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Estimating the Transmission Dynamics of SARS-CoV-2 Calibrated with Severe Health Outcomes: a Modelling Study

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Background

SARS-CoV-2 has led to over seven million deaths globally since its emergence in late 2020. Immunisations are expected to have halved the global mortality toll by the end of 2021, however, more timely and equitable coverage globally could have doubled their impact (1). Hong Kong experienced its largest wave early in 2022 caused by Omicron BA.2 (2). The immunization coverage in high-risk groups lagged other high-income countries (2). During the outbreak, immunisation uptake increased significantly along with the implementation of other infection control measures.

Retrospectively assessing the impact of infection control measures is essential to inform future outbreak control measures. Mathematical models can be used to simulate outbreaks and alternative scenarios. Severe health outcome data can be a superior data stream to assess transmission dynamics (3) and calibrate the model as they may be relatively more robust to the confirmed case data streams, which can fluctuate over time.

Objectives

The objective of this study was to fit a transmission model to observe severe health outcomes to simulate the fifth wave outbreak in 2022. Alternative vaccination coverage scenarios will be simulated using the fit model, to estimate the impact of immunisations campaigns on the transmission and disease burden in Hong Kong.

Methods

Severe COVID-19 events data (hospitalisation, severe or critical condition (SCC) and mortality) were collated from 22 January to 30 April 2022. Using an age- and vaccination-structured SEIR epidemic model (Figure 1), we simulated the transmission. Probability density functions estimated the delay from infection to severe event. During the wave's peak magnifying factors for severe event risk were fit to account for the overwhelmed healthcare system. The model simulated the event dates which were fit to the observed data using negative binomial distributions. Bayesian inference allowed model calibration.

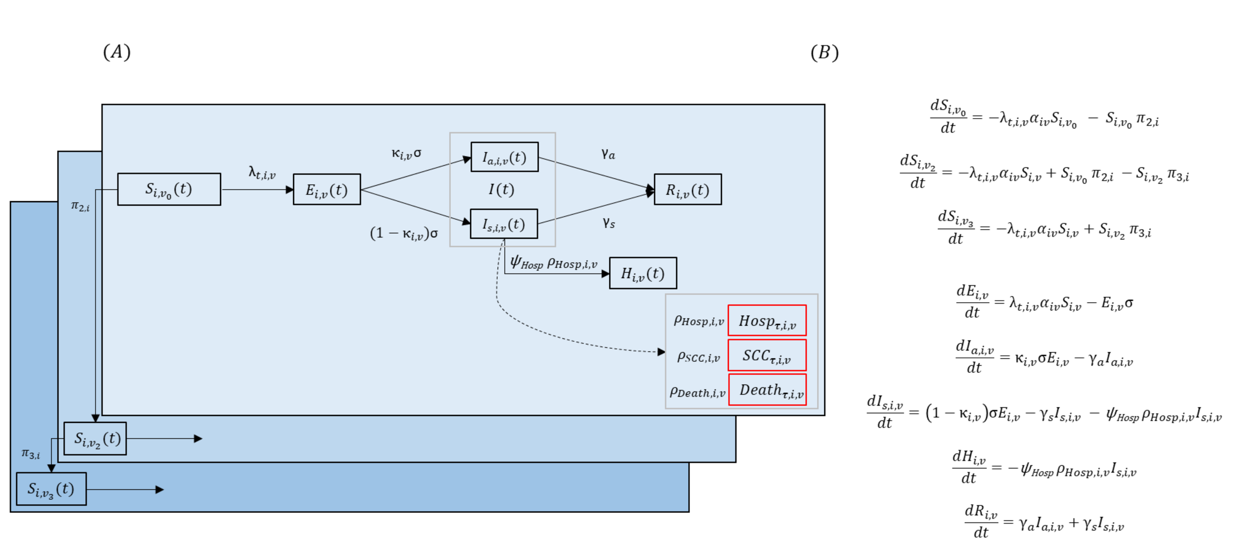

Figure 1. (A) The SEIR model representing the transmission of COVID-19 within a closed population. (B) Differential equations describing the transition of individuals between system variables. Individuals remain within their respective vaccination level after infection, and only transition between levels within the susceptible stage. Hosp, SCC and Death compartments represent the observed data.

We simulated vaccination coverage scenarios, using the fit model with the noted modifications (Figure 2). The total disease outcome of the simulations were analysed, considering infections, infection attract rate (IAR), hospitalisations, SCC and the death toll.

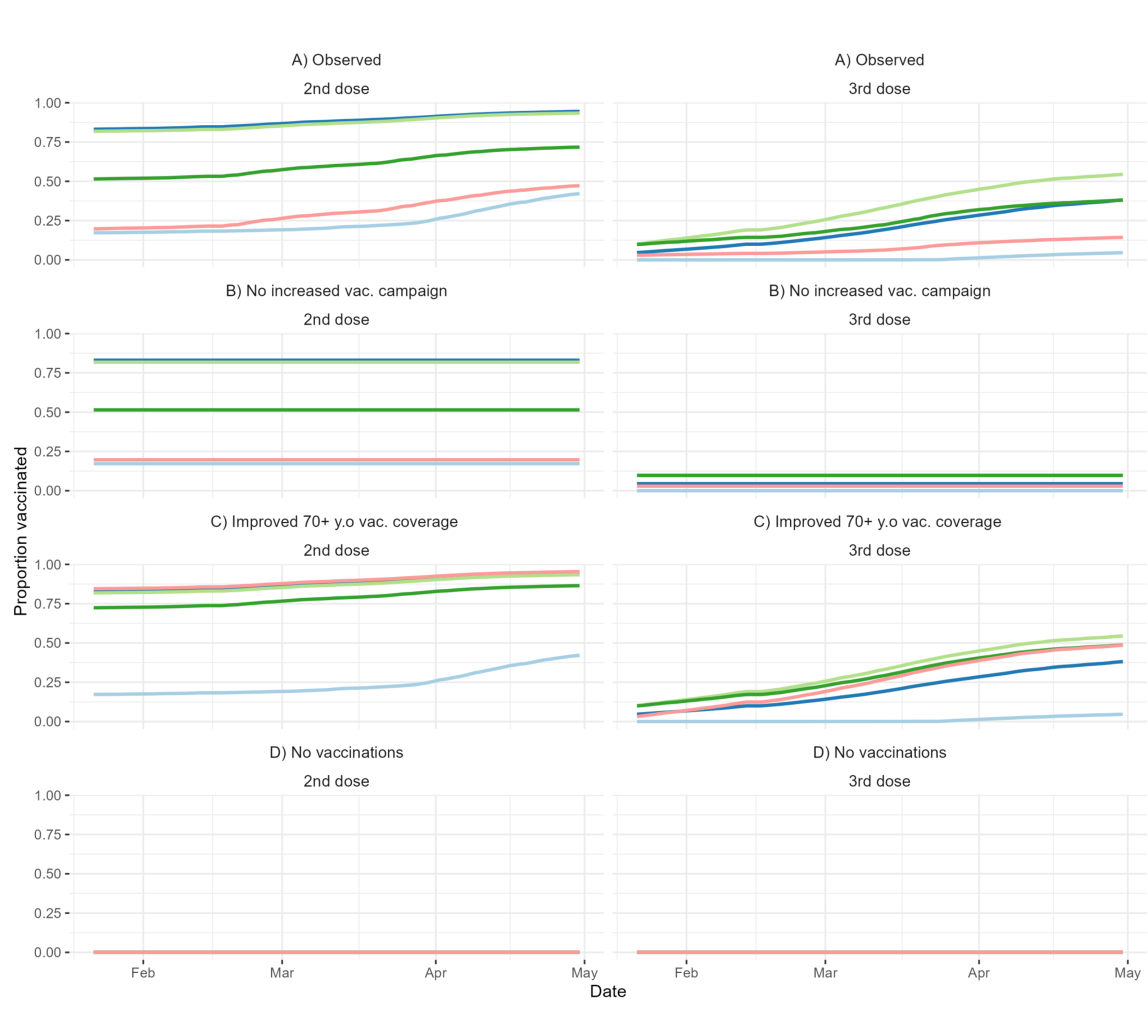

Figure 2. Vaccination coverage simulations scenarios run through fit transmission model. A) Simulation based on observed vaccination coverage and uptake. B) Scenario wherein there was no increased vaccination campaign during the outbreak and coverage remained stagnant. C) Improved coverage in the elderly (+70 y.o) where they have the same coverage and uptake as the most vaccinated age group (40-49 y.o.) D) Scenario where there are no vaccinations.

Results

During the BA.2 outbreak from 22 January and 30 April 2022 in Hong Kong, there were 51,570 hospitalisations, 6,372 severe or critical cases, and 8,379 mortalities. The baseline fit model (A) estimates that 54.1% (95% CI, 45.7 – 59.6%) of the total population were infected during this period. The infections and disease burden estimates, from the baseline model (A) and our alternative scenarios (B–D) are shown cumulatively Table 1 and over-time in Figure 3.

Table 1. Infection and disease burden of COVID-19 in Hong Kong by simulated scenarios, 22 January - 30 April 2022 (per 1000 individuals)

Simulation	Infections	Hospitalisations	Severe or critical cases	Mortalities
A) Observed baseline	3879 (3263-4277)	52 (48-56)	6 (6-7)	9 (8-9)
B) No increased vac. campaign	4457 (3807-4774)	69 (65-74)	8 (8-9)	10 (10-11)
C) Improved 70+ y.o vac. coverage	3818 (3207-4216)	38 (35-41)	3 (3-4)	4 (4-4)
D) No vaccinations	6113 (5409-6712)	240 (215-286)	28 (25-34)	32 (28-36)

[a] Note: Disease burden is measured per 1,000 of infections, hospitalisations, severe or critical cases, and mortalities.

Had Hong Kong's population not undergone an aggressive vaccination campaign during the outbreak, there may have been an excess of 27 – 37% hospitalisations and 10 – 24% mortalities in the population (simulation B). With improved vaccination uptake in the elderly population (simulation C), the total mortality may have been nearly halved, although there was not any significant difference in the total number of individuals infected. In an alternative scenario where there were no available vaccines (simulation D), the model estimates the infection attack ratio in the population would have been between 73 – 91% and the mortality toll would have been more than triple.

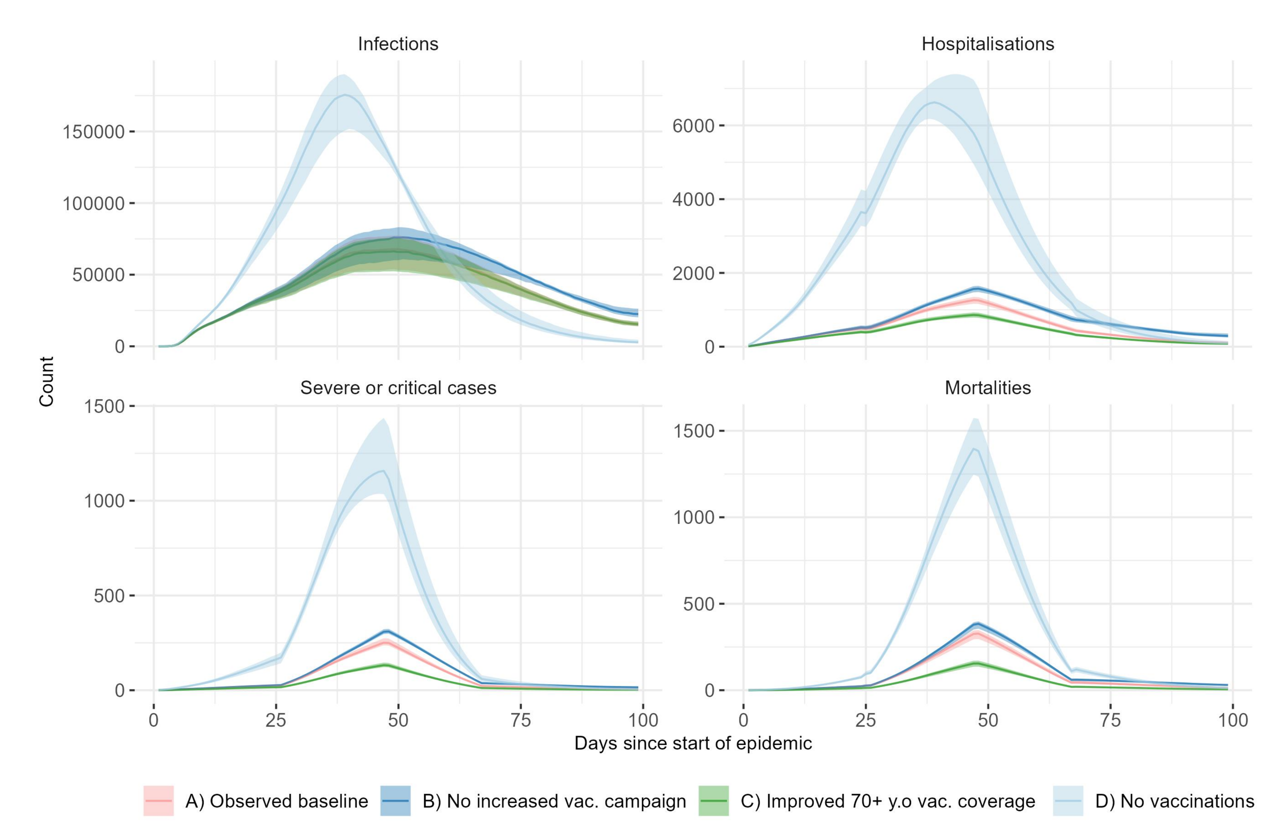

Figure 3. Infection and disease burden of COVID-19 over time in Hong Kong by simulated scenarios, 22 January - 30 April 2022

Conclusion

Despite an unequal distribution of immunisations during the 2022 winter and spring BA.2 outbreak in Hong Kong, administered vaccinations prevented the mortality burden from being over three times as severe. An achievable increase in the elderly's immunisation coverage would have halved the mortality burden during this period. The aggressive immunisation campaign midway through the outbreak prevented at least another thousand deaths from occurring.

Immunisations drastically flattened the infection curve reducing the impact on the healthcare system. Under the observed baseline simulation, we found a 3-4-fold increase in mortality during the wave peak, similar findings were also reported in current literature (3).

Our findings show the impact the immunisations had on transmission suppression and the burden of disease. The findings display what a more optimal distribution in coverage could have attained, and quantify the lives saved from an aggressive immunisation campaign.

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