902	1,072	1,205-1,221	1,391-1,396	1,551-1,561	1,715-1,735	5,213		
	115	*AP*	5,411	0	4,788	0	2,787	3	1,234	27	470	84	161	0		
		"*CAP*"	251,422		225,789		165,249		108,522		71,589		(2,009; 51,853)	94,754		
0.9		*CAP*		251,422		477,211		642,460		750,982		822,571	(874,509)	917,325		
			Peak	End												
		Date	145	278												
	116	*AP*	5,411	0												
		CAP	251,408													
			Epidemic 1		Epidemic 2		Epidemic 3		Epidemic 4		Epidemic 5		Epidemic 6			
syr	*dii*		Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	End		
		Date	125	221-257	374	474-508	654	765-783	945-946	1,069-1,079	1,233-1,240	1,418-1,449	1,469-1,523	4,110		
	100	*AP*	8,670	0	7,374	0	3,664	5	1,304	58	393	119	121	0		
		"*CAP*"	336,155		291,537		195,396		116,304		76,638		60,276			
0.8		*CAP*		336,155		627,692		823,088		939,392		1,016,030		1,076,306		
			Peak	End												
		Date	125	242												
	101	*AP*	8,670	0												
		CAP	336,143													
			Epidemic 1		Epidemic 2		Epidemic 3		Epidemic 4		Epidemic 5					
syr	*dii*		Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	End				
		Date	112	201-234	339	431-463	600	703-720	875	996-1,002	1,150-1,152	3,545				
	92	*AP*	11,596	0	9,614	0	4,317	7	1,320	85	337	0				
		"*CAP*"	400,974		339,725		215,231		119,727		116,823					
0.7		*CAP*		400,974		740,699		955,930		1,075,657		1,192,480				
			Peak	End												
		Date	112	223												
	93	*AP*	11,596	0												
		CAP	400,964													

When the symptomatic rate (*syr*) is 0.8 and the duration of infection-induced immunity (*dii*) is 100 days, reinfection occurs, accompanying 6 outbreaks of the epidemic. The infection ends on day 4,110, and the total number of infected individuals (*CAP*) becomes 1,076,306, exceeding the community population of 1,000,000 (Table 2-A, Figure 13). As shown in Table 2 (A-D), when the value of *syr* is equal to or less than 0.8, if reinfection occurs, *CAP* exceeds the community population of 1,000,000.

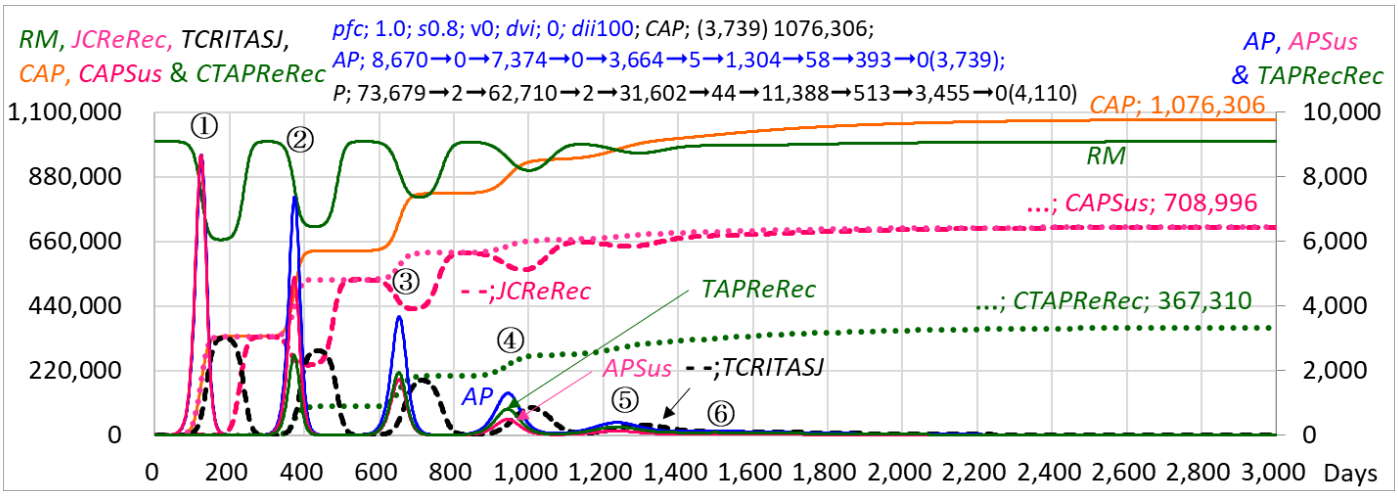

Figure 13: The changes in the composition of *TAPReRec*(*n*), which is the total number of newly reinfected individuals among the susceptible individuals who got back from the recovered individuals, and *APSus*(*n*), which is the number of first-time infected individuals (normal infected individuals) among the currently existing original susceptible individuals. *CAP* is the cumulative number of infected individuals, *CAPSus* is the cumulative number of the first-time infected individuals among the remaining original susceptible individuals, and *CTAPReRec* is the cumulative number of 'newly reinfected individuals' who get reinfected among the susceptible individuals who have got back from recovered individuals. The symptomatic rate (*syr*) is 0.8, and the duration of infection-induced immunity (*dii*) is 100 days.

The relationship between the number of susceptible individuals in the community (*RM*) and the number of individuals infected a day (*AP*) is shown in Figure 14 (A and B). The circles representing the outbreaks of individual epidemics shrink as the outbreaks progress. In the sixth epidemic (⑥), the *AP* increases from 119 at the trough (from day 1,418 to day 1,449) to 121 at the peak (from 1,469 to day 1,523) and then decreases to 0 on day 3,739. However, the sixth epidemic (⑥) is not a neat circle like the fifth epidemic (⑤), and its peak appears to be a 'lull (an inflection point in the trend)' in the fifth epidemic (Figure 14-B).

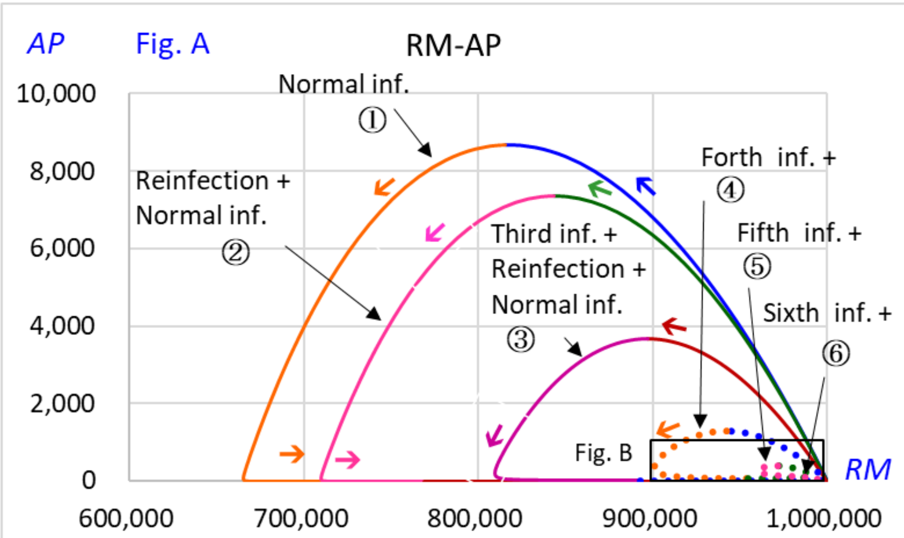

Figure 14-A: Relationships between the number of susceptible individuals in the community (*RM*) and the number of individuals infected a day (*AP*). *RM* decreases with the occurrence of infection. The circles representing the outbreaks of individual epidemics shrink as the outbreaks progress. *RM*(*n*) starts to increase before *AP*(*n*) reaches 0 or the minimum number of each epidemic.

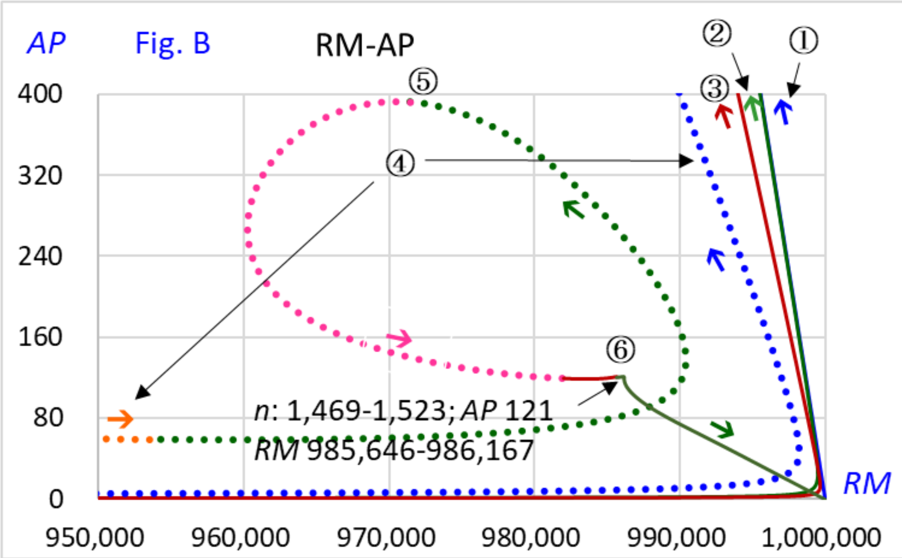

Figure 14-B: Relationships between *RM* and *AP* in the cases of the sixth and seventh epidemics. When *AP*(*n*) becomes relatively small during the latest stage of each epidemic, *RM*(*n*) starts to increase before *AP*(*n*) reaches 0 or the minimum number of each epidemic. *AP* shows 121 at the peak from day 1,469 to day 1,523 for the sixth epidemic (⑥). On day 3,739, when the *AP* reaches 0, the *RM* is 999,934. After *AP*(*n*) becomes 0, *RM*(*n*) continues to increase and reaches 1,000,000 on day 4,216.

The change in the ratio of the number of newly first-time infected individuals (*APSus*(*n*)) and the number of newly reinfected individuals (*TAPReRec* (*n*)) to the total number of individuals infected a day (*AP*(*n*)) is shown in Figure 15. As the number of epidemic outbreaks increases, the total number of individuals infected a day (*AP*(*n*)) decreases. The ratio of the number of newly first-time infected individuals (*APSus* Ratio), among the remaining original susceptible individuals decreases from 1.0 to 0.29. On the other hand, the ratio of the number of newly reinfected individuals (*TAPReRec* Ratio), among the susceptible individuals who got back from recovered individuals increases from 0.0 to 0.71. On days 500 and 501, the *APSus* Ratio and *TAPReRec* Ratio intersect at 0.5, after which the *TAPReRec* Ratio becomes larger than *APSus* Ratio (Figure 15).

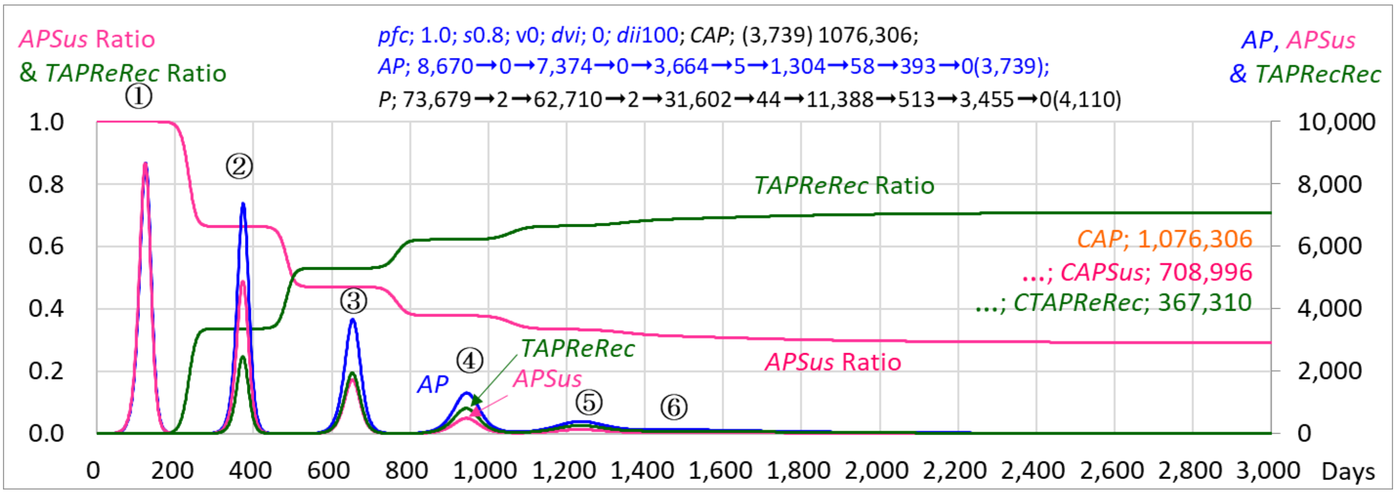

Figure 15: Changes in the ratios of *TAPReRec*(*n*) and *APSus*(*n*) to *AP*(*n*). After day 501, the number of *APSus* becomes less than that of *TAPReRec*. *syr* is 0.8, and *dii* is 100 days.

When the symptomatic rate (*syr*) is 0.5, if the duration of infection-induced immunity (*dii*) is 84 days, reinfection will never occur. However, if *dii* is 83 days, reinfection occurs. Thus, the duration of infection-induced immunity required for reinfection to occur can be said to be 83 days for this case (Table 2-B). With 5 outbreaks of the epidemic, the infection continues until the 4,110th day, and the total number of infected individuals (*CAP*) becomes 1,076,306.

Table 2-B: Duration of infection-induced immunity required for reinfection to occur (*dii*) depending on the symptomatic rate (*syr*; 0.6~0.4). *AP* indicates the number of individuals infected a day, "*CAP*" indicates the total number of infected individuals for each epidemic, and *CAP* indicates the cumulative number of infected individuals. 'End' indicates the day when the number of infected individuals *P*(*n*) becomes 0. If reinfection occurs, when the value of *syr* is 0.6 or 0.5, 5 epidemics occur. As the symptomatic rate decreases, the total number of infected individuals (*CAP*) increases. When *syr* is 0.4, if *dii* is 81, 2 epidemics occur, and if *dii* is 80, 5 epidemics occur.

			Epidemic 1		Epidemic 2		Epidemic 3		Epidemic 4		Epidemic 5	
syr	*dii*		Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	End
		Date	104	188-219	315	402-434	564	662-678	830	947-955	1092-1,101	3,190
	87	*AP*	14,142	0	11,542	0	4,864	8	1,330	85	298	0
		"*CAP*"	451,034		376,360		229,905		121,701		102,421	
0.6		*CAP*	451,034		827,394		1,057,299		1,179,000		1,281,421	
			Peak	End								
		Date	104	210								
	88	*AP*	14,142	0								
		CAP	451,024									
			Epidemic 1		Epidemic 2		Epidemic 3		Epidemic 4		Epidemic 5	
syr	*dii*		Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	End
		Date	97	179-206	297	380-411	535	633-641	793-794	908-919	1,046-1,057	2,920
	83	*AP*	16,342	0	13,206	0	5,358	8	1,345	118	271	0
		"*CAP*"	490,263		405,197		241,651		123,276		91,585	
0.5		*CAP*	490,263		895,460		1,137,111		1,260,387		1,351,972	
			Peak	End								
		Date	97	201								
	84	*AP*	16,342	0								
		CAP	490,255									
			Epidemic 1		Epidemic 2		Epidemic 3		Epidemic 4		Epidemic 5	
syr	*dii*		Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	End
		Date	92	172-196	282	362-393	512	606-617	766-767	884-886	1,016-1,017	2,722
	80	*AP*	18,238	0	14,678	0	5,819	8	1,365	125	252	0
		"*CAP*"	521,468		428,570		251,600		123,606		84,022	
		CAP	521,468		950,038		1,201,638		1,325,244		1,409,266	
			Peak	Trough	Peak	End						
		Date	92	171-198	284	386						
0.4	81	*AP*	18,238	0	14,677	0						
		"*CAP*"	521,465		428,563							
		CAP	521,465		950,028							
			Peak	End								
		Date	92	193								
	82	*AP*	18,238	0								
		CAP	521,458									

When the symptomatic rate (*syr*) is 0.4, if the duration of infection-induced immunity (*dii*) is 82 days, reinfection will never occur. The infection ends on day 193, with a total number of infected individuals (*CAP*) of 521,458. However, if *dii* is 81 days, reinfection occurs, resulting in 2 outbreaks of the epidemic, with an infection duration of 386 days and a *CAP* of 950,028. Furthermore, if *dii* is 80 days, reinfections occur, resulting in 5 outbreaks of epidemic infection duration of 2,722 days and a *CAP* of 1,409,266 (Table 2-B). Thus, in this case, the duration of infection-induced immunity required for one outbreak of reinfection to occur is 81 days, and the duration of infection-induced immunity required for multiple reinfections to occur is 80 days. When multiple reinfections occur, both the duration of infection and the total number of infected individuals significantly increase.

Table 2-C: Duration of infection-induced immunity required for reinfection to occur (*dii*) depending on the symptomatic rate (*syr*; 0.3 and 0.2). *AP* indicates the number of individuals infected a day, "*CAP*" indicates the total number of infected individuals for each epidemic, and *CAP* indicates the cumulative number of infected individuals. 'End' indicates the day when the number of infected individuals *P*(*n*) becomes 0. If reinfection occurs, when the value of *syr* is 0.3 or 0.2, 5 epidemics occur. As the symptomatic rate decreases, the total number of infected individuals (*CAP*) increases. When *syr* is 0.3, if *dii* is 78, 2 epidemics occur, and if *dii* is 77, 5 epidemics occur. When *syr* is 0.2, if *dii* is between 75 and 78, 2 epidemics occur, and if *dii* is 74, 5 epidemics occur.

			Epidemic 1		Epidemic 2		Epidemic 3		Epidemic 4		Epidemic 5	
syr	*dii*		Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	End
	77	Date	88	167-186	269	346-376	491	580-593	739	851-862	977-985	2,554
		AP	19,879	0	15,966	0	6,264	8	1,391	133	237	0
		"*CAP*"	546,638		447,987		260,315		124,931		76,943	
		CAP	546,638		994,625		1,254,940		1,379,871		1,456,814	
			Peak	Trough	Peak	End						
0.3	78	Date	88	166-188	271	370						
		AP	19,879	0	15,969	0						
		"*CAP*"	546,635		447,981							
		CAP	546,635		994,616							
			Peak	End								
	79	Date	88	188								
		AP	19,879	0								
		CAP	546,626									
			Epidemic 1		Epidemic 2		Epidemic 3		Epidemic 4		Epidemic 5	
syr	*dii*		Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	End
	74	Date	85	164-175	257	331-359	470	556-569	713	826-831	939-954	2,410
		AP	21,286	0	17,102	0	6,694	8	1,420	139	225	0
		"*CAP*"	567,193		464,448		268,142		125,239		71,891	
		CAP	567,193		1,031,641		1,299,783		1,425,022		1,496,913	
			Peak	Trough	Peak	End						
	75	Date	85	163-178	259	357						
		AP	21,286	0	17,108	0						
		"*CAP*"	567,191		464,442							
		CAP	567,191		1,031,633							
0.2	⇕		Peak	Trough	Peak	End						
	78	Date	85	161-186	265	359						
		AP	21,286	0	17,120	0						
		"*CAP*"	567,186		464,439							
		CAP	567,186		1,031,625							
			Peak	End								
	79	Date	85	182								
		AP	21,286	0								
		CAP	567,176									

When the symptomatic rate (*syr*) is 0.2, if the duration of infection-induced immunity (*dii*) is 79 days, reinfection never occurs. The infection ends on day 182, with a total number of infected individuals (*CAP*) of 567,286 (Table 2-C). If *dii* is between 78 and 75 days, one reinfection occurs, resulting in 2 outbreaks of the epidemic, with an infection duration of approximately 360 days and a *CAP* of approximately 1,031,630. However, if *dii* is 74 days, multiple reinfections occur, resulting in 5 outbreaks of the epidemic, with an infection duration of 2,410 days and a *CAP* of 1,496,913. Thus, in this case, the duration of infection-induced immunity necessary for one reinfection to occur is between 75 and 78 days, and the duration of infection-induced immunity necessary for multiple reinfections to occur is 74 days. Similarly, when *syr* is 0.3, there are two possible values of *dii* for the occurrence of reinfection: 77 days for one reinfection and 78 days for multiple reinfections (Table 2-C).

Table 2-D: Duration of infection-induced immunity required for reinfection to occur (*dii*) depending on the symptomatic rate (*syr*; 0.1 and 0.0). *AP* indicates the number of individuals infected a day, "*CAP*" indicates the total number of infected individuals for each epidemic, and *CAP* indicates the cumulative number of infected individuals. 'End' indicates the day when the number of infected individuals *P*(*n*) becomes 0. If reinfection occurs, when *syr* is 0.1, if *dii* is between 73 and 77, 2 epidemics occur, and if *dii* is 72, 5 epidemics occur. When *syr* is 0.0, if *dii* is between 71 and 76, 2 epidemics occur, and if *dii* is 70, 5 epidemics occur.

			Epidemic 1		Epidemic 2		Epidemic 3		Epidemic 4		Epidemic 5	
syr	*dii*		Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	End
		Date	82	150-178	248	320-347	455	539-551	696	808-833	915-932	2,308
	72	*AP*	22,538	0	18,151	0	7,113	7	1,451	140	215	0
		"*CAP*"	584,172		478,628		275,256		125,649		67,292	
		CAP		584,172		1,062,800		1,338,056		1,463,705		1,530,997
			Peak	Trough	Peak	End						
		Date	82	161-170	249	345						
	73	*AP*	22,538	0	18,150	0						
		"*CAP*"	584,161		478,631							
		CAP		584,161		1,062,792						
0.1	⇕		Peak	Trough	Peak	End						
		Date	82	157-181	257	348						
	77	*AP*	22,538	0	18,141	0						
		"*CAP*"	584,153		478,632							
		CAP		584,153		1,062,785						
			Peak	End								
		Date	82	180								
	78	*AP*	22,538	0								
		CAP	584,147									
			Epidemic 1		Epidemic 2		Epidemic 3		Epidemic 4		Epidemic 5	
syr	*dii*		Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	End
		Date	79	148-171	238	309-336	441	532-534	679-680	789-795	896-905	2,217
	70	*AP*	23,655	1	19,069	0	7,520	6	1,482	141	207	0
		"*CAP*"	598,321		491,026		281,878		125,916		63,309	
		CAP		598,321		1,089,347		1,371,225		1,497,141		1,560,450
			Peak	Trough	Peak	End						
		Date	79	148-173	240	334						
	71	*AP*	23,655	1	19,068	0						
		"*CAP*"	598,317		491,023							
		CAP		598,317		1,089,340						
0.0	⇕		Peak	Trough	Peak	End						
		Date	79	155-176	250	339						
	76	*AP*	23,655	0	19,062	0						
		"*CAP*"	598,299		505,180							
		CAP		584,153		1,089,333						
			Peak	End								
		Date	79	179								
	77	*AP*	23,655	0								
		CAP	598,294									

When the symptomatic rate (*syr*) is 0.1, if the duration of infection-induced immunity (*dii*) is 78 days, reinfection never occurs. The infection ends on day 180, with a total number of infected individuals (*CAP*) of 584,147 (Table 2-D). If *dii* is between 77 and 73 days, one reinfection occurs, resulting in 2 outbreaks of the epidemic, with an infection duration of approximately 350 and a *CAP* of approximately 1,062,800. However, if *dii* is 72 days, multiple reinfections occur, resulting in 5 outbreaks of the epidemic, with an infection duration of 2,308 days and a *CAP* of 1,530,997. Therefore, in this case, the duration of infection-induced immunity necessary for one reinfection to occur is between 73 and 77 days, and the duration of infection-induced immunity necessary for multiple reinfections to occur is 72 days.

When the symptomatic rate (*syr*) is 0.0, if the duration of infection-induced immunity (*dii*) is 77 days, reinfection never occurs. The infection ends on day 179, with a total number of infected individuals (*CAP*) of 598,294 (Table 2-D). If *dii* is between 76 and 71 days, one reinfection occurs, resulting in 2 outbreaks of the epidemic, with an infection duration of approximately 340 and a *CAP* of approximately 1,089,340. However, if *dii* is 70 days, multiple reinfections occur, resulting in 5 outbreaks of epidemics (a normal infection and 4 reinfections), with an infection duration of 2,217 days and a *CAP* of 1,560,450. Therefore, in this case, the duration of infection-induced immunity necessary for one infection to occur is between 71 and 76 days, and the duration of infection-induced immunity necessary for multiple reinfections to occur is 70 days.

The relationships between the duration of infection-induced immunity (*dii*) and the symptomatic rate (*syr*) for the cases of 'No reinfection where one outbreak of the epidemic occurs', for the cases of 'One reinfection where 2 outbreaks of the epidemic occur', and for the cases of 'Multiple reinfections where 5 or 7 outbreaks of the epidemic occur' are shown in Table 3.

Table 3: Duration of infection-induced immunity required for reinfection to occur (*dii*) depending on the symptomatic rate (*syr*). The 'End' indicates the day when the number of infected individuals *P*(*n*) becomes 0, indicating the end of infection. '*CAP*' is the cumulative number of infected individuals up to the 'End', indicating the total number of infected individuals. 'No reinfection' indicates the occurrence of only the first-time infection (normal infection), 'One reinfection' indicates occurrences of normal infection and one reinfection, and 'Multiple reinfections' indicates occurrences of normal infection and multiple reinfections. 'Times' indicates the number of epidemics, including a normal infection. For example, the number of occurrences of epidemics is seven, that is, one normal infection + six reinfections, for the case where the symptomatic rate is 1.0 and *dii* is 155 days.

	No reinfection			One-time reinfection						Multiple reinfections			
syr	*dii*	End	*CAP*	*dii*	End	*CAP*	*dii*	End	*CAP*	*dii*	Times	End	*CAP*
1.0	156	364	141,874							155	7	8,254	681,562
0.9	116	278	251,408							115	6	5,213	917,325
0.8	101	242	336,143							100	6	4,110	1,076,306
0.7	93	223	400,964							92	5	3,545	1,192,480
0.6	88	210	451,024							87	5	3,190	1,281,421
0.5	84	201	490,255							83	5	2,920	1,351,972
0.4	82	193	521,458	81	386	950,028				80	5	2,772	1,409,266
0.3	79	188	546,626	78	370	994,616				77	5	2,554	1,456,814
0.2	79	182	567,176	78	359	1,031,625	75	357	1,031,633	74	5	2,410	1,496,913
0.1	78	180	584,147	77	348	1,062,785	73	345	1,062,792	72	5	2,308	1,530,997
0.0	77	179	598,294	76	339	1,089,333	71	334	1,089,340	70	5	2,217	1,560,450

If reinfection does not occur due to the long duration of infection-induced immunity, i.e., if an epidemic occurs only once, the infection duration ('End' in Table 3) will be significantly shortened according to a decrease in the symptomatic rate (*syr*), but the number of individuals infected a day at peak and the total number of infected individuals (*CAP*) will increase substantially (Tables 2 and 3). For example, if the symptom rate is 1.0, the number of individuals infected a day at peak becomes 2,136, the total number of infected individuals becomes 141,874, and the infection duration becomes 364 days (Figure 2-A); however, if the symptom rate is 0.0, the number of individuals infected a day at peak becomes 23,655, the total number of infected individuals becomes 598,294, and the infection duration becomes 179 days (Figure 2-D). Even if reinfection does not occur, a marked increase in the number of infected individuals or the total number of infected individuals according to lowering in symptomatic rate, could cause serious damage.

The duration of infection-induced immunity required for reinfection to occur decreases with decreasing symptomatic rates. For example, when the symptomatic rate is 1.0, the duration of infection-induced immunity required for reinfection to occur is 155 days, but when the symptomatic rate is 0.0, the duration of infection-induced immunity required for one reinfection to is anywhere between 76 and 71 days, and the duration of infection-induced immunity required for multiple reinfections to occur is 70 days (Table 3 and Figures 16 and 17).

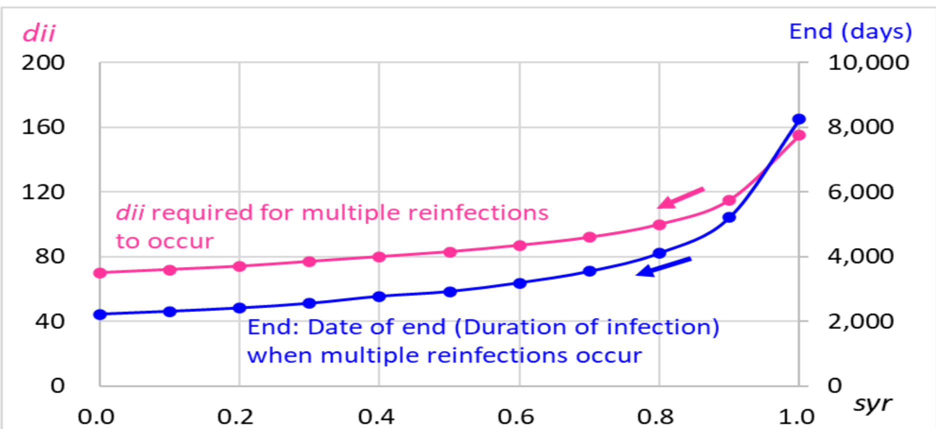

Figure 16: Relationships between the symptomatic rate (*syr*) and the end date of infection (duration of infection; End, days) and between the symptomatic rate and the duration of infection-induced immunity required for multiple reinfections to occur (*dii*). The population of the community is 1,000,000, *pfc* (the potential (biological) infectious capacity of coronavirus) is 1.0, *v* (vaccination rate) is 0 (indicating that vaccination was not performed).

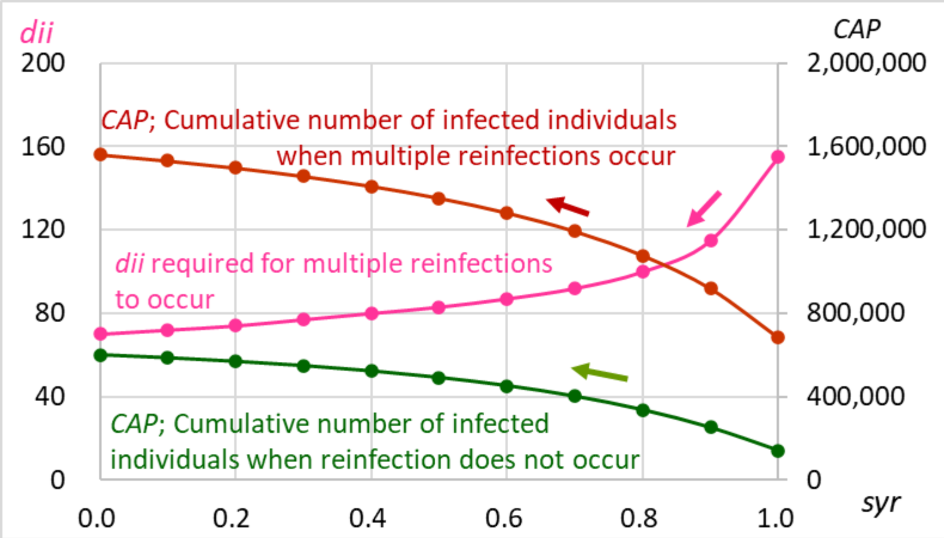

Figure 17: Relationship between the symptomatic rate (*syr*) and duration of infection-induced immunity required for multiple reinfections to occur (*dii*) and the relationship between the symptomatic rate (*syr*) and the cumulative number of infected individuals (*CAP*).

In a model calculation with a population of 1,000,000 and a potential (biological) infectious capacity of coronavirus (*pfc*) of 1.0, if reinfection occurs, one reinfection (two epidemics) will occur; otherwise, four or more reinfections (five or more epidemics) will occur (Table 2A~2D). It is important to note that when reinfection occurs multiple times, the periods when the number of individuals infected a day (*AP*(*n*)) shows 0 are observed between adjacent epidemics. In other words, even if the number of individuals infected a day decreases to 0 and remains that way for several tens of days, this does not necessarily mean that the infection has ended. The infection is considered to have ended completely when the number of infected individuals (*P*(*n*)) becomes 0 because no more infections will occur from that day onward.

It is noted that if multiple reinfections occur, herd immunity is achieved more quickly as the symptomatic rate decreases, and the duration of infection would be significantly shorter according to lowering in symptomatic rate. For example, if the symptomatic rate is 1.0, the epidemic occurs seven times, and the duration of infection is 8,254 days (approximately 23 years); however, if the symptomatic rate is 0.0, the epidemic occurs 5 times, and the duration of infection is 2,217 (approximately 6 years) (Table 3 and Figure 16). If the duration of infection continues for a long time, preventive attitudes and protective measures are likely to break down, and mutated strains of the virus are more likely to emerge.

It must be noted that when the symptomatic rate is 1.0, the total number of infected individuals including reinfected individuals will be 681,562, but when the symptomatic rate is 0.0, the total number of infected individuals including reinfected individuals will be significantly large, 1,560,450 (Table 3 and Figure 17). The increase in the number of infected individuals themselves and the increase in the rate of increase in the number of individuals infected a day will surely overwhelm the medical system and hospital capacity. This must result in enormous damage, including an increase in the number of seriously ill individuals and deaths.

5.4. Relationship between the duration of infection-induced immunity required for reinfection to occur and the potential (biological) infectious capacity of coronavirus

The potential (biological) infectious capacity of coronavirus (*pfc*) indicates an approximate value indicating the number of susceptible individuals infected by an infected individual during the latent period (*lp*(*n*)). In the calculation, the '*pfc*(*n*)/*lp*(*n*)', which means the number of susceptible individuals infected by an infected individual a day, that is, the 'infection rate (persons/person/day)', is used.

As noted previously in section **4.2. 'Change in the number of individuals getting back to susceptible individuals from recovered individuals'**, when the potential (biological) infectious capacity of coronavirus (*pfc*) is 1.0 and the symptomatic rate (*syr*) is 1.0, if the duration of infection-induced immunity (*dii*) is set to 200 days, reinfection does not occur. The number of individuals infected a day (*AP*) increases to a peak of 2,135 on days 191 and 192 and then decreases to 0 on day 326, with a cumulative number of infected individuals of 141,786. The infection ends on day 343, with a total number of infected individuals of 141,790 (Table 4). However, even if the duration of infection-induced immunity (*dii*) is 200 days, if *pfc* is set to 0.9, seven epidemics (one normal infection and six reinfections) occur. The infection ends on day 14,003 (approximately 38 years), and the total number of infected individuals becomes 431,510 (Table 4).

Table 4: The number of individuals infected a day (*AP*), the total number of infected individuals for each epidemic ("*CAP*"), and the cumulative number of infected individuals (*CAP*) for the cases where *pfc* is 0.9 and 1.0. 'End' indicates the day when the number of infected individuals *P*(*n*) becomes 0. When *dii* is 200 days, reinfection occurs. The population of the community is 00,000, the symptomatic rate (*syr*) is 1.0, the vaccination rate (*v*) is 0 (indicating that vaccination was not performed) and the duration of infection-induced immunity (*dii*) is 200 days.

	syr	1	Epidemic 1		Epidemic 2		Epidemic 3		Epidemic 4		Epidemic 5		Epidemic 6		Epidemic 7	
pfc	*dii*		Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	End
		Date	373-380	589-609	838-842	1,049-1,076	1,295-1,306	1,522-1,531	1,762-1,771	1,996-2,002	2,238-2,248	2,475-2,500	2,717-2,752	2,994-3,016	3,212-3,274	14,003
0.9	200	*AP*	327	22	284	29	242	34	194	41	144	49	100	53	69	0
		"*CAP*"	57,314		55,315		51,671		47,604		43,338		38,140		(3,528; 31,098)	138,128
		CAP		57,314		112,629		164,300		211,904		255,242		293,382	(324,480)	431,510
		Date	191-192	343												
1.0	200	*AP*	2,135	0												
		CAP	141,790													

When *pfc* is 0.9, if the duration of infection-induced immunity (*dii*) is 396 days, reinfection does not occur. The infection ends on day 783 (approximately 2 years), with a total number of infected individuals of 54,537 (Table 5). However, when *dii* is 395 days, reinfections occur. Therefore, when *pfc* is 0.9, the duration of infection-induced immunity (*dii*) required for reinfection to occur is 395 days. When *dii* is 395 days, the duration of infection becomes significantly long; that is, 11 epidemics (one normal infection and ten reinfections) occur, and the infection ends on day 24,753 (approximately 68 years) (Table 5).

Table 5: The number of individuals infected a day (*AP*), the total number of infected individuals for each epidemic ("*CAP*"), and the cumulative number of infected individuals (*CAP*) for the cases where *pfc* is 0.9, 1.0 and 1.1. 'End' indicates the day when the number of infected individuals*P*(*n*) becomes 0. The symptomatic rate (*syr*) is 1.0.

	syr=	1	Epidemic 1		Epidemic 2		Epidemic 3		Epidemic 4		Epidemic 5		Epidemic 6	
pfc	*dii*		Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough
		Date	374-378	697-880	1,234-1,240	1,559-1,745	2,111	2,450-2,605	2,990-3,001	3,386-3,438	3,882-3,891	4,233-4,382	4,774-4,790	5,155-5,257
	395	*AP*	323	0	315	0	285	0	238	0	187	1	138	2
		"*CAP*"	54,566		53,450		50,357		45,764		40,462		34,850	
		"*CAP*"		54,566		108,016		158,373		204,137		244,599		279,449
			Epidemic 7		Epidemic 8		Epidemic 9		Epidemic 10		Epidemic 11			
0.9			Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	End		
		Date	5,678-5,686	6,085-6,141	6,588-6,596	6,975-7,101	7,485-7,556	7,966-8,031	8,471-8,496	8,922-9,202	9,350-9,602	24,753		
	395	*AP*	97	4	64	8	39	11	24	13	15	0		
		"*CAP*"	29,577		25,314		20,931		19,822		(10,513; 17,993)	53,603		
		"*CAP*"		309,026		334,340		355,271		375,093	(391,741)	428,696		
			Peak	End										
		Date	374-378	783										
	396	*AP*	323	0										
		CAP	54,537											
			Epidemic 1		Epidemic 2		Epidemic 3		Epidemic 4		Epidemic 5		Epidemic 6	
pfc	*dii*		Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough
		Date	191	332-395	578	721-784	981-982	1,128-1,188	1,390-1,392	1,555-1,583	1,795-1,800	1,967-1,997	2,201-2,208	2,396-2,422
	155	*AP*	2,136	0	1,999	0	1,474	1	905	5	491	21	240	46
		"*CAP*"	141,890		133,811		112,016		86,333		64,358		48,110	
		CAP		141,890		275,701		387,717		474,050		538,408		586,518
			Epidemic 7											
1.0			Peak	End										
		Date	2,612-2,641	8,254										
	155	*AP*	107	0										
		"*CAP*"	(3,079; 46,100)	95,044										
		CAP	(632,611)	681,562										
			Peak	End										
		Date	191-192	364										
	156	*AP*	2,135	0										
		CAP	141,874											
			Epidemic 1		Epidemic 2		Epidemic 3		Epidemic 4		Epidemic 5		Epidemic 6	
pfc	*dii*		Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	Trough	Peak	End
		Date	136	225-261	390	484-516	667	768-788	942	1,054-1,063	1,208-1,211	1,344-1,353	1,476-1,491	4,445
	90	*AP*	5,536	0	4,902	0	2,845	4	1,263	40	488	109	173	0
		"*CAP*"	234,135		210,399		152,742		100,554		67,950		(1,741; 50,309)	89,769
1.1		*CAP*		234,135		444,534		597,276		697,830		765,780	(816,089)	855,549
			Peak	End										
		Date	136	243										
	91	*AP*	5,536	0										
		CAP	234,108											

The number of individuals infected a day (*AP*) increases to its first peak of 323 from day 374 to day 378 during the first epidemic period (①), and decreases to 0 during from day 697 to day 880, increases to the second peak of 315 from day 1,234 to day 1,240 during the second epidemic (②), decreases to 0 during from day 1,559 to day 1,745, increase to the third peak of 285 on day2,111 during the third epidemic (③), decreases to 0 during from day 2,450 to day 2,605, increases to the fourth peak of 238 from day 2,990 to day 3,001 during the fourth epidemic (④), decreases to 0 during from day 3,386 today 3,438, increases to the fifth peak of 187 from day 3,882 to day 3,891 during the fifth epidemic (⑤), decreases to 1 during from day 4,233 to day 4,382, increases to the sixth peak of 138 from day 4,774 to day 4,790 during the sixth epidemic (⑥), deceases to 2 during from day 5,155 to day 5,257, increases to the seventh peak of 97 from day 5,678 to day 5,686 during the seventh epidemic (⑦), and decreases to 4 during from day 6,085 to day 6,141, increases to the eighth peak of 64 from day 6,588 to day 6,396 during the eighth epidemic (⑧), and decreases to 8 during from day 6,975 to day 7,101, increases to the ninth peak of 39 from day 7,485 to day 7,556 during the ninth epidemic (⑨), and decreases to 11 during from day 7,966 to day 8,031, increases to the tenth peak of 24 from day 8,471 to day 8,496 during the tenth epidemic (⑩), and decreases to 13 during from day 8,922 to day 9,202, increases to the eleventh peak of 15 from day 9,350 to day 9,602 during the eleventh epidemic (⑪), and decreases to 0 on day 21,230. Day 21,230, when the *AP* becomes 0, does not indicate a 'true end day of infection,' just as has been seen in past 'interruptions' in epidemics, such as the first epidemic, which showed 0 of *AP* but 4 of *P* on its last day. On day 21,230, the *AP* is 0, but *P* is 4, and there is a possibility of an infection occurring due to some trigger. The number of individuals infected a day (*AP*(*n*)) at the peak declines as the epidemic progresses.

The number of infected individuals (*P*) increases to its first peak of 2,258 on day 378 and day 379 during the first epidemic period (①), and decreases to 1 during from day 757 to day 824, increases to the second peak of 2,205 on day 1,24 and 1,241 during the second epidemic (②), decreases to 1 during from day 1,619 to day 1,688, increase to the third peak of 1,991 on day2,114 during the third epidemic (③), decreases to 2 during from day 2,476 to day 2,583, increases to the fourth peak of 1,668 from day 2,998 to day 2,999 during the fourth epidemic (④), decreases to 3 during from day 3,389 today 3,441, increases to the fifth peak of 1,308 from day 3,888 to day 3,891 during the fifth epidemic (⑤), decreases to 7 during from day 4,278 to day 4,340, increases to the sixth peak of 967 from day 4,782 to day 4,788 during the sixth epidemic (⑥), deceases to 15 during from day 5,186 to day 5,231, increases to the seventh peak of 676 from day 5,682 to day 5,689 during the seventh epidemic (⑦), and decreases to 31 during from day 6,088 to day 6,144, increases to the eighth peak of 445 from day 6,591 to day 6,598 during the eighth epidemic (⑧), and decreases to 54 during from day 7,029 to day 7,051, increases to the ninth peak of 275 from day 7,515 to day 7,532 during the ninth epidemic (⑨), and decreases to 80 during from day 7,969 to day 8,034, increases to the tenth peak of 165 from day 8,474 to day 8,499 during the tenth epidemic (⑩), and decreases to 90 during from day 9,001 to day 9,100, increases to the eleventh peak of 104 from day 9,423 to day 9,535 during the eleventh epidemic (⑪), and decreases to 0 on day 24,753. Day 24,753, when *P* reaches 0, marks the 'true end of infection' because no infections will occur after this date. The number of infected individuals (*P*(n)) at the peak declines with the epidemic.

As shown above, when *dii* is 395 days, the duration of infection (24,753 days (approximately 68 years)) becomes significantly longer than when *dii* is 396 (783 days (approximately 2 years)). The total number of infected individuals (428,696) is much greater than that when *dii* is 396 (54,537).

As examined previously in section **5.3. Relationship between the duration of infection-induced immunity required for reinfection to occur and the symptomatic rate**, when *pfc* is 1.0, if the duration of infection-induced immunity (*dii*) is 156 days, reinfection does not occur. The infection ends on day 364. The total number of infected individuals is 141,874 (Table 2-A and Table 5). However, if *dii* is 155 days, reinfection occurs. Seven outbreaks of the epidemic occur, the duration of infection becomes 8,254 days (approximately 23 years), and the total number of infected individuals becomes 681,562. Both the duration of infection and the total number of infected individuals substantially increase (Table 2-A and Table 5).

On the other hand, when *pfc* is 1.1, if the duration of infection-induced immunity (*dii*) is 91 days, reinfection does not occur. The infection ends on day 243, with a total number of infected individuals of 234,108 (Table 5). However, when *dii* is 90 days, reinfections occur. Therefore, when *pfc* is 1.1, the duration of infection-induced immunity (*dii*) required for reinfection to occur is 90 days. When *dii* is 90 days, 6 epidemics (one normal infection and five reinfections) occur, and the duration of infection is 4,445 days (approximately 12 years), which is significantly longer than when reinfection does not occur. The total number of infected individuals is 855,549, which is much greater than when reinfection does not occur (Table 5).

As examined above, the duration of infection-induced immunity (*dii*) required for reinfection to occur decreases markedly with increasing *pfc* (potential (biological) infectious capacity of coronavirus). For the same *pfc*, if reinfection occurs, the duration of infection will be significantly longer than when reinfection does not occur, and the total number of infected individuals will also be substantially greater.

6. Summary of the results

Individuals who have been infected with COVID-19 and have recovered will return to the community as individuals who have infection-induced immunity after the recovery period ends. However, infection-induced immunity has a duration that indicates the 'validity period of effectiveness of immunity against SARS-CoV-2 infection and/or COVID-19 disease'. In other words, the quantity of antibodies acquired through infection gradually decreases and eventually declines below a certain threshold of immunity level, below which recovered individuals could become infected again.

On the other hand, even if the effectiveness of infection-induced immunity falls below a certain threshold, it does not necessarily mean that reinfection will occur. In other words, even if infection-induced immunity has a duration of effectiveness, if the duration is long, reinfection might not occur. Therefore, this study examined how long duration of immunity is necessary for reinfection not to occur and how long duration of immunity is required for reinfection to occur. Specifically, this study investigated how the duration of infection-induced immunity required for reinfection to occur is controlled by the symptomatic rate and the potential (biological) infectious capacity of the coronavirus.

Furthermore, infections also occur among susceptible individuals who get back from individuals who have recovered from 'reinfection'. Some individuals may be infected multiple times, not only first-time infection (initial infection, normal infection) and second-time infection (reinfection in the narrow sense) but also third-time infection, fourth-time infection and more times. Therefore, the term 'reinfection' was used in a broad sense to refer to any infection that occurs due to loss of infection-induced immune effectiveness, regardless of the interval between infections, indicating all infections after first-time infection; second-time infection, third-time infection, fourth-time infection, and so on. Thus, this study also investigated how the number of infected individuals changes when reinfections occur, how many outbreaks of epidemics occur, and how long the duration of infection is prolonged.

In the simulation, the recovered individuals whose infection-induced immunity decreased to below a certain threshold essentially got back to the 'susceptible individuals', and from both physical and statistical perspectives, they became infected at the same rate as the 'original' susceptible individuals. The simulations were performed in a community with a population of 1,000,000, with an initial number of infected individuals (P(l)) of 1, a latent period (lp(n)) of 5 days, and a recovery period (rp(n)) of 14 days, as well as a varying symptomatic rate (syr) and potential (biological) infectious capacity of coronavirus (pfc). The results of the simulation are as follows:

6.1. The duration of infection-induced immunity required for reinfection to occur differs according to the symptomatic rate (syr). For example, when syr is 1.0, if the duration of infection-induced immunity (dii) is 156 days, reinfection will never occur. However, if dii is 155 days, reinfection occurs. Thus, the duration of infection-induced immunity required for reinfection to occur can be said to be 155 days.

Specifically, if the duration of infection-induced immunity (dii) is 156 days, the number of individuals infected a day (AP) increases to 2,136 at the peak on days 191 and 193 and then decreases to 0. The infection ends on day 364, the day when the number of infected individuals (P) becomes 0. The total number of infected individuals is 141,874. On the other hand, if dii is 155 days, reinfection occurs, causing 7 epidemic outbreaks, including one normal infection epidemic (first epidemic) and six reinfection epidemics. The first epidemic shows a pattern almost identical to that of the epidemic, with a dii of 156 days when reinfection does not occur. The infection ultimately ends on day 8,254 (approximately 23 years), and the total number of infected individuals (CAP) reaches 681,562. Thus, when reinfection occurs, the duration of infection becomes extremely long, and the total number of infected individuals also greatly increases.

Now, note the following: Although each value of dii has been expressed as a specific number of days in units of one day, such as 155 days or 156 days, these values are the raw results of calculations. It seems that the value of dii at the boundary of whether reinfection occurs should be recognized as some day between 150 days and 160 days.

6.2. The duration of infection-induced immunity required for reinfection to occur differs by the symptomatic rate, and the duration of infection-induced immunity required for reinfection 'not' to occur also differs by the symptomatic rate. When the symptomatic rate (syr) is 1.0, the duration of infection-induced immunity (dii) required for reinfection 'not to occur' is 156 days. If the dii is 155 days, 7 epidemics will surely occur, including one normal epidemic and 6 reinfection epidemics. The total number of infected individuals when reinfection does not occur is 141,874, with a duration of infection of 364 days, and that when reinfection occurs is 681,562, with a duration of 8,256 days.

When syr is 0.9, the dii required for reinfection not to occur is 116 days. If dii is 115 days, 6 epidemics will occur, including one normal epidemic and 5 reinfection epidemics. The total number of infected individuals when reinfection does not occur is 251,408, with a duration of infection of 278 days, and that when reinfection occurs is 919,325, with a duration of 5,213 days.

When syr is 0.8, the dii required for reinfection not to occur is 101 days. If dii is 100 days, 6 epidemics will occur, including one normal epidemic and 5 reinfection epidemics. The total number of infected individuals when reinfection does not occur is 386,143, with a duration of infection of 242 days, and that when reinfection occurs is 1,076,306, which is greater than the population of 1,000,000, with a duration of 4,110 days.

When syr is 0.7, the dii required for reinfection not to occur is 93 days. If dii is 92 days, 5 epidemics will occur, including one normal epidemic and 4 reinfection epidemics. The total number of infected individuals when reinfection does not occur is 400,964 with a duration of infection of 223 days, and that when reinfection occurs is 1,192,480 with a duration of 3,545 days.

When syr is 0.6, the dii required for reinfection not to occur is 88 days. If dii is 87 days, 5 epidemics will occur, including one normal epidemic and 4 reinfection epidemics. The total number of infected individuals when reinfection does not occur is 451,024 with a duration of infection of 210 days, and that when reinfection occurs is 1,281,421 with a duration of 3,190 days.

When syr is 0.5, the dii required for reinfection not to occur is 84 days. If dii is 83 days, 5 epidemics will occur, including one normal epidemic and 4 reinfection epidemics. The total number of infected individuals when reinfection does not occur is 490,255 with a duration of infection of 201 days, and that when reinfection occurs is 1,351,972 with a duration of 2,920 days.

6.3. When *syr* is 0.4, the *dii* required for reinfection not to occur is 82 days. If *dii* is 81 days, 2 epidemics occur, that is, one normal epidemic and one reinfection epidemic. However, if *dii* is 80 days, 5 epidemics occur, including one normal epidemic and 4 reinfection epidemics. The total number of infected individuals when reinfection does not occur is 521,458, with a duration of 193 days. The total number of infected individuals when 2 epidemics occur is 950,028, with a duration of 386 days, and that when 5 epidemics occur is 1,409,266 with a duration of 2,772 days.

When *syr* is 0.3, the *dii* required for reinfection not to occur is 79 days. If *dii* is 78 days, 2 epidemics occur, that is, one normal epidemic and one reinfection epidemic. However, if *dii* is 77 days, 5 epidemics occur, including one normal epidemic and 4 reinfection epidemics. The total number of infected individuals when reinfection does not occur is 546,626, with a duration of 188 days. The total number of infected individuals when 2 epidemics occur is 994,616, with a duration of 370 days, and when 5 epidemics occur is 1,456,913, with a duration of 2,554 days.

When *syr* is 0.2, the *dii* required for reinfection not to occur is 79 days. If *dii* is between 78 and 75 days, 2 epidemics occur, that is, one normal epidemic and one reinfection epidemic. If *dii* is 74 days, 5 epidemics occur, including one normal epidemic and 4 reinfection epidemics. The total number of infected individuals when reinfection does not occur is 567,176, with a duration of 182 days. The total number of infected individuals when 2 epidemics occur is between 1,031,625 with a duration of 354 days when *dii* is 78 days, and 1,031,633, with a duration of 357 days when *dii* is 75 days. The total number of infected individuals when 5 epidemics occur is 1,496,913 with a duration of 2,410 days.

When *syr* is 0.1, the *dii* required for reinfection not to occur is 78 days. If *dii* is between 77 and 73 days, 2 epidemics occur, that is, one normal epidemic and one reinfection epidemic. If *dii* is 72 days, 5 epidemics occur, including one normal epidemic and 4 reinfection epidemics. The total number of infected individuals when reinfection does not occur is 584,147 with a duration of 180 days. The total number of infected individuals when 2 epidemics occur is between 1,062,785, with a duration of 348 days when *dii* is 77 days, and 1,062,792, with a duration of 345 days when *dii* is 73 days. The total number of infected individuals when 5 epidemics occur is 1,530,997, with a duration of 2,308 days.

When *syr* is 0.0, the *dii* required for reinfection not to occur is 77 days. If *dii* is between 76 and 71 days, 2 epidemics occur, that is, one normal epidemic and one reinfection epidemic. If *dii* is 70 days, 5 epidemics occur, including one normal epidemic and 4 reinfection epidemics. The total number of infected individuals when reinfection does not occur is 598,294 with a duration of 179 days. The total number of infected individuals when 2 epidemics occur is between 1,089,333 with a duration of 339 days when *dii* is 76 days, and 1,089,340, with a duration of 334 days when *dii* is 71 days. The total number of infected individuals when 5 epidemics occur is 1,560,450 with a duration of 2,217 days.

6.4. When the potential (biological) infectious capacity of coronavirus (*pfc*) is 1.0 and the symptomatic rate is 1.0, if the duration of infection-induced immunity (*dii*) is set to 200 days, reinfection does not occur. The total number of infected individuals is 141,790 with a duration of infection of 343 days. However, even if *dii* is 200 days, if the *pfc* is 0.9, seven epidemics (one normal infection and six reinfections) occur. The total number of infected individuals becomes 431,510, with a duration of infection of 14,003 days.

When the *pfc* is 0.9, the *dii* required for reinfection not to occur is 396 days. The infection ends on day 783 (approximately 2 years), with a total number of infected individuals of 54,537. However, if *dii* is 395 days, reinfections occur. If *dii* is 395 days, eleven epidemics (one normal infection and ten reinfection epidemics) occur. The total number of infected individuals becomes 428,696, with a duration of 24,753 days (approximately 68 years).

When the *pfc* is 1.0, as noted previously, if the duration of infection-induced immunity (*dii*) is 156 days, reinfection does not occur. The infection ends on day 364. The total number of infected individuals is 141,874. However, if *dii* is 155 days, reinfection occurs. Seven epidemics (one normal infection and six reinfections) occur, the duration of infection reaches 8,254 days (approximately 23 years), and the total number of infected individuals becomes 681,562.

On the other hand, when the *pfc* is 1.1, if the duration of infection-induced immunity (*dii*) is 91 days, reinfection does not occur. The infection ends on day 243, with a total number of infected individuals of 234,108. However, when *dii* is 90 days, reinfections occur. Therefore, when the *pfc* is 1.1, the duration of infection-induced immunity (*dii*) required for reinfection to occur is 90 days. When *dii* is 90 days, 6 epidemics (one normal infection and five reinfections) occur, and the duration of infection is 4,445 days (approximately 12 years), which is significantly longer than when reinfection does not occur. The total number of infected individuals is 855,549, which is much greater than when reinfection does not occur.

As examined above, the *dii* required for reinfection decreases markedly with increasing *pfc*. For the same *pfc*, if reinfection occurs, the duration of infection will be significantly longer than when reinfection does not occur, and the total number of infected individuals will also be substantially greater.

6.5. As shown above, the duration of infection-induced immunity required for reinfection to occur decreases with decreasing symptomatic rate and/or increasing potential (biological) infectious capacity of coronavirus. For example, when the potential (biological) infectious capacity of coronavirus is 1.0 and the symptomatic rate is 1.0, the duration of infection-induced immunity required for reinfection to occur is 155 days. However, when the symptomatic rate is 0.0, the duration of infection-induced immunity required for one reinfection to occur can be between 76 and 71 days, and the duration of infection-induced immunity required for multiple reinfections to occur is 70 days. Furthermore, when the potential (biological) infectious capacity of coronavirus is 1.1, the duration of infection-induced immunity required for reinfection to occur is 91 days. On the other hand, when the potential (biological) infectious capacity of coronavirus is 0.9, even if the duration of infection-induced immunity is 395 days, longer than one year, reinfection occurs.

The occurrence of reinfection is controlled by the duration of infection-induced immunity, and when reinfection occurs, the duration of infection and the total number of infected individuals increase significantly. A small change in factors such as the symptomatic rate and the potential (biological) infectious capacity of coronavirus can result in a large change in the duration of infection-induced immunity required for reinfection to occur.

6.6. If reinfection occurs, multiple epidemics will occur. In most cases, five or more epidemics, which include one 'first epidemic (normal epidemic) consisting only of the first-time infected individuals, occur. As a result, when reinfection occurs, several epidemics occur, and the duration of infection becomes extremely long. For example, when multiple reinfections occur, if the symptomatic rate is 1.0, seven epidemics occur, and the duration of infection is 8,254 days (approximately 23 years), which is significantly longer than the 364 days when reinfection does not occur. If the symptomatic rate is 0.0, five epidemics occur, and the duration of infection is 2,217 (approximately 6 years), which is significantly longer than the 179 days when reinfection does not occur. Furthermore, when *pfc* is 0.9, eleven epidemics occur. The duration of infection is 24,753 days (approximately 68 years), which is significantly longer than the 787 days when reinfection does not occur.

6.7. When reinfection occurs, as the number of epidemic outbreaks progresses, the number of individuals infected a day at the peak of each epidemic decreases. On the other hand, regarding the 'troughs' that indicate periods of low numbers of individuals infected a day between adjacent epidemics, there are some troughs where the number of individuals infected a day is 0 for several tens of days. Therefore, even if the number of individuals infected a day ($AP(n)$) decreases to 0 and remains that way for several tens of days, this does not necessarily mean that the infection has ended. The infection is considered to have ended completely when the number of infected individuals ($P(n)$) becomes 0 because no more infections will occur from that day onward.

6.8. There are always many first-time infections, which are infections that occur in original susceptible individuals during every epidemic period. The first epidemic consists of only the 'first-time infected' individuals, and for some early epidemics, a large proportion of the total number of infected individuals is occupied by the 'first-time infected' individuals, indicating that the ratio of the number of 'first-time infected' individuals significantly exceeds the ratio of the number of 'reinfected' individuals. However, as the number of epidemic outbreaks progresses, the ratio of the number of individuals 'first-time infected' decreases. Conversely, the ratio of the number of 'reinfected' individuals increases. Both ratios gradually approach each other, and eventually, the ratio of the number of 'reinfected' individuals becomes larger. On the other hand, as the number of epidemic outbreaks progresses, both the number of 'first-time infected' individuals and the number of 'reinfected' individuals decrease. Thus, the infection will eventually come to an end, although it may take decades for this to end.

6.9. If multiple reinfections occur, several epidemics inevitably occur, and the number of infected individuals becomes extremely large. For example, when the symptomatic rate is 1.0, seven epidemics occur, and the total number of infected individuals is 681,562, which is significantly greater than 141,874 when reinfection does not occur. When the symptomatic rate is 0.0, 5 epidemics occur, and the total number of infected individuals will be 1,560,450, which is significantly greater than the 598,294 when reinfection does not occur and substantially larger than the community population of 1,000,000. Therefore, it can be noted that the occurrence of reinfections inevitably causes multiple outbreaks of the epidemic, produces many infected individuals and repeatedly induces a 'seriously high rate of increase' in the number of individuals infected a day.

7. Conclusion

In this article, the term 'reinfection' was used in a broad sense to refer to any infection that occurs due to loss of infection-induced immune effectiveness, regardless of the interval between infections, indicating infections occurring after the first-time infection, such as second-time infection, third-time infection, fourth-time infection, and so on. The duration of infection-induced immunity required for reinfection to occur was examined in relation to the symptomatic rate and the potential (biological) infectious capacity of the coronavirus. It simulated changes in the number of infected individuals, the number of outbreaks of the epidemic, and the duration of infections when reinfections occur. In the simulation, the recovered individuals whose infection-induced immunity decreased to below a certain threshold essentially get back to susceptible individuals, and from both physical and statistical perspectives, they became infected at the same rate as the 'original' susceptible individuals. The simulations were performed in a community with a population of 1,000,000, with an initial number of infected individuals of 1, a latent period of 5 days, a recovery period of 14 days, and varying values of the symptomatic rate and potential (biological) infectious capacity of coronavirus.

This study clarified the critical values of duration (the threshold of duration) of infection-induced immunity required for reinfection to occur and revealed several important features of the infection process during reinfection, which may provide a reference for medical and policy measures.

7.1. The duration of infection-induced immunity required for reinfection to occur decreases with decreasing symptomatic rates and/or increasing potential (biological) infectious capacity of coronavirus and increases with increasing symptomatic rates and/or decreasing potential (biological) infectious capacity of coronavirus. A small change in factors such as the symptomatic rate and the potential (biological) infectious capacity of coronavirus can result in a large change in the duration of infection-induced immunity required for reinfection to occur. These factors vary depending not only on the characteristics of the coronavirus itself, including its ability to respond to changes in the natural environment and social circumstances, but also on human behaviors, including infection prevention measures such as isolating infected individuals, wearing masks and others. Therefore, it is important to clarify the characteristics of the coronavirus itself as well as to implement infection prevention measures in a timely manner.

7.2. When reinfection occurs, several epidemics inevitably occur, and the duration of infection becomes extremely long. For example, when multiple reinfections occur, if the potential (biological) infectious capacity of coronavirus is 1.0 and the symptomatic rate is 1.0, seven epidemics occur, and the duration of infection is 8,254 days (approximately 23 years). When the potential (biological) infectious capacity of coronavirus is 0.9, eleven epidemics occur. The duration of infection is long, 24,753 days (approximately 68 years). When the duration of infection continues for a long time, preventive attitudes and protective measures are likely to break down, and mutated strains of the virus are also more likely to emerge. The emergence of mutant strains can reset the infection process and is likely to induce a new infection process similar to that observed when reinfection occurs, resulting in a longer duration of infection. Therefore, if a situation arises where reinfection occurs, we must settle down and prepare to care for the 'long-term COVID-19 infections'.

7.3. Between adjacent epidemics, there are ‘troughs’ that indicate periods of time where the number of individuals infected a day shows relatively low. And there are some troughs where the number of individuals infected a day shows 0 for several tens of days. Therefore, even if the number of individuals infected a day ($AP(n)$) decreases to 0 and remains that way for several tens of days, it is too early to conclude that the infection has ended. When the number of infected people ($P(n)$) reaches 0, no more infections will occur from that day onward, and the infection is completely ended.

7.4. When reinfection occurs, as the number of epidemic outbreaks progresses, the number of individuals infected a day at the peak of each epidemic decreases. Thus, the rate of increase in the number of individuals infected a day decreases as the number of epidemic outbreaks progresses. On the other hand, the number of individuals infected a day during troughs increases as the number of epidemic outbreaks progresses. This means that a considerable number of individuals infected a day will constantly occur. It might threaten the capacity of medical care.

7.5. Many first-time infections are observed during every epidemic period. The first epidemic consists of only ‘first-time infected’ individuals. During the early stages of infection, the ratio of the number of 'first-time infected' individuals significantly exceeds the ratio of the number of ‘reinfected’ individuals. However, as the number of epidemic outbreaks progresses, the ratios of both gradually approach each other, and eventually, the ratio of the number of ‘reinfected’ individuals becomes larger. On the other hand, as the number of epidemic outbreaks progresses, not only the number of first-time infected individuals but also the number of reinfected individuals decreases. Thus, the epidemic will eventually come to an end. However, it may take decades for this to end. Since reducing the number of 'first-time' infected individuals induces a decrease in the number of reinfected individuals, medical and policy care for original susceptible individuals, such as vaccination, PCR testing and others, can decrease the total number of infected individuals and shorten the duration of infection.

7.6. If multiple reinfections occur, the number of infected individuals becomes extremely large. For example, when the potential (biological) infectious capacity of coronavirus is 1.0 and the symptomatic rate is 1.0, the total number of infected individuals will be 681,562, substantially larger than that, 141,874 or less, when reinfection does not occur. When the symptomatic rate is 0.0, the total number of infected individuals will be 1,560,450, which is significantly larger than the population of 1,000,000. A ‘high rate of increase’ in the number of individuals infected a day is repeated multiple times. The increase in the number of infected individuals themselves and the increase in the rate of increase in the number of individuals infected a day might inevitably overwhelm the medical system and hospital capacity, especially during the early stage of infection. This must result in enormous damage, including an increase in the number of seriously ill individuals and deaths. Therefore, it is necessary to reduce the occurrence of reinfection in the early stages of infection through vaccination, PCR testing, and other medical and policy care.

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Data availability
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References

1. Gussarow D., Bonifacius A., Cossmann A., Stankov M.V., Mausberg P., Tischer-Zimmermann S., Gödecke N., Kalinke U., Behrens G.M.N., Blasczyk R. and Eiz-Vesper B. (2021): Long-Lasting Immunity Against SARS-CoV-2: Dream or Reality? Front Med (Lausanne). 2021; 8: 770381. Published online 2021 Nov 25. doi: 10.3389/fmed.2021.770381.
2. Townsend J.P., Hayley B Hassler H., Wang Z., Sayaka Miura S., Singhg J., Kumar S., Ruddle N.H., Galvani A.P., Dornburg A. (2021): The durability of immunity against reinfection by SARS-CoV-2: a comparative evolutionary study. Lanset. Volume 2, Issue 12e666-e675December 2021.

3. Kojima N., Shrestha N.K. and Klausner J.D. (2021): A Systematic Review of the Protective Effect of Prior SARS-CoV-2 Infection on Repeat Infection. A Systematic Review of the Protective Effect of Prior SARS-CoV-2 Infection on Repeat Infection. Eval Health Prof. 2021 Dec; 44(4): 327–332. Published online 2021 Sep 30. doi: 10.1177/01632787211047932.
4. Kim P., Gordon S.M., Sheehan M.M. and Rothberg M.B. (2021): Duration of SARS-CoV-2 Natural Immunity and Protection against the Delta Variant: A Retrospective Cohort Study. Clin Infect Dis. 2021 Dec 3 : ciab999. Published online 2021 Dec 3. doi: 10.1093/cid/ciab999.
5. Ren X., Zhou J., Guo J., Hao C., Zheng M., Zhang R., Huang Q., Yao X., Li R. and Jin Y. (2022): Reinfection in patients with COVID-19: a systematic review. *Global Health Research and Policy* **volume 7**, Article number: 12 (2022) Published: 29 April 2022.
6. Goldberg Y., Mandel M., Bar-On Y.M., Bodenheimer O., Freedman L.S., Ash N., Alroy-Preis S., Huppert, A. and Milo R. (2022): Protection and Waning of Natural and Hybrid Immunity to SARS-CoV-2. N Engl J Med. 2022 May 25: NEJMoa2118946. Published online 2022 May 25. doi: 10.1056/NEJMoa2118946.
7. Pilz S., Theiler-Schwetz V., Trummer C., Krause R. and Ioannidis J.P.A. (2022): SARS-CoV-2 reinfections: Overview of efficacy and duration of natural and hybrid immunity. *Environmental Research*, Volume 209, June 2022, 112911.
8. Wu S., Li Y., Mishra S., Bodner K., Baral S, Kwong J.C. and Wei X. (2023): Effect of the incremental protection of previous infection against Omicron infection among individuals with a hybrid of infection- and vaccine-induced immunity: a population-based cohort study in Canada. *International Journal of Infectious Diseases*, Volume 127, February 2023, Pages 69-76. https://doi.org/10.1016/j.ijid.2022.11.028.
9. COVID-19 Forecasting Team (2023): Past SARS-CoV-2 infection protection against reinfection: a systematic review and meta-analysis. *Lancet.* 2023; volume **401**: Issue 10379, p833-842, March 11, 2023.
10. Pooley N., Karim S.S.A., Combadière B., Ooi E.E., Harris R.C., Seblain C.E.G., Kisomi M. and Shaikh N. (2023): Durability of Vaccine-Induced and Natural Immunity Against COVID-19: A Narrative Review. Review, Open access, Published: 09 January 2023, Volume 12, pages 367–387, (2023).
11. Reynolds S.L., Kaufman H.W., Meyer W.A., Bush C., Cohen O., Cronin K., Kabelac C., Leonard S., Anderson S., Petkov V., Lowy D., Sharpless N. and Penberthy L. (2022): Risk of and duration of protection from SARS-CoV-2 reinfection assessed with real-world data. PLoS One. 2023 Mar 21;18(3):e0280584. doi: 10.1371/journal.pone.0280584. eCollection 2023.
12. Bobrovitz N., Ware H., Ma X., Li Z., Hosseini R., Caoa C., Selemond A., Whelan M., Premji Z., Issa H., Cheng B., Raddad L.J.A., Buckeridge D.L., Kerkhove M.D.V., Piechotta V., Higdon M.M, Wilder-Smith A., Bergeri I., Feikin D.R., Arora R.K., Patel M.K. and Subissi L. (2023): Protective effectiveness of previous SARS-CoV-2 infection and hybrid immunity against the omicron variant and severe disease: a systematic review and meta-regression. Lancet Infect Dis. Volume 23, Issue 5p556-567 May 2023.
13. Guo L., Zhang Q., Gu X., Ren L., Huang T., Li Y., Zhang H., Liu Y., Zhong J., Wang X., Chen L., Zhang Y., Li D., Fang M., Xu L., Li H., Wang Z., Li H., Bai T., Liu W., Peng Y., Dong T., Cao B. and Wang J. (2024): Durability and cross-reactive immune memory to SARS-CoV-2 in individuals 2 years after recovery from COVID-19: a longitudinal cohort study. Lancet Microbe, Volume 5, Issue 1e24-e33January 2024.
14. Chemaitelly H., Ayoub H.H., Coyle P., Tang P., Hasan M.R., Yassine H.M., Al Thani A.A., Al-Kanaani Z., Al-Kuwari E., Jeremijenko A., Kaleeckal A.H., Latif A.N., Shaik R.M., Abdul-Rahim H.F., Nasrallah G.K, Al-Kuwari M.G., Butt A.A, Al-Romaihi H.E., Al-Thani M.H., Al-Khal A., Bertollini R. and Abu-Raddad L.J. (2025): Differential protection against SARS-CoV-2 reinfection pre- and post-Omicron. Nature, 639, 1024–1031, Open access, Published: 05 February 2025.
15. Deng L., Li P., Zhang X., Jiang Q., Turner D.A., Zhou C., Gao Y., Qian F., Zhang C., Lu H., Zou H., Vermund S.H. and Qian H. (2022): Risk of SARS-CoV-2 reinfection: a systematic review and meta-analysis. Sci Rep. 2022; 12: 20763. Published online 2022 Dec 1. doi: 10.1038/s41598-022-24220-7.
16. de La Vega M.A., Polychronopoulou E., Xiii A., Ding Z., Chen T., Liu Q., Lan J., Nepveu-Traversyr.E., Fausther-Bovendo H., Zaidan M.F., Wong G., Sharma G., Kobinger G.P. (2023): (2023): SARS-CoV-2 infection-induced immunity reduces rates of reinfection and hospitalization caused by the Delta or Omicron variants. Emerg Microbes Infect. 2023; 12(1): e2169198. Published online 2023 Mar 1. doi: 10.1080/22221751.2023.2169198.
17. Nguyen N.N., Nguyen N.Y., Hoang V.T., Million M. and Gautret P. (2023) : SARS-CoV-2 Reinfection and Severity of the Disease: A Systematic Review and Meta-Analysis. *Viruses*, 14 Apr 2023, 15(4):967, doi: 10.3390/v15040967.
18. Kitamura N., Otani K., Kinoshita R., Yan F., Takizawa Y., Fukushima K., Yoneoka D., Suzuki M. and Kamigaki T. (2023): Protective effect of previous infection and vaccination against reinfection with BA.5 Omicron subvariant: a nationwide population-based study in Japan. Lancet Regional Health – Western Pacific, Volume 41100911December 2023, DOI: 10.1016/j.lanwpc.2023.100911.
19. Sun K., Bhiman J.N., Tempia S., Kleynhans J., Madzorera V.S., Mkhize Q., Kaldine H., McMorrow M.L., Wolter N., Moyes J., Carrim M., Martinson N.A., Kahn K., Lebina L., du Toit J.D., Mkhencele T., von Gottberg A., Viboud C., Moore P.L., Cohen C. and PHIRST-C group (2024): SARS-CoV-2 correlates of protection from infection against variants of concern. nature medicine. Published: 26 July 2024.
20. CDC Archive (Updated Mar. 15, 2023): What is COVID-19 Reinfection? & CDC Archive (June 14, 2024): About Reinfection.
21. Moore M., Anderson L., Schiffer J.T., Matrajt L. and Dimitrov D. (2025): Durability of COVID-19 vaccine and infection induced immunity: A systematic review and meta-regression analysis. Vaccine. 2025 Mar 5:54:126966.
22. Ohmori H. (2022): A flexible compartment model for simulation specific to COVID-19. J Infect Dis Ther, 2022; S5:001.

23. Ohmori H. (2023): Effect of Symptomatic Rate on Spreading of COVID-19 Evaluated by a Flexible Compartment Model. J Clin Res Bioeth. 14:465.
24. Ohmori H. (2024a): Effect of the Mass Vaccination Duration on the Spread of COVID-19 Evaluated by a Flexible Compartment Model. J Vaccines Vaccin. S25:002.
25. Ohmori H. (2024b): Effect of Breakthrough Infection on the Spread of COVID-19 Evaluated by a Flexible Compartment Model. J Infect Dis Ther 12:609.

Supplementary Files

Appendix 1: Explanations of the independent variables and dependent variables used in the Excel file for the 'flexible compartment model for simulation specific to COVID-19 (for "Effect of reinfection on the spread of COVID-19 evaluated by a flexible compartment model") Hiroo Ohmori

1. Independent variables of the model (24 variables)

For simulation, n starts from 1, and the independent variables of twenty-four terms can be set arbitrarily by the user as follows:

1) $TN(1)$: the initial total population of the community, such as a city. $TN(n)$ is changed by the number of susceptible individuals ($NAP(n)$) and/or infected individuals ($UP(n)$) who come in and/or leave the community. $TN(n)=TN(n-1)+NAP(n)+UP(n)$ (101)

2) $P(1)$: the initial number of infected individuals in the community. The infected individuals are those who have been infected and are capable of infecting susceptible individuals. Thus, they can be called 'spreaders'. Infected individuals (UP(n)) other than the initial infected individuals can enter and/or leave the community. Additionally, when the initial incidence rate, $ir(1)$, is given, $P(1)$ is given by the product of $ir(1)$ and $TN(1)$, that is, $ir(1)*TN(1)$, because $ir(n)$ is usually given by $P(n)/TN(1)$. The number of infected individuals in the morning on day n, $P(n)$, is given by the following equation:

$$P(n)= P(n-1(\text{night}))=RP(n-1)+AP(n-1(\text{night})) =RP(n-1)+p(n-1)*RM(n-1) \quad (102)\ (=25)$$

where $P(n-1(\text{night}))$ is the number of infected individuals on the previous night.

3) $NAP(n)$: the number of susceptible individuals who come in and/or leave the community. Specifically, the value of $NAP(n)$ changes according to changes in the number of susceptible individuals who come in or come out of the community, such as travel, self-isolation, and migration (immigration/emigration), etc. In addition, $NAP(n)$ should be added to both $TN(n)$ and $RM(n)$ when $NAP(n)$ is given a positive value, meaning that susceptible individuals enter the community. When NAP(n) is given a negative value, meaning that susceptible individuals leave the community, including self-isolation, the value of $NAP(n)$ should be subtracted from both $TN(n)$ and $RM(n)$. Emergency actions such as 'avoiding any unnecessary outings/travel', 'staying home (self-isolation)' and 'lockdown' for infection prevention practically induce a reduction in the number of susceptible individuals in the real community, indicating that $NAP(n)$ should be given a negative value. By setting $NAP(n)$ for the simulation, the effects of such interventions can be evaluated.

4) $UP(n)$: the number of infected individuals who come in and/or leave the community. Specifically, the value of $UP(n)$ changes according to changes in the number of susceptible individuals who come in or come out of the community, such as travel, self-isolation, migration (immigration/emigration), etc. $UP(n)$ should be added to both $TN(n)$ and $P(n)$ when $UP(n)$ is given a positive value, meaning that infected individuals enter the community. When $UP(n)$ is given a negative value, meaning that infected individuals are not isolated but leave the whole community in Figure 1, the value of $UP(n)$ should be subtracted from both $TN(n)$ and $P(n)$. Since symptomatic infected individuals get isolated, most of the individuals of $UP(n)$ are asymptomatic. In a simulation where asymptomatic infected travelers come into the community from other cities and/or foreign countries, by setting the value of $UP(n)$, the effect of infected individuals coming into the community can be evaluated.

For the model proposed here, $NAP(n)$ and $UP(n)$ are each set once a certain day, and the condition is automatically maintained until it is reset, although the other independent variables should be set every day. For example, if $UP(100)$ is set to a positive value of '10' only on the 100^{th} day and is set to 0 on days before and after the 100^{th} day, 10 infected individuals, as asymptomatic individuals, would come into the community on the 100^{th} day. After they enter the community, they stay in the community and mix with existing infected individuals, causing increases in $TN(n)$ and $N(n)$ after the 100^{th} day. In the calculation, they are treated as 'ordinary' infected individuals who get infected on the 100^{th} day, develop symptoms at a given symptomatic rate, and continue to infect susceptible individuals in the community.

5) $T(n)$: the number of individuals with PCR and/or antibody tests. The test time should be set on the day when the test is performed.

6) $bp(n)$: the multiplier value of the incidence rate in the testing against the incidence rate ($ir(n)$; $P(n)/TN(n)$) in the community. It indicates the value of magnification of the incidence rate in the testing to the incidence rate ($ir(n)$; $P(n)/TN(n)$) in the community. Since the individuals having the test are mainly close contacts, the incidence rate in the tested individuals would be biased to be higher than $ir(n)$. The incidence rate in the testing is given by the magnification with respect to $ir(n)$. Specifically, the number of infected individuals confirmed to be test positive, $CP(n)$, is calculated as follows:

$$CP(n)=T(n)*bp(n)*ir(n) \quad 103)\ (= 5)$$

The value of *bp* (*n*)**ir*(*n*) indicates the percentage of positive results in the PCR and/or antibody test; that is, the positive rate, *tir*(*n*).

7) *vd*(*n*): the vaccination rate used to count the number of individuals newly vaccinated a day to the initial total population of the community. The number of individuals newly vaccinated a day, *V*0(*n*), is given by:

$$V0(n) = TN(1)*vd(n) \quad (104)$$

where *TN* (1) is the initial total population of the community, such as a city.

The cumulative/total number of vaccinated individuals on day *n*, *CV*0(*n*), is given by summing the number of individuals vaccinated a day from the first day of vaccination to day *n*:

$$CV0(n)=\Sigma V0(n)= \Sigma(TN(1)*vd(n)) \quad (105)(=10)$$

Vaccinated individuals have vaccine-induced immunity. They live and work in the real community in Figure 1 (see 'Dependent variables; 2-57 &2-58': *V*0 & *CV*0).

8) *ds*: the starting day of mass vaccination. This indicator indicates the first day of mass vaccination and is used to calculate the first day when individuals getting back (returning) to susceptible individuals appear. The individuals who are vaccinated on the first day of mass vaccination get back to susceptible individuals on the day when the 'duration of vaccine-induced immunity' has elapsed since the first day.

Specifically, it is calculated as follows.

Consider the case where the first date of mass vaccination is *ds* and the duration of vaccine-induced immunity is *dvi* (see 9: *dvi*). The individuals vaccinated on the first day of mass vaccination will get back to susceptible individuals on the (*ds*+*dvi*)th day, which is the first day when the individuals getting back to susceptible individuals appear. Thus, the number of individuals getting back to susceptible individuals on the first day when the individuals getting back to susceptible individuals appear (*ReVac*(*ds*+*dvi*)) is given by:

$$ReVac(ds+dvi)=V0(ds)*bvi(ds) \quad (106)$$

where *bvi*(*n*) is the 'back to rate' at which vaccinated individuals with vaccine-induced immunity get back to susceptible individuals a day (see 10: *bvi*). For example, when the value of *ds* is set to 51, which indicates that mass vaccination started on the 51st day and the duration of vaccine-induced immunity (*dvi*) is set to 150 days, the first individuals who get back to susceptible individuals appear on the 201st day. The number of individuals who get back to susceptible individuals on that day is as follows:

$$ReVac(51+150) = V0(51)*bvi(51) \quad (107)$$

That is,

$$ReVac(201)=V0(201-150)*bvi(201-150) \quad (108)$$

During the period before the 151st day, *ReRVac*(*n*) should be set to 0.

Formula (108) is rewritten by substituting 201 by *n* and 150 by *bvi*;

$$ReVac(n)=V0(n-150)*bvi(n-150) =V0(n-dvi)*bvi(n-dvi) \quad (109)$$

Thus, on and after the 201st day, that is, on and after the (*ds*+*dvi*)th day, *ReVac*(*n*) is given by:

$$ReVac(n)=V0(n-dvi)*bvi(n-dvi) \quad (110)$$

This means that the number of individuals who got back to susceptible individuals on day *n* is equivalent to (the number of individuals who were vaccinated '*dvi*' days before day *n*) * (the vaccination rate '*dvi*' days before day *n*). Specifically, Eq. (110) indicates that the immunity of individuals vaccinated on date (*n*-*dvi*) decreases below a certain threshold on date *n* (see 'Dependent variables; 2-53': *ReVac*(*n*)).

Another example, for a community whose population is 1,000,000, when vaccination at a rate of 0.001 starts on the 51st day and ends on the 300th day and the duration of vaccine-induced immunity is 150 days, the number of vaccinated individuals increases by 1,000 a day, and the number of currently existing vaccinated individuals (*V*(*n*)) becomes 150,000 on the 200th day. Since, after the 201st day, 1,000 vaccinated individuals who were vaccinated 150 days before each day get back to susceptible individuals, *V*(*n*) did not increase until the 300th day, despite vaccinations continuing, and was maintained at 150,000. Since vaccination ends on the 300th day, after the 301st day, *V*(*n*) decreases by 1,000 a day and becomes 0 on the 450th day. The number of susceptible individuals in the community (*RM*) changes with the change in the number of vaccinated individuals (see 'Dependent variables; 2-46': *RM*(*n*)).

9) *dvi*: the duration of vaccine-induced immunity (the validity period of vaccine-induced immunity). This indicates the time interval between when an individual is vaccinated and when his/her antibodies acquired by vaccination decrease below a certain threshold of immunity level at which infection could occur. The value of *dvi* should be determined on the basis that the quantity of antibodies acquired through vaccination decreases below a certain threshold within several weeks and/or several months after vaccination. In other words, on the *dvi*th day after receiving vaccination, since the quantity of antibodies of vaccinated individuals decreases to below a certain threshold of the immunity level at which vaccinated individuals could get infected, vaccinated individuals essentially get back to 'susceptible individuals' and could get infected with COVID-19. In the calculation, the average duration of vaccine-induced immunity is used as the *dvi* value. The number of individuals getting back to susceptible individuals from vaccinated individuals on date *n*, *ReVac*(*n*), is given by:

$$ReVac(n)=V0(n-dvi)*bvi(n-dvi) \quad (111)(=110)$$

where the coefficient '*bvi*' is the 'back-to-rate' at which vaccinated individuals with vaccine-induced immunity get back to susceptible individuals a day. (see 'Dependent variables; 2-58': *ReVac*(*n*))

10) *bvi*(*n*): the 'back to rate' at which vaccinated individuals with vaccine-induced immunity get back to susceptible individuals a day. It indicates the ratio of the number of individuals who get back to susceptible individuals from vaccinated individuals to the number of vaccinated individuals who were vaccinated on the same day. The 'getting back to susceptible individuals' occurs '*dvi*' days after the day of vaccination. Since the average duration of vaccine-induced immunity is used, the value of *bvi*(*n*) is typically assigned a value of 1.0. However, if, for example, 20% of vaccinated individuals develop permanent immunity, *bvi*(*n*) should be assigned a value of 0.8 because 80% of vaccinated individuals should get back to susceptible individuals. The individuals getting back to susceptible individuals could be attacked by breakthrough infection. However, all individuals who got back to susceptible individuals do not always get infected. In the calculation, the individuals who got back to susceptible individuals got infected in the same manner (at the same rate) as the 'original' susceptible individuals got. (see 'Dependent variables; 2-58': *ReVac*(*n*))

11) *dii*: the duration of infection-induced immunity (the validity period of infection-induced immunity). This indicates the time interval between when an individual recovers from COVID-19 and when his/her quantity of antibodies acquired through infection decreases below a certain threshold. Infected individuals acquire immunity and become 'recovered' individuals after the end of the recovery period (*rp*). For COVID-19, the effectiveness of the immunity acquired through infection does not continue permanently but decreases gradually below a certain threshold. The value of *dii* should be determined while referring to the decrease in the quantity of antibodies acquired through infection below a certain threshold several months after infected individuals have recovered. In other words, on the dii^{th} day after infection, since the quantity of antibodies of recovered individuals decreases to below a certain threshold of the immunity level at which recovered individuals could become infected, the recovered individuals essentially get back to 'susceptible individuals' and could get infected with COVID-19. In the calculation, the average duration is used as the *dii* value and recovered individuals get back to 'susceptible individuals' on the day '*dii*' days after they have returned to the community, and on and after that day, they could get infected again.

Since the infected individuals would recover and return to the community on the day '(*rp* +2)' days after infection, the recovered individuals would get back to 'susceptible individuals' on the day '(*rp*+2+*dii*)' days after infection. For example, when the recovery period (rp) is set to 14 and dii is set to 150, individuals infected on the first day of simulation will recover on day 16 (=14+2) and will get back to susceptible individuals on day 166 (=16+150), which is the day 150 days after the infected individuals have recovered. Conversely, the number of individuals getting back to susceptible individuals from isolated-recovered individuals on day 166, *ReRT* (166), is given by:

$$ReRT(166)= RT\,(16)*bii(16)= RT\,(166-150)*bii(166-150) \quad (112).$$

Specifically, the number of individuals getting back to susceptible individuals from isolated-recovered individuals on day *n*, *ReRT*(*n*), is given by:

$$ReRT(n)= RT\,(n\text{-}dii)*bii(n\text{-}dii) \quad (113)$$

where coefficient '*bii*' is the 'back-to' rate at which recovered individuals with infection-induced immunity get back to susceptible individuals a day. *RT*(*n*) is the number of recovered individuals who were isolated because they were symptomatic in the community and returned to the community after the isolation period ended. (see 'Dependent variables: 2-39': *ReRT*(*n*): Eqs. (223, 224, 225).

12) *bii*(*n*): the 'back-to' rate at which recovered individuals with infection-induced immunity get back to susceptible individuals a day. This index represents the ratio of the number of individuals who get back to susceptible individuals from recovered individuals to the number of recovered individuals who were infected on the same day and recovered on the same day after the recovery period. However, note the following: The number of recovered individuals is not always equal to the number of infected individuals, because the number of recovered individuals is the number obtained by subtracting the number of deaths from the number of infected individuals. An 'getting back to susceptible individuals' occurs on the day '*dvi*' days after an infected individual has recovered. (see 'Dependent variables 2-39': *ReRT*(*n*): Eq. (223)).

Since the average duration of infection-induced immunity is used, the value of *bii*(*n*) is typically set to 1.0. However, if, for example, 20% of infected individuals develop permanent immunity, the value of *bii*(*n*) should be set to 0.8 because 80% of infected individuals and/or recovered individuals get back to susceptible individuals. The individuals getting back to susceptible individuals could be attacked by 'reinfection'. However, all individuals who got back to susceptible individuals do not always become infected. In the calculation, the individuals who got back to susceptible individuals will get infected in the same manner (at the same rate) as the 'original' susceptible individuals.

13) *icf*(*n*): the infection reduction rate by infectious control measures preventing the spread of viruses, such as facemasks, partitions and disinfectants. When the reduction effect of infectious control measures does not need to be considered, the value of *icf*(*n*) should be set to 1. On the other hand, when the number of infected individuals is reduced to 0.9 by a control measure, the value of *icf*(*n*) is set to 0.9. Additionally, it consists of several reduction steps, such as wearing a facemask, wearing *icf*1(*n*), partitioning, wearing *icf*2(*n*), disinfecting, and wearing *icf*3(*n*).

$$icf(n)= icf1(n)*\,icf2(n)*\,icf3(n) \quad (114)$$

When *icf*1(*n*)=0.9 and *icf*2(*n*)=0.8, the reduction rate is given by:

$$icf(n)= icf1(n)*\,icf2(n)=0.9*0.8=0.72 \quad (115)$$

The reduction effect increases with decreasing *icf*(*n*). By giving a value to *icf*(*n*), the effect of the control measure can be evaluated on the basis of the differences in the number of infected individuals calculated.

14) $i(n)$: the isolation rate for individuals who are confirmed to be infected because they test positive. All confirmed infected individuals are not always isolated. The number of isolated individuals, $I(n)$, is given by:

$$I(n)= CP(n-1)*i(n-1) \qquad (116)\ (= 4)$$

where $CP(n)$ is the number of confirmed infected individuals. The value of $i(n)$ indicates the ratio of the number of isolated individuals to the total number of infected individuals confirmed to be positive. When all confirmed infected individuals are isolated, the value of $i(n)$ should be set to 1. The value of $i(n)$ is controlled by medical environments. For calculation, as shown by Eq. (4), the individuals who must be isolated are isolated the next day. Specifically, $I(n)$ is practically given by equation (116): $I(n)=CP(n-1)*i(n-1)$.

15) $syr(n)$: the symptomatic rate, which is the ratio of the number of individuals who become symptomatic to the total number of individuals infected on the same day. The term '$syr(n)$' indicates the symptomatic rate of individuals who are confirmed to be infected because they are symptomatic in the community and are isolated. Since not all infected individuals are symptomatic, all infected individuals are not always isolated. The number of isolated individuals, $PI(n)$, is given by:

$$PI(n)= AP(n-(lp+1))* syr(n-(lp+1)) \qquad (117)\ (= 14)$$

where $(n-(lp+1))$ is the day one day before the 'latent period' before the n^{th} day, indicating the day after the end of the latent period, since the infected individuals become symptomatic and are isolated the day after the end of the latent period.

The symptomatic rate (syr) can be used as an isolation rate for infected individuals in the community.

The value of $AP(n-(lp+1))$ indicates the number of infected individuals who were newly infected on the $(n-(lp+1))$ and were isolated on day n, that is, the day after the end of the latent period. For example, when the latent period lp is 5 and n is 157, $lp+1=6$; then, $(n-(lp+1))=(157-6)=151$, indicating that the number of individuals isolated on the 157^{th} is (the number of individuals newly infected on the 151^{st})*$syr(151)$, that is, $AP(151)*syr(151)$. The $AP(n-(lp+1))$ value includes symptomatic infected individuals, asymptomatic infected individuals in the community and individuals who tested positive but were not isolated. When $AP(n)$ becomes less than '$pfc(n)/rp(n)-0.0001$', $AP(n)$ is set to 0. However, the number of asymptomatic infected individuals, $AS(n)$, is given by:

$$AS(n) = AP(n-(lp+1)) - PI(n) \qquad (118)\ (= 15)$$

Asymptomatic individuals are not isolated. They stay in the community and continue to infect susceptible individuals until the recovery period ends, after which they become recovered individuals in the community, although the true number of recovered individuals is the value minus the number of deaths.

16) $pfc(n)$: the potential (biological) infectious capacity of coronavirus (persons/person), which is an approximate value suggesting the number of susceptible individuals infected by an infected (infectious) individual during the latent period (and/or during the recovery period). Although infection starts two or three days before the end of the latent period, the infection rate given by the value of $pfc(n)/lp(n)$ (persons/person/day) is used for calculation.

The infection rate is generally defined as the product of the biological infection rate p_b (persons/person) and the contact number m of a person a day (persons/person/day), that is, $p_b * m$ (persons/person/day). The practical infection rate, however, is usually affected by the infection reduction effect induced by infection control measures such as facemasks. The model used here included the effect of the infection reduction rate, $icf(n)$, induced by infection control measures. Specifically, for calculation, the practical infection rate, $p(n)$, which is the infection coefficient indicating the practical infection rate used in calculation and includes the effect of the infection reduction rate, is used here. $p(n)$ is given by:

$$p(n)= (pfc(n)/lp(n))*(RM(n)/N(n))*icf(n)*(1-(AL(n)/N(n)))*(RP(n)/N(n)) \qquad (119)\ (=23)$$

where $AL(n)/N(n)$ is $(alI(n)*(RI(n)+RT(n))+al(n)*RAS(n)+alV(n)*V(n))/N(n))$, and the term $(1-(AL(n)/N(n)))$ is the reduction rate of the contact rate, which is equivalent to the term $(1-\delta(R(n)/N(n)))$ of Eq. (1):

$$cr(n)=(S(n)/N(n))(1-\delta(R(n)/N(n))) \qquad (1)$$

As previously explained, $p(n)$ indicates an infectious capacity, including the contact rate changing with the number of susceptible individuals ($RM(n)$), recovered individuals ($RI(n)$, $RT(n)$, and $RAS(n)$); vaccinated individuals ($V(n)$); and the population excluding the individuals kept in isolation and dead but including the recovered individuals who returned to the community, that is, the total number of individuals living and working in the community ($N(n)$).

17) $lp(n)$: the latent period, which is the time interval between when an individual is infected and when he/she is symptomatic. The latent period is usually defined as the time interval between when an individual is infected and when he/she is symptomatic and infectious. Specifically, infected individuals can infect susceptible individuals after the latent period. However, for COVID-19, infections have occurred and spread even during the latent period. Infected individuals infect susceptible individuals even during the latent period. However, when an infected individual becomes symptomatic after the latent period ends, he/she is isolated. Thus, infected individuals can potentially infect susceptible individuals throughout the recovery period, including the latent period, but since infected individuals who become symptomatic are isolated, they cannot infect susceptible individuals after the latent period. The infected individuals who do not develop symptoms, that is, those who are asymptomatic, are not isolated, remain in the community and continue to infect susceptible individuals in the community.

18) $rp(n)$: the recovery period, which is the time interval between when an individual is infected and when he/she recovers from one's disease and when he/she is not capable of infection. This period is also equivalent to the infectious period. However, for infected individuals who are isolated because of a positive test, the recovery period is equal to the isolation period, as explained by 19) $rpI(n)$. The recovered individuals return to the community the day after the end of the recovery period.

The variables *lp* and *rp* are used in the following calculation:

$$RAS(n)=AS(n-(rp-lp))-DAS(n-(1+\text{trunc}((rp-lp)/2))) = AS(n-(rp-lp))-AS(n-(rp-lp))*fr(n-(rp-lp)) \quad (120)\ (=17)$$

where $RAS(n)$ is the number of 'recovered' individuals who were infected but did not develop symptoms, were asymptomatic, were not isolated, were staying in the community, had continued to infect until the recovery period ended, and then had become 'recovered' individuals on day *n*. $AS(n-(rp-lp))$ is the number of asymptomatic infected individuals who were infected on day $(n-(rp-lp))$, were not isolated, were staying in the community and could be recovered individuals on day *n* and was calculated by subtracting the *PI* from the *AP*, as shown in Eq. (118). The deaths of infected individuals occurred during the middle of the isolation period; that is, 'trunc(rp-lp)/2'. Specifically, some of the infected individuals who have been isolated on date *n* die on date (n+trunc(rp-lp)/2). For asymptomatic individuals, the same procedure was used. Specifically, when the number of asymptomatic individuals infected on date *n* is $AS(n)$ and the fatality rate for the asymptomatic infected individuals in the community is $fr(n)$, the $AS(n)* fr(n)$ individuals die on date (n+trunc(rp-lp)/2). Conversely, the death toll of asymptomatic individuals on date *n*, $DAS(n)$, is given by Eqs. (16) and (123). Thus, in the actual calculation, $RAS(n)$, which is the number of individuals recovered from asymptomatic infected individuals excluding the death toll, is given by Eq. (120).

For the Excel file, the row and column number should be given not by function (and/or formula) but by a numerical value. For example, column BN is assigned to the number of recovered individuals in the community (*RAS*), and BN(n) indicates the value of $RAS(n)$ on date *n*. In the attached Excel file, the calculation of $RAS(n)$ is expressed as follows:

$$[\text{BN } (n)] = \text{IF}(\text{V}(n)>\text{N}(n)+1, \text{AQ } (n-(rp - lp))-\text{AT } (n-(1+\text{trunc}(rp - lp)/2)),0) \quad (121)$$

where column V is assigned to the time (*n*; the number of trials); column N is the recovery period (*rp*); column AQ is the number of asymptomatic infected individuals in the community ($AS(n)$); and column AT is the number of individuals who are asymptomatic and die of infection after the latent period in the community, that is, the death toll in the community ($DAS(n)$). When the time is 1, the row number, *n*, is 24. Since n-(rp-lp)=24-(14-5)=24-9=15 and (n-(1+trunc(rp-lp)/2)) =24-(1+trunc(14-5)/2)) =24-(1+trunc(9)/2)=24-(1+4)=24 - 5=19, formula (121) should be rearranged as follows:

$$[\text{BN } (24)] = \text{IF}((\text{V24}>\text{N24}+1, \text{AQ } 15 - \text{AT19}, 0) \quad (122)$$

As mentioned above, when the latent period and/or the recovery period are set, the row numbers for the columns corresponding to the recovery and death periods should be assigned unique numerical values calculated in the same manner as (n-(rp-lp)) and (n-(1+trunc(rp-lp)/2)). When the values of *lp*, *rp* and *rpI* are set in the designated columns of the 24th row, the unique numerical values equivalent to '15' and '19', which are applied to the individual columns in the 24th row, are automatically calculated and shown in the columns necessary for rearranging in the 23rd row. Once you have changed all the columns required to be changed in row 24, copy everything from column A to column DZ in row 24, paste it into the next row, and continue from the 25th row until the row where another independent variable is required to be set/changed. When copies and pastes are finished at the end row necessary, the calculation is finished, and the numerical results and a graph expressing the changes in the number of infected individuals and others are shown in the Excel file.

19) $rpI(n)$: the recovery period, which is the time interval between when an individual is isolated because of a positive test and when he/she returns to the community. This period is equivalent to the 'isolation period' for test-positive individuals. For the recovered individuals who were infected, symptomatic, isolated and returned to the community since they were isolated after the latent period, the 'isolation period' is '$rp(n)$ - $lp(n)$'. However, the 'isolation period' together with the recovery period is set not only from a medical point of view but also from a policy point of view.

20) alI (n): the activity level of the recovered individuals who returned to the community from the isolated category. In other words, it is the activity level for individuals who were isolated because both tested positive and symptomatic and who returned to the community after the recovery period (after the isolation period).

21) al (n): the activity level of the recovered individuals who were asymptomatic, were not isolated and recovered in the community after the recovery period.

22) $alV(n)$: the activity level of the vaccinated individuals who have immunity.

23) $fr(n)$: the fatality rate for asymptomatic infected individuals in the community. Since symptomatic infected individuals should be isolated, $fr(n)$ is applied to asymptomatic infected individuals in the community. For the model proposed here, some infected individuals die on the middle date of the recovery period. Specifically, some of the individuals infected and/or isolated on date *n* die on date (n+(rp-lp)/2). For asymptomatic individuals, when the number of asymptomatic individuals infected on date *n* is $AS(n)$, the $AS(n)* fr(n)$ individuals die on date (n+(rp-lp)/2). Conversely, the death toll of asymptomatic individuals on date *n*, $DAS(n)$, is given by:

$$DAS(n)=AS(n\text{-trunc}((rp\text{-}lp)/2))*fr(n\text{-trunc}((rp\text{-}lp)/2))$$
(123) (=16)

24) *frI*(*n*): the fatality rate for the isolated individuals. Individuals who are confirmed to be infected because they are symptomatic in the community and/or because they test positive are isolated and receive some medical treatment. The fatality rate for isolated individuals is probably different from that for asymptomatic individuals in the community.

For the model proposed here, some isolated individuals die on the middle date of the recovery period; for example, *rpI*/2 is used for individuals who are isolated because they test positive, and (*rp*-*lp*)/2 is used for individuals who are isolated because they are symptomatic. For example, some of the individuals isolated because they test positive on date *n* die on date (*n*+*rpI*/2) days after date *n*. Specifically, when the number of individuals isolated on date *n* is *I*(*n*), the *I*(*n*)* *frI*(*n*) individuals die on date (*n*+*rpI*/2) days after date *n*. Conversely, the death toll on date *n*, *DTI*(*n*), is given by:

$$DTI(n)=I(n\text{-trunc}(rpI/2))*frI(n\text{-trunc}(rpI/2))$$
(124) (= 19)

An Excel table was also used for the recovery period. For example, the column AM is assigned to the death toll (*DTI*), and AM(*n*) indicates the value of *DTI*(*n*) on date *n*. The calculation of *DTI*(*n*) is expressed as follows:

[AM (*n*)] =IF(V(*n*)>trunc(O(*n*)/2), AF(*n*-trunc(*rpI*/2))*I (*n*-trunc(*rpI*/2)), 0) (125)

where column V is assigned to the time (*n*, the number of trials); column O is the recovery period for the isolated individuals because of a positive test (*rpI*); column AF is the number of individuals newly isolated because of a positive test (*I*(*n*)); and column I is the fatality rate for the isolated individuals (*frI*(*n*)). For example, when the recovery period is 14 days and the number of trials is 100, the row number, *n*, is 123. Since *n*-trunc(*rpI*/2)) =123 - trunc(14/2) =123 - 7=116, formula (125) should be rearranged as follows:

[AM123] =IF(V123> trunc(O123/2), AF116 *I116, 0) (126)

Consequently, the number of individuals recovered on date *n*, *RI*(*n*), is given by:

$$RI(n)=I(n\text{-}rpI)\text{-}DTI(n\text{-}(1+\text{trunc}(rpI/2))) = I(n\text{-}rpI)\text{-}I(n\text{-}rpI)*frI(n\text{-}rpI)$$
(127) (= 18)

For the individuals isolated due to being symptomatic, *PI*(*n*), for the calculation of the number of recovered individuals who returned to the community, the same procedure as *rp*(*n*) was used.

Note the following: In the calculation, the numbers below the decimal point are used; however, for the expression of the number of individuals in the table, the nearest whole number is rounded. Specifically, the number of individuals is rounded to a whole number, that is, ‘0.5≦Number of Individuals, then Number=1; 0.5 >Number, then Number=0’. Therefore, regarding the cumulative number and/or total number and/or sum, there may be cases that show a difference of a few persons between the cumulative number/total number/sum of the converted integer and the cumulative number/total/sum number calculated including the decimal point.

2. Dependent variables of the model (results of simulation (101 variables))

The values of the dependent variables are uniquely determined on the basis of the values of the independent variables that you specify. The meanings and calculation processes of the dependent variables are as follows:

2-1) *TN*(*n*): the total population of the community, such as a city, on date *n*. Although *TN* (1) is the initial total population of the community, specified by you, *TN*(*n*) is changed by the number of susceptible individuals (*NAP*(*n*)) and/or infected individuals (*UP*(*n*)) who come in and/or come out of the community, both of which are also specified by you. *TN*(*n*) is given by Eq. (201).

$$TN(n)=TN(n\text{-}1)+NAP(n)+UP(n)$$
(201)(=101)

2-2) *N*(*n*): the population of the 'real' community on the morning of day *n*, excluding the individuals kept in isolation and dead. It is given by:

$$N(n)=TN(n\text{-}1) - (CI(n\text{-}1) + CPI(n\text{-}1) + CDAS(n\text{-}1)) + CRI(n\text{-}1) + CRT(n\text{-}1)$$
(202) (= 26)

while *N* (1) is *TN* (1).

2-3) *P*(*n*): the number of infected individuals in the morning on date *n*, which is equal to the number of infected individuals at night on the previous day, that is, *P*(*n*-1(night)). The initial number of infected individuals (*P*(1)) is specified by you. *P*(*n*) in the morning on the second day and thereafter (*n*>1) is given by:

$$P(n)= P(n\text{-}1(\text{night}))=RP(n\text{-}1)+AP(n\text{-}1(\text{night})) =RP(n\text{-}1)+p(n\text{-}1)*RM(n\text{-}1)$$
(203) (=102, 25)

where *P*(*n*-1(night)) is the number of infected individuals on the previous night. Since an infection occurs during the day from the morning to the evening in the model, the *AP*(*n*(night)), which is the value of *AP*(*n*) at night, is the correct number of individuals newly infected a day.

As noted in the text, the ‘number of infected individuals: *P*(*n*)’ is not the ‘number of individuals newly infected a day: *AP*(*n*)’ but rather the total number of infected individuals currently existing in the community, that is, the sum of the number of infected individuals during the latent period and/or the recovery period.

2-4) trunc (*P*(*n*)): the number of infected individuals truncating the decimal point for reference. for reference.

2-5) *ir*(*n*): the incidence rate in the whole community:

$$ir(n)=P(n)/TN(n)$$
(204) (= 6)

It is expressed not as "per 10,000 person-days" but as a "ratio" for convenience of calculation.

2-6) *tir*(*n*): the percentage of positive results in the PCR test and/or antibody test; that is, the positive rate:

$$tir(n)=bp(n)*ir(n) \quad (205)$$
(= 7)

2-7) *CP*(*n*): the number of individuals confirmed to be infected because they tested positive:

$$CP(n)=T(n)*bp(n)*ir(n) \quad (206)$$
(=103, 5)

2-8) *CCP*(*n*)=Σ*CP*(*n*)

2-9) trunc*CP* (*n*): the number truncating the decimal point of the infected individuals confirmed because they tested positive. This figure is for your reference.

2-10) *TCP*(*n*)=Σtrunc*CP*(*n*)

2-11) *I*(*n*): the number of individuals isolated because they tested positive:

$$I(n)= CP(n-1)*i(n-1) \quad (207)$$
(=116, 4)

where *i*(*n*) is the isolation rate for individuals who are confirmed to be infected because they test positive. The individuals confirmed to be infected on the previous day, the date of (*n*-1), are isolated on date *n* for the purpose of calculation. Thus, *I*(*n*) is given by *I*(*n*)= *CP*(*n*-1) * *i*(*n*-1).

2-12) *CI*(*n*)=Σ*I*(*n*)

2-13) *RAI*(*n*): the remaining number of isolated individuals minus the number of recovered individuals and death toll from the number of individuals isolated due to being test positive:

$$RAI(n)=CI(n) - (RI(n) + DTI(n))$$
(208)

2-14) *RPM*(*n*): the remaining number of infected individuals in the community excluding the number of individuals isolated due to being test positive but including the individuals who tested positive but were not isolated and were staying in the community.

$$RPM(n) =P(n) + UP(n) - I(n-1)$$
(209)

2-15) *AP*(*n*): the number of individuals newly infected for one day from the morning to the night on day *n*. Since infections occur during the day from the morning to the evening in the model, *AP*(*n*) can also be expressed as *AP* (*n* (night)):

$$AP(n)= AP\ (n\ (\text{night}))=RPM(n) – RP(n-1)$$
(210)

The value of *AP*(*n*) includes symptomatic infected individuals, asymptomatic infected individuals in the community and individuals who tested positive but were not isolated and were staying in the community.

Thus, in the Excel file, *AP*(*n*) is given by:

[AJ (*n*)] = AI(*n*)-CI(*n*-1)) (211)

where column AJ is assigned to the *AP*, column AI is assigned to the *RPM* and column CI is assigned to the *RP*. Formula (211) means that

'*AP*(*n*)=*RPM*(*n*)- *RP*(*n*-1)'

2-16) *CAP*(*n*)=Σ*AP*(*n*)

2-17) *DTI* (*n*): the death toll of the individuals isolated because they tested positive. The isolation period was *rpI*:

$$DTI(n)=I(n-\text{trunc}(rpI/2))*frI(n-\text{trunc}(rpI/2))$$
(212) (=124, 19)

2-18) *CDTI*(*n*)=Σ*DTI*(*n*)

2-19) *PI*(*n*): the number of isolated individuals who are isolated because they are symptomatic in the community.

$$PI(n)=AP(n-(lp+1))*\ syr(n-(lp+1)) \quad (213)$$
(=117, 14

2-20) *CPI*(*n*)=Σ*PI*(*n*)

2-21) *AS*(*n*): the number of asymptomatic infected individuals in the community, that is, the number of infected individuals excluding the individuals isolated due to being symptomatic in the community:

$$AS(n)=AP(n-(lp+1))-PI(n) \quad (214)\ (=118, 15)$$

Since asymptomatic individuals are not isolated, they continue to infect susceptible individuals in the community until the recovery period ends, after which they become recovered individuals in the community.

2-22) *CAS*(*n*)=Σ*AS*(*n*)

2-23) *DAS*(*n*): the number of individuals who are asymptomatic and die of infection after the latent period in the community, that is, the death toll in the real community:

$$DAS(n)=AS(n-\text{trunc}((rp-lp)/2))*fr(n-\text{trunc}((rp-lp)/2))$$
(215) (=123, 16)

The date of death of asymptomatic infected individuals remaining in the community was the same as that of symptomatic/isolated infected individuals, as explained by Eqs. (16) and (123).

2-24) *CDAS*(*n*)=Σ*DAS*(*n*)

2-25) *DT*(*n*): the death toll of the individuals isolated due to being symptomatic in the community:

$$DT(n)=PI(n-trunc((rp-lp)/2))*frI(\text{n-trunc}((rp-lp)/2))$$
(216) (= 21)

2-26) *CDT*(*n*)=Σ*DT*(*n*)

2-27) *DDTI*(*n*): the death toll of the individuals isolated because they test positive and symptomatic:

$$DDTI\ (n)= DTI\ (n)+DT\ (n) \quad (217).$$

2-28) $CDDTI(n) = \Sigma DDTI(n)$.

2-29) $DSUM(n)$: sum of the death tolls:

$$DSUM(n)=DTI(n)+DAS(n)+DT(n) \quad (218)$$

2-30) $CDSUM(n) = \Sigma DSUM(n)$

2-31) $RI(n)$: the number of recovered individuals who were isolated because they tested positive and returned to the community after the isolation period ended. It is the number of isolated individuals excluding the death toll. The isolation period was rpI:

$$RI(n)=I(n\text{-}rpI)\text{-}DTI(n\text{-}(1+\text{trunc}(rpI/2))) = I(n\text{-}rpI)\text{-}I(n\text{-}rpI)*frI(n\text{-}rpI) \quad (219)\ (=127, 18)$$

2-32) $CRI(n)=\Sigma RI(n)$

2-33) $ReRI(n)$: the number of individuals who got back to susceptible individuals from recovered individuals (RI) who were isolated because they tested positive:

$$ReRI(n)=CRI(n\text{-}dii)*bii(n\text{-}dii) \quad (220)$$

2-34) $CReRI(n)= \Sigma ReRI(n)$

2-35) $JCReRI(n)$: the adjusted $ReRI(n)$: the number of currently existing susceptible individuals who got back to susceptible individuals from recovered individuals (RI) who were isolated because the test was positive:

$$JCReRI(n)= ReRI(n)\text{-}CAPReRI(n\text{-}1) \quad (221)$$

2-36) $CRIJ(n)$: the number of remaining recovered individuals who were isolated because they tested positive: $CRIJ(n)=CRI(n)\text{-}JCReRI(n)$

2-37) $RT(n)$: the number of recovered individuals who were isolated because they were symptomatic in the community and returned to the community after the isolation period ended. It is the number of isolated individuals excluding the death toll. The isolation period is the value after the latent period is subtracted from the recovery period, that is, rp(n)-lp(n), because these individuals were symptomatic after the end of the latent period, were isolated the next day, and recovered from the disease when the recovery period, which includes the latent period, ended and subsequently returned to the community:

$$RT(n)=PI(n\text{-}(rp\text{-}lp))\text{-}DT(n\text{-}(1+\text{trunc}((rp\text{-}lp)/2)))$$

$$=PI(n\text{-}(rp\text{-}lp))\ \text{-}PI(n\text{-}(rp\text{-}lp))*frI(n\text{-}(rp\text{-}lp)) \quad (222)$$
(= 20)

2-38) $CRT(n) = \Sigma RT(n)$

2-39) $ReRT(n)$: the number of individuals who got back to susceptible individuals from recovered individuals (RT) who were isolated because they were symptomatic:

$$ReRT(n)=CRT(n\text{-}dii)*bii(n\text{-}dii) \quad (223)$$

where $bii(n)$ is the 'back-to' rate at which recovered individuals with infection-induced immunity get back to susceptible individuals a day.

As explained before (see 'Independent variables 11': *dii*), in the calculation, recovered individuals get back to susceptible individuals on day '*dii*' days after they return to the community, and on and after the day, they could become infected again. Since the infected individuals would recover and return to the community on the day '*rp* +2' days after infection, the recovered individuals get back to susceptible individuals on the day '*rp*+2+*dii*' days after infection.

For example, when the recovery period (*rp*) is set to 14 and *dii* is set to 150, the individuals infected on the first day of simulation recover on day 16 and get back to susceptible individuals on day 166, which is the day 150 days after the isolated-recovered individuals return to the community. Conversely, the number of individuals 'getting back to susceptible individuals from isolated-recovered individuals' on day 166, *ReRT* (166), is given by:

$$ReRT(166)= RT\ (16)*bii(16)= RT\ (166 - 150)*bii(166 -150) \quad (224)$$

Eq. (224) is rewritten by substituting 166 by *n* and 150 by *dii*:

$$ReRT(n)= RT\ (n\text{-}dii)*bii(n\text{-}dii) \quad (225)(=223, 113)$$

Eq. (225) indicates the number of individuals getting back to susceptible individuals from isolated-recovered individuals on day *n*. In the Excel file, Eq. (225) is expressed as follows:

$$[BJ(y)] = BH(x)*\ E(x) \quad (226)$$

where *y* is the starting row number (= the starting date when the individuals getting back to susceptible individuals appear) of column BJ, which is assigned to the number of susceptible individuals ($ReRT(n)$) who got back from isolated-recovered individuals; *x* is the row number set to column BH, which is assigned to the number of isolated-recovered individuals a day ($RT\ (n)$); and it is also the row number set to column E, which is assigned to $bii(n)$, which is the 'back-to' rate of individuals with infection-induced immunity a day.

In the Excel file, the 24th row was set to the first day of simulation, and the values of *y* and *x* are given by:

$$y= (23+dii+rp(n)+2) \quad (227)$$

and

$$x= (23+ rp(n)+2) \quad (228)$$

For the Excel file, as mentioned before, the row and column numbers should be given not by function (and/or formula) but by a numerical value. For example, when *dii* is set to 150 and $rp(n)$ is set to 14, the value of *y* becomes 189=23+150+14+2), and the value of *x* becomes 39 (=23+14+2). This indicates that the values of column BH should be set to 0 until date 188, and the first day when the individuals get back to susceptible individuals appear is day 189. Thus, the formula in the 189th row of column BJ is expressed as:

[BJ189] = BH39* E39 (229)

When the value of *dii* is set in the 23rd row of column E and the value of *rp* is set in column N, the unique numerical value of *y*, which is equivalent to '189', is automatically calculated and shown in the 23rd row of column BH, and the unique numerical value of *x*, which is equivalent to '39', is automatically calculated and shown in the 23rd row of column BJ. For the row after the 189th row, the cell of BJ189 should be copied and pasted to the following rows (from the 190th row to the end row necessary). The formulas in the following rows are automatically changed as follows:

[BJ190]= BH40* E40

[BJ191]= BH41* E41

and in the n^{th} row,

[BJ(*n*)] = BH(*n-dii*)* E(*n-dii*) (230)

Formula (230) is mathematically equivalent to

ReRT(*n*)=*RT*(*n-dii*)**bii*(*n-dii*) (231)(=225, 223, 113)

When the COVID-19 epidemic ends, the number of recovered individuals themselves should ultimately be 0. When the number of recovered individuals becomes 0 on date *m*, the value of *ReRT* (*m*+ *dii*) on date (*m*+ *dii*) automatically becomes 0 because *RT* (*m*) becomes 0; that is, the value of BH(*m*) becomes 0. Thus, Eq. (231) indicates that when the epidemic ends on date *m*, the values of *ReRT*(*n*) automatically become 0 on and after date (*m*+ *dii*).

2-40) *CReRT*(*n*)= Σ*ReRT*(*n*)

2-41) *JCReRT*(*n*): the adjusted *ReRT*(*n*): the number of currently existing susceptible individuals who got back to susceptible individuals from recovered individuals (*RT*) who were isolated because they were symptomatic:

JCReRT(*n*)= *CReRT*(*n*)-*CAPReRT*(*n-1*) (232)

where *CAPReRT*(*n*)= Σ *APReRT*(*n*), and *APReRT*(*n*): the number of reinfected individuals among susceptible individuals (*ReRT*) who got back from recovered individuals (*RT*) who were isolated because they were symptomatic:

APReRT(*n*)=*AP*(*n*)*(*JCReRT*(*n*)/*RM*(*n*)) (see 2-83: *APReRT*(*n*)).

2-42) *CRTJ*(*n*): the number of remaining recovered individuals who were isolated because they were symptomatic:

CRTJ(*n*)=*CRT*(*n*)-*JCReRT*(*n*) (233)

2-43) *RAS*(*n*): the number of recovered individuals who were infected once but did not become symptomatic, were asymptomatic, were not isolated, were living in the community, continued to infect susceptible individuals until the recovery period ended, and subsequently recovered. It is equal to the number of asymptomatic infected individuals excluding the death toll:

RAS(*n*)=*AS*(*n*-(*rp*-*lp*))-*DAS*(*n*-(1+trunc((*rp*-*lp*)/2)))= *AS*(*n*-(*rp*-*lp*))-*AS*(*n*-(*rp*-*lp*))**fr*(*n*-(*rp*-*lp*)) (234) (=120, 17)

(see 'Independent variables; 18': *rp*(*n*), Eq. (120))

2-44) *CRAS*(*n*)=Σ*RAS*(*n*)

2-45) *ReRAS*(*n*): the number of individuals who got back to susceptible individuals from recovered individuals (*RAS*; asymptomatic-recovered individuals) who were asymptomatic and were not isolated, were living in the community and had recovered:

ReRAS(*n*)=*CRAS*(*n-dii*)**bii*(*n-dii*) (235)

2-46) *CReRAS*(*n*)= Σ*ReRAS*(*n*)

2-47) *JCReRAS*(*n*): the adjusted *CReRAS*(*n*)

JCReRAS(n)= *CReRAS*(*n*)-*CAPReRAS*(*n*-1) (236)

2-48) *CRASJ*(n): the adjusted number of remaining recovered individuals who were asymptomatic, not isolated and remained in the community:

CRASJ(*n*)=*CRAS*(*n*)- *JCReRAS*(*n*) (237)

2-49) *CRITAS*0(*n*): the total number of the cumulative number of recovered individuals:

*CRITAS*0(*n*) =*CRI*(*n*)+*CRT*(*n*)+*CRAS*(*n*) (238)

2-50) *TReRIRTRAS*(*n*): the total number of susceptible individuals who got back to susceptible individuals from recovered individuals (*RI*, *RT* & *RAS*)

TReRIRTRAS(*n*)=*ReRI*(*n*)+ *ReRT*(n)+*ReRAS*(*n*) (239)

2-51) *JCReRec*(*n*): the cumulative number of susceptible individuals who got back from recovered individuals, excluding the number of individuals who got reinfected, that is, the number of currently existing susceptible individuals who got back from recovered individuals. *JCReRec*(*n*) is the sum of the adjusted *ReRI*(*n*)(=*JCReRI*(*n*)), the adjusted *ReRT*(*n*)(=*JCReRT*(*n*)) and the adjusted *ReRAS*(*n*)(=*JCReRAS*(*n*)):

JCReRec(*n*)=*JCReRI*(*n*)+*JCReRT*(*n*)+*JCReRAS*(*n*) (240)

2-52) *CRITASJ*(*n*): the total number of remaining recovered individuals in the community:

CRITASJ(*n*)=*CRIJ*(n)+*CRTJ*(*n*)+*CRASJ*(*n*) (241)

2-53) *TCRITASJ*(*n*): the adjusted total number of remaining recovered individuals (Susceptible - (Infected +Reinfected)):

TCRITASJ(*n*)=*CRIJ*(*n*)+*CRTJ*(*n*)+*CRASJ*(*n*)-*CTAPReRec*(*n*-1) =*CRITASJ*(*n*)-*CTAPReRec*(*n*-1)(=*SRT*(*n*)) (242)

2-54) *irN*(*n*): the incidence rate in the real community (%). It is for your reference:

irN(*n*)=*P*(*n*)/*N*(*n*)*100 (243)

2-55) *trCP* (*n*): the percentage of positive PCR and/or antibody test results; that is, the positive rate; (%). It is for your reference:

trCP(*n*)=(*CP*(*n*)/*T*(*n*))*100 (244)

2-56) $RM00(n)$: the number of currently existing susceptible individuals in the community at night:

$$RM00(n)= TN(n)+JCReRec(n)-(CI(n)+CAP(n)) \ (=(TN(n)-(CI(n)+CAP(n))) +JCReRec(n)) \quad (245)$$

where $TN(n)$ is the total population of the community; $JCReRec(n)$ is the cumulative number of susceptible individuals who got back from recovered individuals, excluding the number of individuals who got reinfected, that is, the number of currently existing susceptible individuals who got back from recovered individuals; $CI(n)$ is the cumulative number of individuals isolated because they tested positive; and $CAP(n)$ is the $\Sigma AP(n)$, that is, the cumulative number of individuals up to the n^{th} day, including the number of individuals who tested positive but were not isolated and remain in the community. Eq. (245) represents the sum of the number of 'remaining original' susceptible individuals (TN(n)-(CI(n)+CAP(n))) and the number of currently existing susceptible individuals who got back from recovered individuals ($JCReRec(n)$).

2-57) $V0(n)$: the number of individuals vaccinated a day:

$$V0(n) =TN(1)*vd(n) \quad (246)(=104)$$

where $vd(n)$ is the vaccination rate, which is the ratio of the number of individuals newly vaccinated a day to the initial total population of the community. (see 'Independent variables; 7': $vd(n)$, Eq. (104))

2-58) $CV0(n)$: the cumulative number of vaccinated individuals up to day n:

$$CV0(n)=\Sigma V0(n)= \Sigma(TN(1)*vd(n)) \quad (247)(=105,10)$$

Vaccinated individuals have vaccine-induced immunity. They live and work in the real community in Figure 1 (see 'Independent variables; 7': *vd*, Eqs. (104 & 105)).

However, the total number of currently existing vaccinated individuals ($CV0(n)$) must be less than or equal to the total number of the community's population ($TN(n)$) and the number of susceptible individuals in the community ($RM00(n)$). Specifically, ($TN(n)+ RM00(n)-CV0(n)$) should be greater than or equal to 0; that is, $(TN(n)+ RM00(n)-CV0(n))\geqq 0$. Thus, $CV0(n)$ should be less than or equal to the value of $(TN(n)+RM00(n))$; that is, $CV0(n)\leqq(TN(n) +RM00(n))$. Therefore, if $CV0$(n) calculated via Eq. (247) becomes larger than $(TN(n) +RM00(n))$, $CV0$(n) should be set to $(TN(n) +RM00 (n))$; otherwise, $CV0$(n) is given by Eq. (247).

2-59) $JCV0(n)$: the adjusted $CV0(n)$, which is the value of $CV0$(n) adjusted in the manner explained above.

$$JCV0(n)=IF(CV0(n)< (TN(n) +RM00(n)), (TN(n) +RM00(n)), (TN(n) +RM00(n))) \quad (248)(=11)$$

In the Excel file, $JCV0(n)$ is expressed as follows:

[CF(n)-=IF(CE(*n*)<($U(*n*)+CC(*n*)),CE(*n*),($U(*n*)+CC(*n*)))
(249)

where column CF is assigned to $JCV0$; column CE is assigned to $CV0$; column U is assigned to TN; and column CC is assigned to $RM00$. As shown by Eq. (245), $RM00(n)$), $RM00(n)=TN(n)+JCReRec(n)-(CI(n)+CAP(n))$. Formula (249) indicates that:

'If $CV0(n) < (TN(n) +RM00(n))$, then $JCV0 (n)= CV0 (n)$; otherwise, $JCV0(n)= (TN(n) +RM00(n))$'

2-60) $ReVac(n)$: the number of individuals getting back to susceptible individuals from vaccinated individuals:

$$ReVac(n)=V0(n-dvi)*bvi(n-dvi) \quad (250)(=111, 110)$$

where dvi is the duration of vaccine-induced immunity (the validity period of vaccine-induced immunity) and $bvi(n)$ is the 'back to rate' at which vaccinated individuals with vaccine-induced immunity get back to susceptible individuals a day (see 'Independent variables; 8': *ds*, 9: *dvi* & 10: *bvi*).

As explained before (see 'Independent variables 8': *ds*), on the first date when the individuals getting back to susceptible individuals appear, the number of individuals getting back to susceptible individuals ($ReVac(ds+dvi)$) is given by:

$$ReVac(ds+dvi)=V0(ds)*bvi(ds) \quad (251)(=106)$$

where ds is the starting date of mass vaccination, dvi is the duration of vaccine-induced immunity (the validity period of vaccine-induced immunity), and $bvi(n)$ is the 'back to rate' of individuals with vaccine-induced immunity.

For example, ds is set to 51, indicating that vaccination starts on date 51, and the duration of vaccine-induced immunity (dvi) is set to 100, indicating that vaccinated individuals get back to susceptible individuals 100 days after vaccination. The first day when the individuals getting back to susceptible individuals appear is day 151, and the number of individuals getting back to susceptible individuals on that day is as follows:

$$ReVac(51+100)= ReVac(151)=V0(51)*bvi(51) =V0(151-100)*bvi(151-100) \quad (252)$$

Before day 151, $ReVac(n)$ should be set to 0.

Formula (252) is rewritten by substituting 151 by n and 100 by dvi:

$ReVac (151) =V0(151-100) *bvi(151-100)$; that is,

$$ReVac(n)=V0(n-dvi)*bvi(n-dvi) \quad (253)(=250, 111, 110)$$

This indicates that on and after date 151, $ReVac(n)$ is given by Eq. (253), which means that the number of individuals getting back to susceptible individuals on day n is equivalent to (the number of individuals who recovered 'dvi' days before day n) * (the vaccination rate 'dvi' days before day n). As previously noted, Eq. (253) indicates that the immunity of individuals vaccinated on date ($n-dvi$) decreases below a certain threshold on date n.

In the Excel file, Eq. (253) is expressed as follows:

$$[CG(y)]=IF(C(x)>0, CD(x)*D(x), 0) \quad (254)$$

where y is the starting row number (= the starting date when the individuals getting back to susceptible individuals appear) of column CG, which is assigned to the number of individuals ($ReVac(n)$) who get back to susceptible individuals from vaccinated individuals, x is the row number set to both column CD, which is assigned to the number of individuals vaccinated individuals a day ($V0(n)$), and column D, which is assigned to the 'back to rate (bvi)' of individuals with vaccine-induced immunity a day. Column C, which is assigned to the vaccination rate a day ($vd(n)$), indicates that when $vd(n)$ is equal to or less than 0, $ReVac(n)$ is 0.

In the Excel file, the 24th row was set to the first day of simulation, and the values of y and x are given by:

$$y= (23 + ds + dvi) \quad (255)$$

and

$$x= (23+ds) = (y-dvi) \quad (256)$$

For the Excel file, as mentioned before, the row and column numbers should be given not by function (and/or formula) but by a numerical value. For example, when ds is set to 51 and dvi is set to 100, the value of y becomes 174 (=23+51+100), and the value of x becomes 74 (=23+51). This indicates that the value of the column CG should be set to 0 until day 173, and the first date when the individuals getting back to susceptible individuals appear is day 174. Thus, the value of the 174th row of column CG should be expressed as:

$$[CG174]= IF(C74>0, CD74* D74, 0) \quad (257)$$

When the value of ds is set in the 23rd row of column C, the unique numerical value of y, which is equivalent to '174', is automatically calculated and shown in the 23rd row of column CD. When the value of bvi is set in the 23rd row of column D, the unique numerical value of x, which is equivalent to '74', is automatically calculated and shown in the 23rd row of column CG. For the row after the 174th row of column CG, the cell of the CG174 is copied and pasted to the following rows (from the 175th row to the end row necessary). The formulas in the following rows are automatically changed as follows:

[CG175] = IF(C75>0, CD75* D75, 0)

[CG176] = IF(C76>0, CD76* D76, 0)

and in the nth row,

$$[CG(n)] = IF(C(n-dvi)>0, CD(n-dvi)* D(n-dvi), 0) \quad (258)$$

Formula (258) is mathematically equivalent to

$$ReVac(n)=V0(n-dvi) *bvi(n-dvi) \quad (259)(= 253, 250, 111, 110)$$

Additionally, if mass vaccination starts on the 51st day, continues until the 200th day and ends on the 201st day, the value of the 224th row of column C, which is assigned to the vaccination rate $vd(n)$, should be set to 0, that is, C224= 0. Formula (258) is rewritten as

$$[CG324] = IF(C224>0, CD224* D224, 0) \quad (260)$$

where 224=201 (the end date of mass vaccination), +23 (the first row of the simulation), and 324=100 (dvi; the duration of vaccine-induced immunity) +224.

Formula (260) indicates that "when C224 is equal to or less than 0 (since CD224 becomes 0), then CG324 is 0". In other words, the vaccination rate on the 201st day, $vd(201)$ (=C224), is equal to or less than 0, since the number of individuals vaccinated a day on the 201st day ($V0(201)$ (=CD224) becomes 0, then the number of individuals who get back to susceptible individuals from vaccinated individuals on the 301st day ($ReVac(301)$ (=CG324) is 0". Thus, when mass vaccination ends on the 201st day and the values on and after the 224th row of column C are set to 0, the values of column CG (the number of individuals who get back to susceptible individuals from vaccinated individuals) become 0 on and after the 301st day.

As explained above, when the mass vaccination program ends on day m, the values of $ReVac(n)$ become 0 on and after day ($m+dvi$).

2-61) $CReVac0(n)=\Sigma ReVac(n)$

2-62) $JCReVac(n)$: the adjusted $CReVac(n)$. Since susceptible individuals who get back from vaccinated individuals could be infected with breakthrough infection, the number of susceptible individuals who get back from vaccinated individuals, $CReVac(n)$, decreases, accompanied by an increase in breakthrough infection. The adjusted $CReVac(n)$, which is expressed by $JCReVac(n)$, is given by:

$$JCReVac(n) =CReVac(n)-CAPReVac(n-1) \quad (261)$$

$JCReVac(n)$ indicates the number of currently existing susceptible individuals who got back from vaccinated individuals.

2-63) $V(n)$: the number of currently existing vaccinated individuals who have immunity, excluding individuals who have got back to susceptible individuals:

$$V(n) = JCV0(n)-CReVac(n) \quad 262)(= 9)$$

2-64) N (n (night)): the population excluding the individuals kept in isolation and the dead individuals in the real community at night:

$$N(n(\text{night}))=TN(n)-(CI(n)+CPI(n)+CDAS(n)+CDT(n))+CRI(n)+CRT(n) \quad (263)$$

2-65) $RM0(n)$: the number of susceptible individuals excluding the individuals who have got back from vaccinated individuals to susceptible individuals, that is, the number of 'original' susceptible individuals:

$$RM0(n)= TN(n)-(CI(n)+CAP(n)+JCV0(n))+JCReRec(n) \quad (264)$$

where $TN(n)$ is the total population of the community, such as a city, that is, the number of living individuals and the toll of death in the community; $CI(n)$ is $\Sigma I(n)$, that is, the cumulative number of isolated individuals who test positive; $CAP(n)$ is $\Sigma AP(n)$, that is, the cumulative number of individuals newly infected a day, including the number of individuals who test positive but are not isolated; $JCV0(n)$ is the 'adjusted $CV0(n)$' and $CV0(n)$ is the cumulative number of vaccinated individuals up to day n (see 2-59: $JCV0(n)$); and $JCReRec(n)$: the cumulative number of susceptible individuals who got back from recovered individuals, excluding the number of individuals who got reinfected, that is, the number of currently existing susceptible individuals who got back from recovered individuals: $JCReRec(n)=JCReRI(n)+JCReRT(n)+JCReRAS(n)$ (see 2-51: $JCReRec(n)$).

Note the following: $TN(n)$ changes with changes in the number of susceptible individuals ($NAP(n)$) and/or infected individuals ($UP(n)$) coming in and/or coming out of the community. However, since the vaccinated individuals are living in the community and the recovered individuals also have already lived in the community, $TN(n)$ itself is not changed by changes in the numbers of $V(n)$ and $JCReRec(n)$.

2-66) $RM(n)$: the number of susceptible individuals in the community at night, that is, the number of currently existing susceptible individuals, including the 'original' susceptible individuals and the susceptible individuals who got back from recovered individuals:

$$RM(n)= TN(n)-(CI(n)+CAP(n)+V(n))+JCReRec(n) \quad (265)\ (= 46, 3)$$

where $TN(n)$ is the total population of the community such as a city; $CI(n)$ is $\Sigma I(n)$; $CAP(n)$ is $\Sigma AP(n)$; $V(n)$ is the number of vaccinated individuals who are living in the community; and $JCReRec(n)$ is the number of susceptible individuals who got back from recovered individuals. Specifically, Eq. (265) indicates that the number of susceptible individuals $RM(n)$ is calculated by subtracting the cumulative number of individuals tested positive-isolated (CI) and the cumulative number of infected individuals (CAP), including recovered individuals and dead individuals, and moreover, by subtracting the number of vaccinated individuals (V) and adding the number of currently existing susceptible individuals ($JCReRec(n)$). Here, $V(n)$ is the number of currently existing vaccinated individuals who have immunity, excluding individuals who got back to susceptible individuals (see 2-63: $V(n)$):

$$V(n) = JCV0(n)-CReVac(n) \quad (266)(=262, 9).$$

$JCReRec(n)$ is the cumulative number of susceptible individuals who got back from recovered individuals, excluding the number of individuals who got infected again. It indicates the number of currently existing susceptible individuals who got back from recovered individuals (see 2-51: $JCReRec(n)$).

$$JCReRec(n)=JCReRIRT(n)+JCReRAS(n)(=JCReRI(n)+JCReRT(n)+JCReRAS(n)) \quad (267)(=240)$$

2-67) $RP(n)$: the 'Spreader': the number of infected individuals excluding the individuals kept in isolation and the dead:

$$RP(n)=\Sigma(AP(n)-PI(n-1)-DAS(n-1)-RAS(n)) = CAP(n)-CPI(n)-CDAS(n)-CRAS(n) \quad (268)\ (=13)$$

$RP(n)$ indicates the number of infected individuals who are practically infecting susceptible individuals in the real community; this parameter includes the number of individuals who test positive but are not isolated and should be categorized as the 'Spreader' to distinguish from $P(n)$ and $P(n(\text{night}))$, each of which is the gross number of infected individuals before any isolated individuals and/or the dead individuals have been removed.

In an Excel file, for example, $RP(n(\text{night}))$ is given by:

$$[CO(n)] = AK(n)-AP(n)-AU(n)-BO(n) \quad (269)$$

where column CO is assigned to RP; column AK is assigned to CAP; column AP is assigned to CPI; column AT is assigned to $CDAS$; and column BP is assigned to $CRAS$. Formula (269) means that:
$RP(n(\text{night})) =CAP(n)-CPI(n)-CDAS(n)-CRAS(n)$'.

2-68) $SRT(n)+V(n)$: the sum of the number of recovered individuals, $SRT(n)$, and the number of vaccinated individuals who are vaccinated and have immunity, $V(n)$. The value of $SRT(n)$ is the sum of the number of recovered individuals who were isolated due to being test positive, $CRI(n)$, the number of recovered individuals who were isolated due to being symptomatic in the community, $CRT(n)$, and the number of recovered individuals who were asymptomatic infected individuals who continued infecting susceptible individuals in the community until the recovery period ended and then became recovered individuals, $CRAS(n)$:

$$SRT(n))+V(n)=CRI(n)+CRT(n)+CRAS(n)+V(n) \quad (270)$$

From another point of view, $SRT+V$ individuals are those who are not currently infected, and since they have immunity, they will not get infected unless their immunity wanes and will not infect others in the community in the future. However, if their immunity wanes and falls below a certain threshold, they become 'susceptible individuals'.

2-69) $I2(n)$: the number of individuals who are kept in isolation:

$$I2(n)=(CI(n) - CDTI(n)) + (CPI(n) - CDT(n)) - CRI(n) - CRT(n) \quad (271)$$

where $CI(n)=\Sigma I(n)=\Sigma(CP(n-1)^* i(n-1))= \Sigma(T(n-1)^* tr(n-1))$ (272) (see 2-12: $CI(n)$)

$CDTI(n)=\Sigma DTI(n)=\Sigma(I(n-\text{trunc}(rpI/2))^*frI(n-\text{trunc}(rpI/2)))$ (273) (see 2-18: $CDTI(n)$)

$CPI(n)= \Sigma PI(n)=\Sigma(AP(n-(lp+1))^* syr(n-(lp+1)))$ (274) (see 2-20: $CPI(n)$)

$CDT(n)=\Sigma DT(n)=\Sigma(PI(n-\text{trunc}((rp-lp)/2))^*frI(n-\text{trunc}((rp-lp)/2)))$ (275) (See 2-26: $CDT(n)$)

$CRI(n)= \Sigma RI(n)=\Sigma(I(n-rpI)-DTI(n-(1+\text{trunc}(rpI/2))))$ $= \Sigma(I(n-rpI)-I(n-rpI)^*frI(n-rpI))$ (276) (see 2-32: $CRI(n)$)

$CRT(n)=\Sigma RT(n)=\Sigma(PI(n-(rp-lp))-DT(n-(1+\text{trunc}((rp-lp)/2))))$

$= \Sigma(PI(n-(rp-lp))-PI(n-(rp-lp))*frI(n-(rp-lp)))$ (277) (see 2-38: *CRT*(*n*))

2-70) *SN*1(*n*): the population of the whole community in Figure 1 for verification. It is the sum of the number of susceptible individuals in the community at night, *RM*(*n*); the number of infected individuals excluding the individuals kept in isolation and the number of dead individuals, *RP*(*n*); the number of recovered individuals, *SRT*(*n*); the number of vaccinated individuals, *V*(*n*); the number of individuals kept in isolation, *I*2(*n*); the death toll of the individuals isolated due to being test positive, *CDTI*(*n*); the death toll of the individuals isolated due to being symptomatic in the community, *CDT*(*n*); and the number of individuals who are asymptomatic and die of infection after the latent period in the community, *CDAS*(*n*):

$$SN1(n)=RM(n)+ RP(n) + SRT(n)+V(n)+ I2(n) + CDTI(n) + CDT(n) + CDAS(n) \quad (278)$$

2-71) *SN*2(*n*): the population of the whole community for verification. The population values were calculated using the different variables from the case of *SN*1(*n*): the sum of the population excluding the individuals kept in isolation and the dead individuals in the real community at night (*N*(*n*(night))+the number of individuals isolated due to being test positive (*CI*(*n*))+the number of individuals isolated due to being symptomatic in the community (*CPI*(*n*))+ the number of individuals who were asymptomatic and died of infection after the latent period in the community (*CDAS*(*n*)+ the number of currently existing susceptible individuals who got back from the 'isolated-recovered individuals'(*JCReRI* (*n*)+*JCReRT*(*n*))-the number of recovered individuals who were the individuals isolated due to being test positive (*CRI*(*n*))-the number of recovered individuals who were the individuals isolated due to being symptomatic in the community (*CRT*(*n*)):

$$SN2(n)=N(n(\text{night}))+ CI(n) +CPI(n)+ CDAS(n)+JCReRI(n)+JCReRT(n)-CRI(n)-CRT(n) \quad (279$$

2-72) *SN*3(*n*): the population of the whole community for verification and is given by:

$$SN3(n)=CAP(n)-JCReRec(n)-CRITASJ(n)+RM(n)+SRT(n)+V(n) \quad (280)$$

where *CAP*(*n*) is the Σ*AP*(*n*), that is, the cumulative number of individuals up to the n^{th} day, including the number of individuals who test positive but are not isolated and were staying in the community; *JCReRec*(*n*) is the cumulative number of susceptible individuals who got back from recovered individuals, excluding the number of individuals who got infected again, that is, the number of currently existing susceptible individuals who got back from recovered individuals'; *CRITASJ*(*n*): the total number of remaining recovered individuals in the community: *CRITASJ*(*n*)=*CRIJ*(n)+*CRTJ*(*n*)+*CRASJ*(*n*) (see 2-52: *CRITASJ*(*n*)); and *RM*(*n*) is the number of susceptible individuals in the community at night and (*SRT*(*n*)+*V*(*n*)) is the sum of the number of recovered individuals (*SRT*(*n*)) and the number of vaccinated individuals who are vaccinated and have immunity (*V*(*n*)).

2-73) *AL*(*n*): the sum of the activity levels of recovered individuals and vaccinated individuals:

$$AL(n)=alI(n)*(CRI(n)+CRT(n))+al(n)*CRAS(n)+alV(n)*V(n) \quad (281)\ (= 24)$$

where *alI* (*n*) is the activity level of the recovered individuals returning from the isolated category, *al*(*n*) is that of the individuals recovered from the 'asymptomatic' category in the community and *alV*(*n*) is that of the vaccinated individuals. The term *AL*(*n*) is equivalent to the term *δ***R*(*n*) of Eq. (1).

2-74) *cr*(*n*): the contact rate between infected individuals and susceptible individuals:

$$cr(n)=(RM(n)/N(n))\ (1-AL(n)/N(n)) =(RM(n)/N(n))*\ (1-(alI(n)*CRT(n)+alV(n)*V(n))/N(n)) \quad (282)\ (=1, 1')$$

where *RM*(*n*) is the sum of the number of susceptible individuals in the community at night, equivalent to *S*(*n*), and *N*(*n*) is the population excluding the individuals kept in isolation and dead in the real community in the morning. The term (1-(*AL*(*n*)/*N*(*n*))) is the reduction rate of the contact rate, which is equivalent to (1-*δ**(*R*(*n*)/*N*(*n*)) of Eq. (1), expressing the contact rate as:

$$cr(n)=(S(n)/N(n))(1-\delta*(R(n)/N(n))) \quad (1)$$

where *S*(*n*) is the number of susceptible individuals in the community and *R*(*n*) is the number of recovered individuals who returned to the community. Since the number of susceptible individuals (S(n)) is practically represented by *RM*(*n*) and (1-*δ*(*R*(*n*)/*N*(*n*)) is also replaced by '(1-*AL*(*n*)/*N*(*n*))' and/or by '(1-(*alI*(*n*)* *CRT*(*n*)+*alV*(*n*)**V*(*n*))/*N*(*n*))', Eq. (280) is equivalent to Eq. (1) and/or to Eq. (1'):

$$cr(n) =(S(n)/N(n))*\ (1-(alI(n)*\ CRT(n)+alV(n)*V(n))/N(n)) \quad (1')$$

2-75) *p*(*n*): the infection coefficient, which indicates the practical infection rate used in the calculation. This coefficient indicates the infectious capacity, including the contact rate, which changes with the change in the number of susceptible individuals and recovered individuals:

$$p(n)= (pfc(n)/lp(n))*(RM(n)/N(n))*\ icf(n)*\ (1-(AL(n)/N(n)))*(RP(n)/N(n)) \quad (283)\ (=119, 23)$$

2-76) *AP*1(*n*(night)): the number of individuals newly infected on date *n*, that is, the number of infected individuals who increased for one day from the morning to the night on date *n*.

$$AP(n(\text{night}))=(pfc(n)/lp(n))*(RM(n)/N(n))*icf(n)*(1-(alI(n)*(CRI(n)+CRT(n))+al(n)*CRAS(n)+alV(n)*V(n))/N(n))*(RP(n)/N(n))*RM(n) \quad (284)\ (=22, 2)$$

2-77) *CAP*1(n(night)): Σ*AP*(n(night)) for verification.

2-78) *APSus*(*n*): the number of infected individuals among the individuals who were 'original' susceptible individuals until then:

$$APSus(n)=AP(n(\text{night}))*((RM(n)-(CReRI(n)+CReRT(n)+CReRAS(n)+JCReVac(n)))/RM(n)) \quad (285)$$

where *AP* (*n*) (night) is the number of individuals newly infected on date *n*, *RM*(*n*) is the sum of the number of susceptible individuals in the community at night, *CReRI*(*n*)= Σ*ReRI*(*n*), and *ReRI*(*n*) is the number of susceptible individuals who got back to susceptible individuals from recovered individuals (*RI*) who were isolated because they tested positive, *CReRT*(*n*)= Σ*ReRT*(*n*), and *ReRT*(*n*) is the number of susceptible individuals who got back to susceptible individuals from recovered individuals (*RT*) who were isolated because they became symptomatic, *CReRAS*(*n*)=Σ*ReRAS*(*n*), and *ReRAS*(*n*) is the number of individuals who got back from asymptomatic-recovered individuals to susceptible individuals. *JCReVac*(*n*) is the adjusted *CReVac*(*n*) and indicates the number of currently existing susceptible individuals who got back from vaccinated individuals.

2-79) *APSus* (*n*) Ratio: the ratio of *APSus* (*n*) to the total number of infected individuals a day.

2-80) *CAPSus*(*n*) =Σ*APSus*(*n*)

2-81) *APReRI*(*n*): the number of reinfected individuals among susceptible individuals who got back from recovered individuals who were isolated because they tested positive:

$$APReRI(n)=AP(n)*(JCReRI(n)/RM(n)) \quad (286)$$

2-82) *CAPReRT*(*n*)=Σ*APReRT*(*n*)

2-83) *APReRT*(*n*): the number of reinfected individuals among susceptible individuals who got back from recovered individuals who were isolated because they were symptomatic:

$$APReRT(n)=AP(n)*(JCReRT(n)/RM(n)) \quad (287)$$

2-84) *CAPReRT*(*n*)=Σ*APReRT*(*n*)

2-85) *APReRAS*(*n*): the number of reinfected individuals among susceptible individuals who got back from asymptomatic-recovered individuals:

$$APReRAS(n)=AP(n)*(JCReRAS(n)/RM(n)) \quad (288)$$

2-86) *CAPReRAS*(*n*)=Σ*APReRAS*(*n*)

2-87) *APReVac*(*n*): the number of individuals infected with breakthrough infection a day, that is, the number of individuals infected a day among the susceptible individuals who got back from vaccinated individuals. They once had vaccine-induced immunity and became infected with breakthrough infection:

$$APReVac(\text{n})=p(n)*JCReVac(n) \quad (289)$$

where

$$p(n)=(pfc(n)/lp(n))*(RM(n)/N(n))*icf(n)*(1-(AL(n)/N(n)))*(RP(n)/N(n)) \quad (290)(=283, 119, 23)$$

where *AL*(*n*) is the sum of the activity levels of the recovered individuals and vaccinated individuals:

$$AL(n)=alI(n)*(CRI(n)+CRT(n))+al(n)*CRAS(n)+alV(n)*V(n) \quad (291)(=281, 24)$$

The term *AL*(*n*)/*N*(*n*) is equivalent to the term δ(*R*(*n*)/*N*(*n*)), and the term '1-(*AL*(*n*)/*N*(*n*))' is equivalent to the term (1-*δ*(*R*(*n*)/*N*(*n*)) of Eq. (1). *JCReVac*(*n*) is the adjusted number of individuals getting back to susceptible individuals from vaccinated individuals, which indicates the number of currently existing susceptible individuals who got back from vaccinated individuals and is given by Eq. (261).

2-88) *APReVac*2(*n*): the number of individuals infected a day among the susceptible individuals who got back from vaccinated individuals, that is, the number of individuals who are infected with breakthrough infection a day, for verification:

$$APVac2(n)= AP(n(\text{night}))*JCReVac(n)/RM(n) \quad (292)$$

where *AP*(*n* (night)) is the number of individuals newly infected on day *n* and *RM*(*n*) is the sum of the number of susceptible individuals in the community at night.

2-89) *APReVac*(*n*) Ratio: the ratio of *APReVac*(*n*) to the total number of infected individuals a day among susceptible individuals (*AP*(*n* (night))):

$$APReVac(n)\ \text{Ratio}=APReVac(n)/AP(n(\text{night})) \quad (293)$$

2-90) *CAPReVac*(*n*)= Σ*APReVac*(*n*)

2-91) *TAPReRec*(*n*): the total number of individuals who got breakthrough infected among susceptible individuals who got back from recovered individuals:

$$TAPReRec(n)=APReRI(n)+APReRT(n)+APReRAS(n)$$

$$=AP(n)*(JCReRI(n)/RM(n))+AP(n)*(JCReRT(n)/RM(n))+AP(n)*(JCReRAS(n)/RM(n))$$

$$=AP(n)*((JCReRI(n)+JCReRT(n)+JCReRAS(n))/RM(n)$$
$$=AP(n)*(JCReRec(n)/RM(n)) \quad 294)$$

Note the following: The cumulative number (*JCReRec*(*n*)) of susceptible individuals getting back from recovered individuals, excluding the number of individuals who got infected again. *JCReRec*(*n*) is the sum of the adjusted *ReRI*(*n*)(=*JCReRI*(*n*)), the adjusted *ReRT*(*n*)(=*JCReRT*(*n*)) and the adjusted *ReRAS*(*n*)(=*JCReRAS*(*n*)) and is given by Eqs. (240) and (267):

$$JCReRec(n)=JCReRI(n)+JCReRT(n)+JCReRAS(n)) \quad (240\ \&\ 267)$$

2-92) *TAPReRec*(*n*) Ratio: the ratio of *TAPReRec*(*n*) to the total number of infected individuals a day among susceptible individuals (*AP*(*n*(night))):

$$TAPReRec(n)\ \text{Ratio}=TAPReRec(n)/AP(n(\text{night})) \quad (295)$$

$$\text{2-93) } CTAPReRec(n)=\Sigma TAPReRec(n)=\Sigma(APReRI(n)+APReRT(n)+APReRAS(n)) \quad (296)$$

2-94) *TRecVac* Ratio(*n*): the total ratio of the *APReVac*(*n*) Ratio and the *TAPReRec*(*n*) Ratio:

$TRecVac(n)$Ratio=$APReVac$Ratio(n)+$TAPReRec$Ratio(n) (297)

2-95) TRatio(n): Total ratio for verification (total should be 1.0):

TRatio(n) =$APSus(n)$ Ratio+$APReVac(n)$ Ratio+$TAPReRec(n)$ Ratio (298)

2-96) $P(n(\text{night}))$: the number of infected individuals at night, that is, the total number of infected individuals in the morning and the individuals newly infected on date n:

$P(n(\text{night})) = RP(n)+AP(n(\text{night})) = RP(n) + p(n) * RM(n)$ (299) (=203, 102, 25)

where $RP(n)$ is the number of infected individuals excluding the individuals kept in isolation and the dead individuals.

In an Excel file, for example, $P(n(\text{night}))$ is given by:

[DT(n)] = (CX(n)*CN(n)) +CO(n) (300)

where column DT is assigned to P (n (night)); column CO is assigned to RP; column F is assigned to pfc; column N is assigned to rp; and column CX is assigned to p. Additionally, column CN is assigned to RM, which means that:

P (n (night)) =$p(n)$*$RM(n)$+$RP(n)$'.

In addition, $P(n)$ is given by:

[X(n)] = DT(n-1) (301)

where column X is assigned to $P(n)$, which is the number of infected individuals in the morning on day n. This means that '$P(n)$ is equal to the number of infected individuals on the previous night (n-1(night))':

$P(n)= P(n-1(\text{night}))$ (=$AP(n-1(\text{night})+ RP(n-1)) = p(n-1)*RM(n-1)+ RP(n-1)$ (203)) (see 2-3: $P(n)$)

2-97) $AP2(n)$: the number of individuals newly infected on date n for verification:

$AP2(n)=P(n(\text{night})) +UP(n)-RP(n)$ (302)

2-98) $CAP2(n)=\Sigma AP2(n)$

2-99) trunc$AP2(n)$: the number truncating the decimal point of the individuals newly infected on date n. It is for your reference.

2-100) $TAP2(n)= \Sigma \text{trunc}AP2(n)$

2-101) $\Delta P1(n)$: the increment of newly infected individuals, AP, per day,

$\Delta P1(n) = AP(n(\text{night})) - PI(n)$ (303)

where $AP(n(\text{night}))$ is the number of individuals newly infected on date n,

$AP(n(\text{night}))= p(n)* RM(n)$ (304) (= 22)

and $PI(n)$ is the number of individuals isolated because they are symptomatic in the community,

$PI(n)= AP(n-(lp+1))* syr(n-(lp+1))$ (305) (=213, 117, 14)

2-102) $\Delta P2(n)$: the increment of infected individuals, P, per day for verification:

$\Delta P2(n)=P(n(\text{night})) - P(n-1(\text{night}))$ (306)

where $P(n(\text{night}))$ is the number of infected individuals at night,

$P(\text{n(night)}) = RP(n)+AP(n(\text{night}))$ (307) (=299, 203, 102, 25)

2-103) $\Delta P3(n)$: the increment of infected individuals, P, per day on the previous day, for verification,

$\Delta P3(n)=P(n) - P(n-1)$ (308)

where $P(n)$ is the number of infected individuals in the morning on date n (=the number of infected individuals at the night before; P(n-1(night)).

Appendix 2: Part of the Excel file of the 'flexible compartment model for simulation specific to COVID-19 (for "Effect of reinfection on the spread of COVID-19 evaluated by a flexible compartment model") H. Ohmori

rp (n): the recovery period which is the time interval between when an individual is infected and when he/she is not capable of infecting.

fiI (n): the fatality rate for the isolated individuals

rpI (n): the recovery peri…od which is the time interval between when an individual is isolated due to being test positive and when he/she comes back to the community, that is, the 'isolation p…

syr (n): the symptomatic rate of the individuals who are confirmed to be infected due to being symptomatic in the community and are isolated

pfc (n): the potential(biological) infectious capacity of coronavirus which is an approximate value indicating that the number of susceptible infected by an infected individual during the latent period.

bii (n): the ' back to' rate for individuals with infection-induced immunity a day and

dii: the duration of infection-induced immunity (in the 23rd row)

icf (n): the infec…tion reduction rate by infectious control measures preventing the spread of virus by such as facemask, partition and disinfectant.

bvi (n): the 'back to' rate for individuals with vaccine-induced immunity a day, and

dvi: the duration of vaccine-induced immunity (in the 23rd row)

bp (n): t…he magnification of incidence rate for PCR test to the incidence rate ir (n) (=P (n)/TN (n)) in the community.

alV (n): the activity level of the vaccinated indivi…duals.

vd (n): the vaccination rate for individuals vaccinated a day and **ds**: the date of start of vaccination (in the 23rd row)

alI (n): the activity level of the recovered individuals return from is…olated category

al (n): the activity level of individuals recovered from the '…asymptomatic' in the community

fr (n): the fatality rate for the asymptomatic infeced individuals in the community

i (n): the isolation rate for the individuals who are confirmed to be infected due to test positive.

lp (n): the latent period which is the time i…nterval between when an individual is infected and when he/she is symptomatic.

CP (n): the number of infected individu…

N (n): the population excluding the individuals kept in isolation and dead in the community: N (n)=TN (n)-…

ir (n): the incidence rate in the community: ir (n)=P (n)/TN (…

truncP (n): the number of infected individuals truncating the decimal point f…

truncCP (n): the…

CCP (n)=ΣCP (n).

NAP (n): the value of increase or decrease in number of susceptible individuals due to external factors such as travelling and migration.

UP (n): the value of increase or decrease in number of infected individuals due to external factors such as travelling and migration

TN (n): the total population of the community; TN (1): the initial population, arbitrarily set in the cell of row 23. TN (n) is changed…

T (n): the number of individuals having PCR and/or antibody tests.

P (n): the infected individuals (P (n -1(night)) & **P (1)**: the initial number of infected individual…

tir (n): the positive rate for the test: bp (n)*ir (n)…

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
Time: Trial n	i (n)	vd (n) →CF	bvi (n) →CE,CF	bii (n)→BD,BE; BJ,BK;BQ,BR;	pfc (n)	syr (n)	fr (n)	fiI (n)	alI (n)	al (n)	alV (n)	lp (n)	rp (n)	rpI (n)	icf (n)	bp (n)
		ds	**dvi**	**dii**												
0		**0**	**0**	**0**												
1	1.000	0.000	1.000	1.000	1.000	1.000	0.0000	0.0000	1.00	1.00	1.00	5.00	14.0	14.0	1.000	5.00
2	1.000	0.000	1.000	1.000	1.000	1.000	0.0000	0.0000	1.00	1.00	1.00	5.00	14.0	14.0	1.000	5.00
3	1.000	0.000	1.000	1.000	1.000	1.000	0.0000	0.0000	1.00	1.00	1.00	5.00	14.0	14.0	1.000	5.00
4	1.000	0.000	1.000	1.000	1.000	1.000	0.0000	0.0000	1.00	1.00	1.00	5.00	14.0	14.0	1.000	5.00
5	1.000	0.000	1.000	1.000	1.000	1.000	0.0000	0.0000	1.00	1.00	1.00	5.00	14.0	14.0	1.000	5.00
6	1.000	0.000	1.000	1.000	1.000	1.000	0.0000	0.0000	1.00	1.00	1.00	5.00	14.0	14.0	1.000	5.00
7	1.000	0.000	1.000	1.000	1.000	1.000	0.0000	0.0000	1.00	1.00	1.00	5.00	14.0	14.0	1.000	5.00

R	S	T	U	V	W	X	Y	Z	AA	AB	AC	AD
T (n)	NAP (n); NAP (1)=0	UP (n); UP (1)=0	TN (n)	**Time: Trial n**	N (n); N (1)=TN (1)	P (n) X(n)=DT(n -1)	trunc(P (n)) for reference	ir (n)	tir (n)	CP (n)	CCP (n)	truncCP (n) for reference
						P (1)						
	0	**0**	**1,000,000**	**0**		**1**						
0	**0**	**0**	**1,000,000**	**1**	1,000,000	1	**1**	0.00000	0.00001	0	0	0
0	0	0	1,000,000	**2**	1,000,000	1	1	0.00000	0.00001	0	0	0
0	0	0	1,000,000	**3**	1,000,000	1	1	0.00000	0.00001	0	0	0
0	0	0	1,000,000	**4**	1,000,000	2	1	0.00000	0.00001	0	0	0
0	0	0	1,000,000	**5**	1,000,000	2	2	0.00000	0.00001	0	0	0
0	0	0	1,000,000	**6**	1,000,000	2	2	0.00000	0.00001	0	0	0
0	0	0	1,000,000	**7**	1,000,000	3	2	0.00000	0.00001	0	0	0

AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS
uals confirmed due to being test positive: *CP*(*n*)=*T*(*n*)**bp*(*n*)**ir*(*n*).														
eriod'.														
-(*CI*(*n*)+*CPI*(*n*)+*CDAS*(*n*)+*CDT*(*n*))+*CRI*(*n*)+*CRT*(*n*).														*DAS*(*n*): t
n)).												*AS*(*n*): the number of asymptoma		
or reference.								*DTI*(*n*): the death toll of the individuals isolated due to being test positive:						
e number truncating the decimal point of infected individuals confirmed due to being test positive											*CPI*(*n*)= Σ*PI*(*n*)			
TCP(*n*)= Σtrunc*CP*(*n*)					*AP*(*n*) : the number of infected individuals having increased for one day from the previous day: *AP*(*n*)= *RPM*									
		CI(*n*)=Σ*I*(*n*).	*RPM*(*n*) : the remainder of infected individuals in the community excluding the individuals isolated due to being test-posit											
			RAI(*n*): the remainder of isolated individuals subtracting the number of recovered individuals and death toll from the number of indiv											
by coming in/going out of the susceptible (*NAP*(*n*)) and/or the infected (*UP*(*n*))									*CDTI*(*n*)=Σ*DTI*(*n*)					
s in the community, arbitrarily set in the cell W of row 23.						*CAP*(*n*) =Σ*AP*(*n*).				*PI*(*n*): the number of individuals isolated due to being s				
.	*I*(*n*): the number of individuals isolated due to being positive for PCR test: *I*(*n*)=*i*(*n*-1)**CP*(*n*-1)=*T*(*n*-1)**tr*(*n*-1).												*CAS*(*n*)=Σ*AS*(*n*)	
TCP(*n*) for reference	*I*(*n*)	*CI*(*n*)	*RAI*(*n*)	*RPM*(*n*)	*AP*(*n*)	*CAP*(*n*)	**Time: Trial, *n***	*DTI*(*n*)	*CDTI*(*n*)	*PI*(*n*)	*CPI*(*n*)	*AS*(*n*)	*CAS*(*n*)	*DAS*(*n*)
	ABx,Bx							AFx,Ix		AJx,Gx		AJx		AQx,Hx
	23					指定すべきコラムNo. **x**	**0**	**17**		**18**		**18**		**20**
0	0	0	0	1	1	1	**1**	0	0	0	0	0	0	0
0	0	0	0	1	0	1	**2**	0	0	0	0	0	0	0
0	0	0	0	1	0	1	**3**	0	0	0	0	0	0	0
0	0	0	0	2	0	2	**4**	0	0	0	0	0	0	0
0	0	0	0	2	0	2	**5**	0	0	0	0	0	0	0
0	0	0	0	2	0	2	**6**	0	0	0	0	0	0	0
0	0	0	0	3	0	3	**7**	0	0	1	1	0	0	0

AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF
the number of individuals who are asymptomatic and die of infection after the latent period in the community, that is, the death toll in the community: *DAS*(*n*)=*AS*(*n*-trunc((*rp*-*lp*)/2))**fr*												
atic infected individuals in the community: *AS*(*n*)=*AP*(*n*-(*lp*+1))-*PI*(*n*).												
DTI(*n*)= *I*(*n*-trunc(*rpI*/2)**frI*(*n*-trunc(*rpI*/2)).												
	DT(*n*): the death toll of the individuals isolated due to being symptomatic in the community: *DT*(*n*)=*PI*(*n*-trunc((*rp*-*lp*)/2))**frI*(*n*-trunc((*rp*-*lp*)/2)).											
(*n*) – *RP*(*n*-1).			*DDTI*(*n*):the death toll of the individuals isolated due to being test positive and ymptomatic: *DDTI*(*n*)= *DTI*(*n*)+*DT*(*n*).									
tive: *RPM*(*n*)=*P*(*n*)+*UP*(*n*)-*I*(*n*-1).					*DSUM*(*n*):sum of the death toll:*DSUM*(*n*)=*DTI*(*n*)+*DAS*(*n*)+*DT*(*n*).							
iduals isolated due to being test positive: *RAI*(*n*)=*CI*(*n*)-(*RI*(*n*)+*DTI*(*n*)).								*RI*(*n*): the number of recovered individuals who were isolated due to being test pos				
CDAS(*n*)= Σ*DAS*(*n*)										*ReRI*(*n*): the number of susceptible individualswho got bac		
ymptomatic in the community: *PI*(*n*)= (*AP*(*n*-(*lp*+1))* *syr*(*n*-(*lp*+1)).						*CDSUM*(*n*) =Σ*DSUM*(*n*)					*CReRI*(*n*): the cumulative number o	
		CDT(*n*)= Σ *DT*(*n*)	*CDDTI*(*n*) =Σ*DDTI*(*n*).						*CRI*(*n*)= Σ *RI*(*n*)			*JCReRI*(*n*): the
CDAS(*n*)	*DT*(*n*)	*CDT*(*n*)	*DDTI*(*n*)	*CDDTI*(*n*)	*DSUM*(*n*)	*CDSUM*(*n*)	**Time: Trial, *n***	*RI*(*n*)	*CRI*(*n*)	*ReRI*: BD(*n*)= BB(*n*-*dii*)*$E(*n*-*dii*)	*CReRI*(*n*): Σ*ReRI*(*n*)	*JCReRI*(*n*)= BE(n)-DE(*n*-1)
	AOx,Ix							BB=AFx, AMx		**y** line of BD=	**x** of BBx* $Ex in **y**	
	20						**0**	**10**	**16**	**0**	**0**	
0	0	0	0	0	0	0	**1**	0	0	0	0	0
0	0	0	0	0	0	0	**2**	0	0	0	0	0
0	0	0	0	0	0	0	**3**	0	0	0	0	0
0	0	0	0	0	0	0	**4**	0	0	0	0	0
0	0	0	0	0	0	0	**5**	0	0	0	0	0
0	0	0	0	0	0	0	**6**	0	0	0	0	0
0	0	0	0	0	0	0	**7**	0	0	0	0	0

BG	BH	BI	BJ	BK	BL	BM	BN	BO	BP	BQ
(*n* -trunc((*rp-lp*)/2)).										
CRIJ (*n*): the number of remaining recovered individuals who were isolated due to being test positive: *CRIJ* (*n*)=*CRII* (*n*)-*JCReRI* (*n*)								*RAS* (*n*): the number of recovered individuals		
			ReRT (*n*): the number of susceptible individuals who got back from Recovered (*RT*) who were isolated due to being symptomatic : *ReRT* (*n*)							
		CRT (*n*) = Σ *RT* (*n*)								
	RT (n): the number of recovered individuals who have been isolated due to being symptomatic in the community: *RT* (*n*)=*PI* (*n*- (*rp-lp*))-*DT* (*n* -trunc((*rp-lp*)/2)).									
sitive: *RI* (*n*)=*I* (*n* -*rpI*)-*DTI* (*n* -(1+trunc(*rpI* /2)))=*I* (*n* -*rpI*)-*I* (*n* -*rpI*)**frI*(*n* -*rpI*)						*CRTJ* (*n*): the number of remaining recovered individuals who were isolated c				
k to Susceptible from Recovered (*RI*) who were isolated due to being test positive : *ReRI* (*n*)=*CRI* (*n* -*dii*)**bii* (*n* -*dii*)										*ReRAS* (*n*): the numb
f susceptible individuals who got back from Recovered (*RI*)= Σ*ReRI* (*n*)					*JCReRT* (*n*): the ajdusted *ReRT* (*n*)= *ReRT(n)-CAPReRT* (*n*-				*CRAS* (*n*)=Σ*RAS* (*n*)	
e ajdusted *ReRI* (*n*)= *ReRI(n)-CAPReRI* (*n*- 1)				*CReRT* (*n*): the cumulative number of susceptible individuals who got back from Recovered (*RT*)=Σ*ReRT* (*n*)						
CRIJ (*n*)= *CRI* (*n*)-*JCReRI* (*n*)	*RT* (*n*)	*CRT* (*n*)	*ReRT* : BJ(*n*)= BH(*n-dii*)*$E(*n-dii*)	*CReRT* (*n*): Σ*ReRT* (*n*)	*JCReRT* (*n*)= BK(*n*)-DG(*n* -1)	*CRTJ* (*n*)= *CRT* (*n*)-*JCReRT* (*n*)	**Time: Trial, *n***	*RAS* (*n*)	*CRAS* (*n*)	*ReRAS* : BQ(*n*)= BO(*n-dii*)*$E(*n-dii*)
	BH=AOx, AUx		**y** line of BJ=	**x** of BH* $Ex in **y**				BO=AQx, ASx		**y** line of BQ=
	15 19		**0**	**0**			**0**	**15 19**		**0**
0	0	0	0	0	0	0	1	0	0	0
0	0	0	0	0	0	0	2	0	0	0
0	0	0	0	0	0	0	3	0	0	0
0	0	0	0	0	0	0	4	0	0	0
0	0	0	0	0	0	0	5	0	0	0
0	0	0	0	0	0	0	6	0	0	0
0	0	0	0	0	0	0	7	0	0	0

BR	BS	BT	BU	BV	BW	BX	BY	BZ
							TCRITASJ (*n*): Adjusted total numb	
						CRITASJ (*n*): total number of remaining recovered individu		
s who have been asymptomatic infected individuals, having continued infecting in the community until the recovery period was ended and then have become the recovered individuals: *RAS* (*n*								
=*CRT* (*n* -*dii*)**bii* (*n* -*dii*)					*JCReRec* (*n*): Total of the cumulative numbers of susceptible individuals gett			
		CRASJ (*n*): the number of remaining recovered individuals who were asymptomatic, not isolated and staying in the community: *CRASJ* (*n*)=*CRAS*						
				TReRIRTRAS (*n*): Total of the number of susceptible individuals who got back to Susceptible from R				
lue to being symptomatic: *CRIJ* (*n*)=*CRII* (*n*)-*JCReRI* (*n*)			*CRITAS* 0(*n*): total number of the cumulative number of Recovered individuals: *CRITAS* 0(*n*) =*CRI* (*n*)+*CRT(n*)+*CRAS* (*n*					
er of susceptible individuals who got back to Susceptible from Recovered (RAS) who were asymptomatic and staying in the community: *ReRAS* (*n*)= *CRAS* (*n-dii*)*dvi(*n-dii*)								
	JCReRAS (*n*): the ajdusted *ReRAS* (*n*)= *ReRAS(n)-CAPReRAS* (*n*- 1)							
CReRAS (*n*): the cumulative number of susceptible individuals who got back from Recovered (*RAS*)= Σ*ReRAS* (*n*)								
CReRAS (*n*): Σ*ReRAS* (*n*)	*JCReRAS* (*n*)= BR(*n*)-DI(*n* -1)	*CRASJ* (*n*)= *CRAS* (*n*) - *JCReRAS* (*n*)	*CRITAS* 0(*n*); BC(*n*)+BI(*n*)+BP(*n*)	*TReRIRTRAS* (*n*)= BD(*n*)+BJ(*n*)+BQ(*n*)	*JCReRec* : BF(*n*) +BL(*n*)+BS(*n*)	*CRITASJ* (*n*);BG(*n*) +BM(*n*)+BT(*n*)	*TCRITASJ* (*n*);BG(*n*)+ BM(*n*)+BT(*n*)-DQ(*n* -1)	**Time: Trial, *n***
x of BOx* $Ex in **y**								
0								**0**
0	0	0	0	0	0	0	0	1
0	0	0	0	0	0	0	0	2
0	0	0	0	0	0	0	0	3
0	0	0	0	0	0	0	0	4
0	0	0	0	0	0	0	0	5
0	0	0	0	0	0	0	0	6
0	0	0	0	0	0	0	0	7

er of remaining recovered individuals (Susceptible - (Infected +Reinfected)): CRITASJ (n)=CRIJ (n)+CRTJ (n)+CRASJ (n)-CTAPReRec (n -1)=CRITASJ (n)-CTAPReRec (n -1)(=SRT (r

ıals who have not got reinfected yet: CRITASJ (n)=CRIJ (n)+CRT J(n)+CRASJ (n)

)=AS (n -(rp -lp))-DAS (n- (1+trunc(rp-lp)/ 2))=AS (n -(rp -lp))-AS (n -(rp -lp))*fr (n -(rp -lp))

:ing back from Recovered: JCReRec (n)=JCReRI (n)+JCReRT (n)+JCReRAS (n)

JCReVac (n): the adjusted CReVac 0(n) =Σ

(n)-JCReRAS (n)

CV0 (n): the number of vaccinated individuals who are vaccinated and have immunity: CV 0(n) =ΣV 0(n)

Recovered (RI , RT & RAS)=ReRI (n)+ ReRT (n)+ReRAS (n)

ReVac (n): the number of individuals getting back to Susceptible from Vaccinated: ReV

)

V 0(n): the number of vaccinated individuals who are vaccinated and have immunity: V 0(n) = TN (1)*vd (n).

trCP (n) : the positive rate for the test: trCP (n)= (CP (n)/T (n))* 100.

CReVac 0(n)=ΣReVac (n)

V (n): the adjusted nu

RM 00(n): the number of susceptible individuals in the community at night (before Vaccination): RM 00(n)= TN (n)+JReRec (n)-(CI (n)+CAP (n))

irN (n): the incidence rate in the real community: irN (n)=(P (n)/N (n)))*100

JCV 0(n): the adjusted CV0 (n) =ΣV 0(n). If CV 0(n) < (TN (n) +RM 00(n)), then JCV 0 (n)= CV 0 (n); ot

CA	CB	CC	CD	CE	CF	CG	CH	CI	CJ	CK
irN (n), %	trCP (n), %	RM 00(n);U(n)+BW(n) -(AG(n) +AK(n))	V 0(n)	CV 0(n)= ΣV 0(n)	JCV 0(n)= adjusted CV 0	ReVac (n): **CGy=IF(Cx>0,CDx*Dx,0)**	CReVac 0(n)= ΣReVac (n)	JCReVac (n)= adjusted CReVac 0	V (n)	**Time: Trial, n**
					y of CGy=	**x of Cx, CDx*Dx of CGy**				
				0	**0**	**0**	**0**	**0**		**0**
0.000	0.000	999,999	0	0	0	0	0	0	0	1
0.000	0.000	999,999	0	0	0	0	0	0	0	2
0.000	0.000	999,999	0	0	0	0	0	0	0	3
0.000	0.000	999,998	0	0	0	0	0	0	0	4
0.000	0.000	999,998	0	0	0	0	0	0	0	5
0.000	0.000	999,998	0	0	0	0	0	0	0	6
0.000	0.000	999,997	0	0	0	0	0	0	0	7

RM 0(n): the number of susceptible individuals excluding the individualswho have got back from vaccinated individuals (fter Vaccination): RM 0(n)= TN (n)-(CI (n)+CAP (n)+JCV 0

RM (n): the number of susceptible individuals in the community at night (after Duration of Immunity/ Breakthrough Infection and/or Reinfection): RM (n)= TN (n)-(CI (n

ı))

RP (n),'Spreader': the number of infected individuals excluding the individuals kept in isolation and the dead: RP (n)=CAP (n)-CPI (n) - CDAS (n)-CRASJ (

SN 1(n): the population of the whole community: SN 1(n)=RM (n)+RP (n)+SRT (n))+V (n)+II (n)+CDTI (n)+CDT (n)

SN 2(n): the population of the whole community: SN 2(n)=N (n (night))+ CI (n) +CPI (n)+ CDAS(n)+JC

ReVac 0(n)-CAPVac (n -1)

SN 3(n)= CAP (n)-JCReRec (n)-CRITASJ (n)+RM (n)+SRT (n)+V (n)

AP 1(n (night)):

N (n (night)): the population excluding the individuals kept in isolation and dead in the real community at night: N (n)=TN (n)-(CI (n)+CPI (n)+CDAS (n))+JCReRI (n)+JCReRT (n)+(CRITASJ (n)

ıc (n)=V 0(n -dvi)*bvi (n-dvi)

I2 (n): the number of individuals kept in isolation: I 2(n)=CI (n)- DTI (n)+CPI (n)-CDT (n)-CRI (n)-CRT (n).

AL (n): the sum of the activity levels of the recovered individuals a

ımber of vaccinated individuals who are vaccinated and have immunity: V (n) = JCV 0(n)-CReVac 0(n)

p (n): the infection coefficient: p (n

cr (n): the contact rate: cr (n)=(RM (n)/N (n)) (1-AL

herwise, JCV 0(n)= (TN (n) +RM 00(n))

SRT (n))+V (n): the sum of the number of recovered individuals, SRT (n)(=TCRITASJ (n)), and the number of vaccinated individuals who are v

CL	CM	CN	CO	CP	CQ	CR	CS	CT	CU	CV	CW	CX	CY
N (n (night))	RM 0(n) ; (night)	RM (n) ; (night)	RP (n); (night)	SRT (n))+V (n) (night)	I 2(n) (night)	SN 1(n) for verification	SN 2(n) for verification	SN 3(n) for verification	**Time: Trial, n**	AL (n) (night)	cr (n) contact rate	p (n) (night)	AP 1(n) (night)
			0						**0**				
1,000,000	999,999	999,999	1	0	0	1,000,000	1,000,000	1,000,000	1	0.00	1.00	0.0000002	0.2000
1,000,000	999,999	999,999	1	0	0	1,000,000	1,000,000	1,000,000	2	0.00	1.00	0.0000002	0.2400
1,000,000	999,999	999,999	1	0	0	1,000,000	1,000,000	1,000,000	3	0.00	1.00	0.0000003	0.2880
1,000,000	999,998	999,998	2	0	0	1,000,000	1,000,000	1,000,000	4	0.00	1.00	0.0000003	0.3456
1,000,000	999,998	999,998	2	0	0	1,000,000	1,000,000	1,000,000	5	0.00	1.00	0.0000004	0.4147
1,000,000	999,998	999,998	2	0	0	1,000,000	1,000,000	1,000,000	6	0.00	1.00	0.0000005	0.4977
999,999	999,997	999,997	2	0	1	1,000,000	1,000,000	1,000,000	7	0.00	1.00	0.0000004	0.3972

CZ	DA	DB	DC	DD	DE	DF	DG	DH	DI	DJ	DK
(n))+JCReRec (n)											
)+CAP (n)+V (n))+JCReRec (n)+CTAPReRec (n -1)											
n)											
+CDAS (n)	APSus (n): the number of infected individuals excluding the number of 'Newly multi-time Reinfected individuals': APSus (n)=AP 1(n (night))*((RM (n)-(CJCReRI (										
CReRI (n)+JCReRT (n)-CRI (n)-CRT (n)											
the number of individuals newly infected on the day for the currently existing susceptible individuals: AP 1(n (night))=p (n)*RM (n);Calculate including decimal places											
-CRASJ (n))								APReRAS (n): the number of individuals who were reco			
CAP 1(n (night)): the cumulative number of infected individuals: ΣAP1(n (night); n +1(in the next morning))											
nd vaccinated individuals: AL (n)=alI (n)*(CRI (n)+CRT (n))+al (n)*CRAS (n)+alV (n)*V (n)											APVac (n): t
)= (pfc (n)/lp (n))* (RM (n)/N (n))* icf(n)* (1-AL (n)/N (n)) *(RP (n)/N (n))						APReRT (n): the number of individuals who were recovered individuals and got reinfectio					
(n)/N (n))				APReRI (n): the number of individuals who were recovered individuals and got reinfection among RI : APReRI (n)=AP (n							
accinated and have immunity, V (n).			CAPSus (n) =ΣAPSus (n)		CAPReRI (n)=ΣAPReRI (n)		CAPReRT (n)=ΣAPReRT (n)		CAPReRAS (n)=ΣAPReRAS (n)		
CAP 1(n) (night)	APSus (n)	APSus (n) Ratio	CAPSus (n)	APReRI (n)	CAPReRI (n)	APReRT (n)	CAPReRT (n)	APReRAS (n)	CAPReRAS (n)	**Time: Trial, n**	APVac (n)
										0	
1.20	0.200	1.0000	1.20	0.000	0.000	0.000	0.000	0.000	0.000	**1**	0
1.44	0.240	1.0000	1.44	0.000	0.000	0.000	0.000	0.000	0.000	**2**	0
1.73	0.288	1.0000	1.73	0.000	0.000	0.000	0.000	0.000	0.000	**3**	0
2.07	0.346	1.0000	2.07	0.000	0.000	0.000	0.000	0.000	0.000	**4**	0
2.49	0.415	1.0000	2.49	0.000	0.000	0.000	0.000	0.000	0.000	**5**	0
2.99	0.498	1.0000	2.99	0.000	0.000	0.000	0.000	0.000	0.000	**6**	0
3.38	0.397	1.0000	3.38	0.000	0.000	0.000	0.000	0.000	0.000	**7**	0

DL	DM	DN	DO	DP	DQ	DR	DS	DT	DU	DV	DW
									AP 2(n): the number of infected individuals (		
									AP 2(n)=P (n (night))+UP (n)-RP (n)+TAPRe		
APVac 2(n): the number of individuals who got breakthrough infection among ReVac : APVac 2(n)=AP (n)*(JCReVac (n)/RM (n))											trunc(AP 2(n)) :
n)+JCReRT (n)+JCReRAS (n)+JCReVacJ (n)))/RM (n))											on the day
						TRecVac Ratio(n): Ratio of total of breakthrough infection among ReRec (got back from infect					
						and ReVac (got back from vaccinated individuals): TRecVac (n)=APVac Ratio(n)+APRec Ratio					
vered individuals and got reinfection among RAS : APReRas (n)=AP (n)*(JCReRAS (n)/RM (n))										CAP 2(n)=ΣAP 2(n) (Calculate	
			TAPReRec (n): the total number of individuals who were recovered individuals returned from isolation and got Newly multi-time Reinfection (se								
he number of individuals who got breakthrough infection among ReVac (the individuals who got back to Susceptive from Vaccinated): APVac (n)=p (n)*ReVac (n)											
n among RT: APReRT (n)=AP (n)*(JCReRT (n)/RM (n))								P (n (night): the number of infected individuals at night: P (n (			
)*(JCReRI (n)/RM (n))					CTAPReRec (n): the cumulative number of 'Newly reinfected (newly multi-time infected) individuals': TAPReRe						
		CAPVac (n)=ΣAPVac (n)					TRatio: Total of ratios: TRatio (n)=APSus Ratio(n)+APVac Ratio(n)+APRec R				
APVac 2(n) verification	APVac (n) Ratio	CAPVac (n)	TAPReRec (n)	APRec (n) Ratio	CTAPReRec(n)	TRecVac Ratio(n)	TRatio (n): for verification	P (n (night))	AP 2(n) for verification	CAP 2(n) for verification	trunc(AP 2(n)) for reference
		0	**0**		**0**			**1.0**			
0.00	0.000	0	0.000	0.000	0.000	0.000	1.000	1.2000	0	1	0
0.00	0.000	0	0.000	0.000	0.000	0.000	1.000	1.4400	0	1	0
0.00	0.000	0	0.000	0.000	0.000	0.000	1.000	1.7280	0	2	0
0.00	0.000	0	0.000	0.000	0.000	0.000	1.000	2.0736	0	2	0
0.00	0.000	0	0.000	0.000	0.000	0.000	1.000	2.4883	0	2	0
0.00	0.000	0	0.000	0.000	0.000	0.000	1.000	2.9860	0	3	0
0.00	0.000	0	0.000	0.000	0.000	0.000	1.000	2.3832	0	3	0

Citation: Ohmori H (2025) Effect of Reinfection on the Spread of COVID-19 Evaluated by a Flexible Compartment Model. Ameri J Clin Med Re: AJCMR-238. *https://doi.org/10.71010/2835-9496/ajcmr-e240.*

DX	DY	DZ	EA	EB
New and Reinfec) on the day:				
Rec (*n*);Calculate including decimal places				
the number truncating the decimal point of individuals newly infected .				
ed individuals)				
(*n*)				
including decimal places)				
econd/third/+): *TAPReRec* (*n*)=*APReRI* (*n*)+*APReRT* (*n*)+*APReRAS* (*n*)				
TAP 2(*n*)=Σtrunc(*AP* 2(*n*))			ΔP 2=*P* (*n* (night)) -	
(night)) =*p* (*n*)**RM* (*n*)+*RP* (*n*)=*AP* (*n*)+*RP* (*n*)			*P* (*n* -1(night))	
c (*n*): *CTAPReRec* (*n*)=Σ*TAPReRec* (*n*)				ΔP 3=(*P* (*n*) -*P* (*n* -1))
atio(*n*)		ΔP 1=*AP* (*n* (night)) -*PI* (*n*)		
TAP 2(*n*) for reference	Time: Trial, n	ΔP 1(*AP* (*n* (night)) - *PI* (*n*))	ΔP 2 for verification	ΔP 3 for verification
	0			
1	1	1.20	1.20	1.00
1	2	0.24	0.24	0.20
1	3	0.29	0.29	0.24
1	4	0.35	0.35	0.29
1	5	0.41	0.41	0.35
1	6	0.50	0.50	0.41
1	7	-0.60	-0.60	0.50

EC	ED	EE	EF	EG	EH	EI	EJ
TN (1)= 1,000,000		*P* (1)= 1.000		*pfc* = 1.000		*lp* = 5.00	
rp = 14.0		*aII* = 1.000		*aI* = 1.000		*aIV* = 1.000	
		activity level of Iso.		act. level in city		act. level of Vac.	
syr = 1.000		*fr* = 0.000		*frI* = 0.000			
symptomatic rate		fatality rate in city		fatality rate of Iso.