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SHORT REPORT

The estimated impact of decreased childhood vaccination due to COVID-19 using a dynamic transmission model of mumps in Japan

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ABSTRACT

The exact impact of the decline in childhood vaccination coverage during COVID-19 outbreak has not been estimated for any vaccine-preventable diseases. Our objective was to evaluate the impact of decreased mumps vaccination due to COVID-19 on the disease burden of mumps in Japan. Using a previously validated dynamic transmission model of mumps infection in Japan, the incidence rate of mumps over the next 30 y since July 2020 was estimated. The estimated average incidences were 269.1, 302.0, and 455.4/100,000 person-years in rapid recovery, slow recovery, and permanent decline scenarios. Compared with the rapid recovery scenario, the incremental number of mumps cases, total costs, and QALYs loss over the next 30 y were 6.53 million cases, 2.63 billion USD, and 49,246 for the permanent decline scenario, respectively. In conclusion, the persistent decline of mumps vaccination rate as an impact of COVID-19 causes a significant incremental disease burden of mumps, which is consistent irrespective of the possible decline of transmission rate of mumps infection, unless the rapid recovery of coverage rate is achieved. The immediate measures to advocate the vaccination program is essential to mitigate the incremental disease burden in the COVID-19 period.

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Background

Decreased childhood vaccine coverage rate due to the coronavirus disease 2019 (COVID-19) outbreak is a serious public health threat.[1] Japan has also reported that the national or regional vaccine coverage rates have dropped since January 2020.[2] If the suboptimal vaccine coverage persists, a subsequent surge of vaccine-preventable diseases may be unavoidable.

Mumps is one of the vaccine-preventable diseases, which has caused a significant disease burden where the vaccine coverage rate is low. In countries where the vaccine coverage rate is suboptimal, mumps epidemics usually occur every 4–5 y. Given that the basic reproductive number of mumps is between 4 and 10, at least 75–90% of the population should be immune to mumps to suppress endemics.[3] In the Japanese national immunization program, the mumps vaccine is included in voluntary vaccination, for which families are required to pay the vaccine cost out-of-pocket. The national coverage rate of mumps vaccine had been as low as 30–40% for the first dose in Japan before 2014.[4] The suboptimal coverage caused uncontrolled epidemics. A previous study revealed that mumps-induced sensorineural hearing loss was a major cause of acquired hearing loss, accounting for up to 25% of pediatric single-sided deafness between 2006 and 2016.[5] However, the recent advocate programs have improved the coverage rate. A recent study reported that the vaccine coverage rate improved to approximately 60% since 2014 when varicella vaccine was included into routine immunization.[4] A national report showed that the national number of mumps vaccinations in 2017–2018 further increased by approximately 20% compared to that in 2014–2016 (Supplemental Figure S1).[6] Subsequently, the national disease incidence rate has decreased. A national sentinel report revealed that the annual number of mumps cases per designated medical facility was reduced to 4.8–50.4 (average 22.6) from 2015 to 2019 compared to 21.7–61.3 (average 41.3) from 2005 to 2009.[7]

However, there is a concern that the incidence of mumps infection may rise again if the drop in childhood vaccine coverage rate persists due to the impact of COVID-19. To our knowledge, the exact impact of the decline in childhood vaccination coverage during COVID-19 outbreak has not been estimated for any vaccine-preventable diseases. Our objective was to evaluate the impact of decreased mumps vaccination due to COVID-19 on the disease burden of mumps in Japan.

Materials and methods

Using a previously validated SEIR (Susceptible-Exposed-Infected-Recovered) dynamic transmission model of mumps infection in Japan (Figure S2),[8] the incidence rate of mumps over the next 30 y from July 2020 was estimated. The data of recent coverage rate (Figure S1) and national population were incorporated in the model.[2,4,6,9–11] The details of the model were provided in Supplemental file. Since January 2020, the

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coverage was assumed to linearly decrease until June 2020, reaching a 35% relative reduction in June 2020 compared to that from 2015 to 2019 (Table S1).[2] The coverage rate of second dose was assumed to be half of that of first dose from a previous study.[9] The model run was conducted from January 2015 to December 2049. The validation of the model was performed by comparing the incidence from the model run from January 2015 to December 2019 to the observed incidence in the same 5-y period. The model was programmed in Berkeley Madonna version 8.3.18 (Berkeley, CA, USA) and Microsoft Excel 2016 (Redmond, WA, USA).

In the base scenario, the reduction of mumps transmission rate by measures to mitigate the impact of COVID-19 (self-isolation, social distance, etc.) was estimated since January 2020 in the model (20% of relative reduction from January to June 2020 compared to that from 2015 to 2019). The reduction of transmission rate was assumed to be halved from July 2020 compared to that of January to June 2020 period because of governmental phased reduction of mitigating measures with some expected permanent effects of COVID-19 on the transmission rate due to lifestyle changes (10% reduction in transmission rate since July 2020 compared to that from 2015 to 2019).[12] However, due to a large uncertainty of the future transmission rate, a sensitivity analysis with a wide range of reduction in transmission rate was performed (0% to −30% reduction from January 2020 to December 2049 compared to that from 2015 to 2019) since January 2020 to December 2049 compared to that from 2015 to 2019. In terms of the recovery of mumps vaccine coverage rate in the COVID-19 period, the rapid recovery scenario and permanent decline scenarios were prepared to evaluate the effect of decline in mumps vaccine rate over time. The rapid recovery scenario assumed a full recovery of vaccination rate to that in pre-COVID-19 period since July 2020, while the permanent decline scenario had permanent negative effect on mumps vaccination rate throughout the study period. In addition, a slow recovery scenario a decreased coverage rate for the next 5 y until June 2025 and then a full recovery of vaccination rate to that in pre-COVID-19 period was also created because previous data about a drop of a national childhood vaccination rate showed that the full recovery could take several years or more once it had dropped.[13,14] Medical and social costs, as well as quality-adjusted life years (QALYs) loss, were calculated using the method described in our previous studies with a 3% discount rate.[8,15] The evaluated outcomes of the study were differential number of mumps infections, quality-adjusted life years (QALY) loss, medical cost, and total cost between rapid recovery scenario and permanent decline scenario.

We performed a one-way sensitivity analysis to evaluate the uncertainty of impact of COVID-19 on incidence of mumps infections with the following parameters: the base mumps vaccination rate without COVID-19 impact (first and second doses: 60–90% and 30–45%, respectively), the relative reduction in mumps vaccination due to the impact of COVID-19 (20–50% of relative reduction compared to that in the pre-COVID-19 period), and the relative reduction of transmission rate throughout the COVID-19 period (0% to −30% compared with that of pre-COVID-19 period).[2,16]

Results

The previously validated model with the input of recent vaccination coverage rate and population data in the pre-COVID-19 period showed the incidence rate for the first 5 y (2015–2019) was 423.8/100,000 person-years (Figure 1), whereas the real range of total incidence rate by national data from 2015 to 2019 was 411.3/100,000 person-years (the annual incidence rate in 2019 was a preliminary report at the time of our model run).[6] This model reproduced the observed mumps incidence in the pre-COVID-19.

Then, the model had the linear reduction of vaccine coverage rate as well as the 20% reduction of transmission rate in the first 6 months (from January to June 2020). The incidences of the three scenarios (gradual recovery, rapid recovery, and permanent decline in vaccination rates) over the next 30 y since July 2020 are shown in Figure 1. The estimated average incidences in the three scenarios were 269.1, 302.0, and 455.4/100,000 person-years in rapid recovery, slow recovery, and permanent decline scenarios, respectively, with periodic

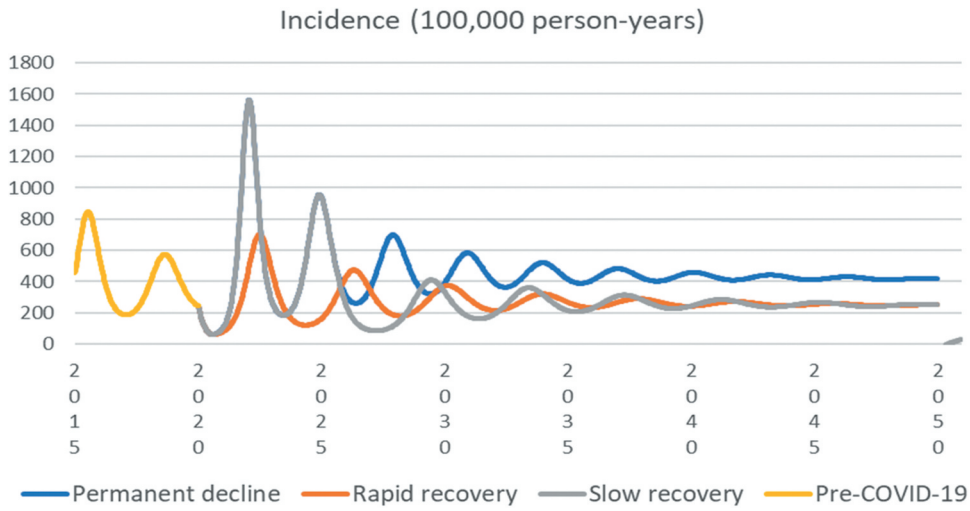

Figure 1. Incidences of mumps infection in the three scenarios (permanent decline, slow recovery, and rapid recovery). Incidences in permanent decline and slow recovery scenarios are identical until July 2025.

Table 1. The incremental disease burden of mumps in permanent decline scenario compared to rapid recovery scenario due to the impact of COVID-19 on mumps vaccination rate.

	Incremental number of cases	QALYs loss	Incremental medical costs loss[a]	Incremental total costs loss[a]
1 y	73,288	787	$12,179,636	$41,955,305
3 y	777,934	8,180	$126,636,951	$436,227,488
5 y	1,815,071	18,141	$280,841,982	$967,419,002
10 y	2,559,602	24,540	$379,896,706	$1,308,633,735
30 y	6,528,855	49,246	$762,374,910	$2,626,159,985

[a]Unit, US dollar. QALY, quality-adjusted life year.

epidemics over the study period. Compared with the rapid recovery scenario, the incremental number of mumps cases and total costs as well as incremental QALYs loss over the next 30 y were 6.53 million cases, 2.63 billion USD, and 49,246 for the permanent decline scenario, respectively (Table 1). There were 1.23 million incremental mumps cases, 0.69 billion USD incremental total costs, and 12,941 incremental QALYs loss over the next 30 y in the slow recovery scenario compared to the rapid recovery scenario.

The results of the one-way sensitivity analysis are shown in Figure 2. In all the three parameters, the number of mumps cases in the next 30 y in permanent decline scenarios were larger than that in rapid recovery scenario with the incremental number of cases ranging from 3.99 million to 9.15 million.

Discussion

The study showed a significant incremental disease burden of mumps if the decline of vaccination rate was persistent in the COVID-19 period. This incremental disease burden is consistent irrespective of expected reduction in mumps transmission rate due to the impact of COVID-19. The study also revealed that a rapid recovery of vaccination coverage significantly decreases the disease burden compared with those in slow recovery and permanent decline. These results confirmed the importance of the rapid recovery of vaccination rate to mitigate the impact of declined vaccination rate due to COVID-19.

Some factors which were not included in our study could have affected our results. A consideration of catch-up vaccination during the recovery phase can decrease the incremental disease burden. Financial support from a government is known to be the key factor to raise mumps vaccine rate.[9,17] Our study has several limitations. First, there is a large uncertainty about the duration and the magnitude of impact of COVID-19 on childhood vaccination rate and transmission rate of mumps. Even though there were some previous data about national decline in childhood vaccination rate, these events occurred due to concerns of vaccine side effects.[13,14] The current decline in vaccination rate in Japan is from parental hesitation to visit health-care facilities amid the impact of COVID-19.[2] However, the wide estimated ranges of the parameters in the sensitivity analysis did not change our main findings, which supports the robustness of our conclusion. Second, the model did not consider the differential impact of age on mumps transmission rate due to mitigation measures of COVID-19 and assumed the same impact of declined mumps transmission rate throughout all the age groups. The exact estimation of the age-specific differential impact of COVID-19 on transmission rate of mumps may not be possible due to the lack of accurate data,

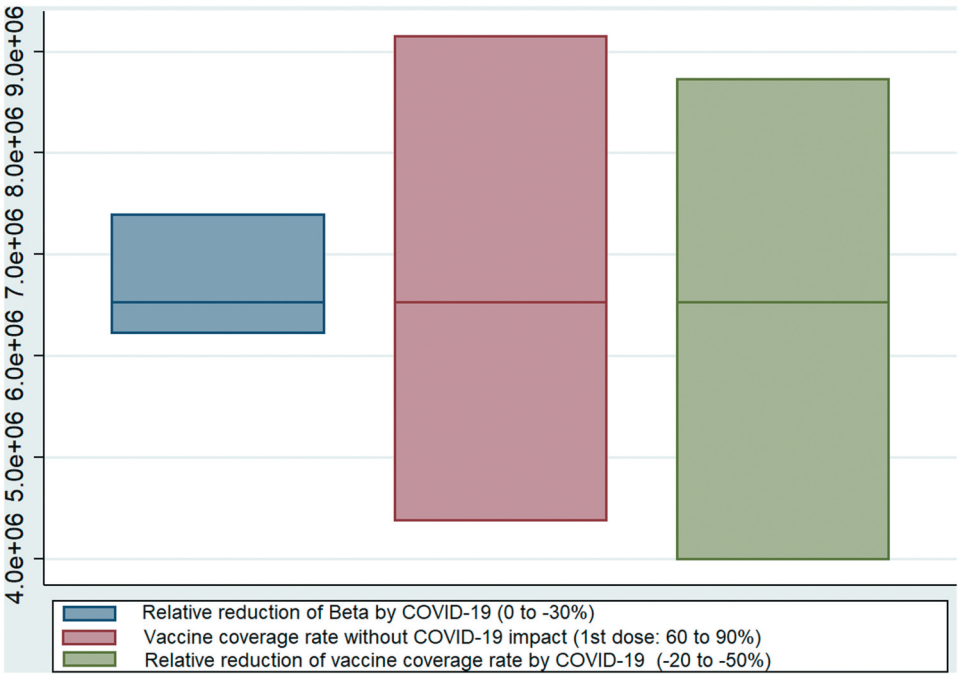

Figure 2. Sensitivity analysis for incremental number of mumps cases in permanent decline scenario compared to rapid recovery scenario from 2020 to 2049. In the base case scenario, the transmission rate from January to June 2020 and from July 2020 to December 2049 was reduced by 20% and 10% compared to that from 2015 to 2019. One-way sensitivity analyses were performed as following ranges of each factor; the relative reduction of transmission rate in the COVID-19 period (0% to −30% compared with that of pre-COVID-19 period), the base mumps vaccination rate without COVID-19 impact (first and second doses: 60–90% and 30–45%) and the relative reduction in mumps vaccination due to the impact of COVID-19 (20–50% of relative reduction compared to that in the pre-COVID-19 period).[2,14]

considering the age-specific factor may present some additional result once more detailed data of the differential impact of transmission rate on respiratory viruses due to COVID-19 outbreak by age is available. Third, given the nature of our deterministic model without forcing, our model showed a decreasing magnitude of cyclic outbreaks, approaching an endemic equilibrium in the later half of the study period. Although this may not reflect the cyclic nature of mumps endemics, we believe that the significant difference in the cumulative incidence over the study period among the different scenarios is still informative.

In conclusion, the persistent decline of mumps vaccination rate as an impact of COVID-19 causes a significant incremental disease burden of mumps, which is consistent irrespective of the possible decline of transmission of mumps infection by COVID-19 mitigation measures, unless the rapid recovery of coverage rate is achieved. The immediate measures to advocate the vaccination program is essential to mitigate the incremental disease burden in the COVID-19 period.

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Disclosure of potential conflicts of interest

No potential conflicts of interest were disclosed.

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