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Short Communications

A metropolitan-scale, three-dimensional agent-based model to assess the effectiveness of the COVID-19 Omicron wave interventions in a hyperdense city: a case study of Hong Kong

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ABSTRACT

We simulated the COVID-19 Omicron spread in Hong Kong, China, by building a novel three-dimensional agent-based model that incorporates its vertically expanded, hyperdense urban environment. The model examined the effectiveness of the 'zero-COVID' interventions (i.e., Compulsory Universal Testing (CUT) and citywide lockdown) that were for debate during the Omicron wave in Hong Kong. We found that such stringent interventions would be effective only with even faster and stricter implementation. Therefore, flexible long-term strategies should also be considered to contain and prevent future infectious diseases.

Despite its stringent containment measures, Hong Kong has experienced a most challenging COVID-19 wave due to the Omicron variant (Mallapaty, 2022). Implementing a citywide 'compulsory universal testing' (CUT) and a citywide lockdown was a subject of debate in March 2022 (South China Morning Post, 2022).

Agent-based models (ABMs) have been extensively applied to examine various topics of COVID-19 (Müller *et al.*, 2021). Existing COVID-19 ABMs, however, have often been criticized for lack of detailed geographic consideration in modeling (Gomez *et al.*, 2021). We aimed to build a three-dimensional (3D) ABM that assesses the effectiveness of the then-proposed Omicron interventions in Hong Kong by incorporating its vertically expanded, hyperdense urban environment.

Our novel modeling strategies are threefold: (i) capturing urban environments in a 3D framework based on building heights, floors, and indoor areas; (ii) using a territory-representative, public daily travel survey to simulate the commute/trip patterns; and (iii) applying varied probability of close contact exposure and potential infection by trip origins/destinations, trip purposes, space capacity, social distancing rules, and indoor air ventilation regulations in our ABM (see Appendix I).

We mainly used the latest public data for the ABM. Additional location-related data were obtained from valid sources on the Internet (see Appendix II). A 10% random sample of Hong Kong's synthetic population (n = 730,090) was used for faster model running with sufficient contacts among the population. AnyLogic 8.7.5 (The AnyLogic Company) was used to build our ABM, and the subsequent spatial analysis was conducted on QGIS 3.22 (QGIS Development Team).

An epidemic compartmental model was used to design the Omicron transmission dynamics (see Appendix III) (Müller *et al.*, 2021; Gomez *et al.*, 2021). The total period in the model is one year from December 17, 2021—the date of the first confirmed Omicron variant case detected in Hong Kong. The baseline scenario was compared with three different CUT/lockdown scenarios based on the latest information from the government press releases and the media reports during the Omicron wave in Hong Kong (The Standard, 2022; Hong Kong Food and Health Bureau, 2022; Global Times, 2022).

(1) **Scenario 1 (Baseline)**: This was a condition that was most similar to the reality in early February and thereafter. Since February 1, 2022, 50% of the population would work from home, with a gradual increase in the daily booster shots administration.

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Table 1
Point estimates and their ranges of major Omicron infection statistics from different scenarios

	Peak period	Maximum daily reported cases during the peak	Total deceased population	The date of the end wave	Second wave	Total infected population	Hospital average waiting time (days)
Scenario 1	3/8/2022 -3/14/2022	63,000 (61,000-65,000)	1,450 (1,380-1,527)	Continue	Yes (Nov 2022)	2,543,000 (2,511,000-2,576,000)	164 (163-166)
Scenario 2	3/8/2022 -3/14/2022	61,000 (57,000-64,000)	1,377 (1,210-1,544)	6/22/2022 -7/29/2022	No	2,116,000 (2,045,000-2,187,000)	50 (46-54)
Scenario 3	3/8/2022 -3/14/2022	48,000 (40,000-55,000)	1,067 (888-1,245)	6/4/2022 -6/19/2022	No	1,703,000 (1,584,000-1,823,000)	35 (30-41)
Scenario 4	3/2/2022 -3/8/2022	40,000 (36,000-45,000)	990 (750-1,230)	5/3/2022 -6/9/2022	No	1,296,000 (1,078,000-1,513,000)	28 (18-38)

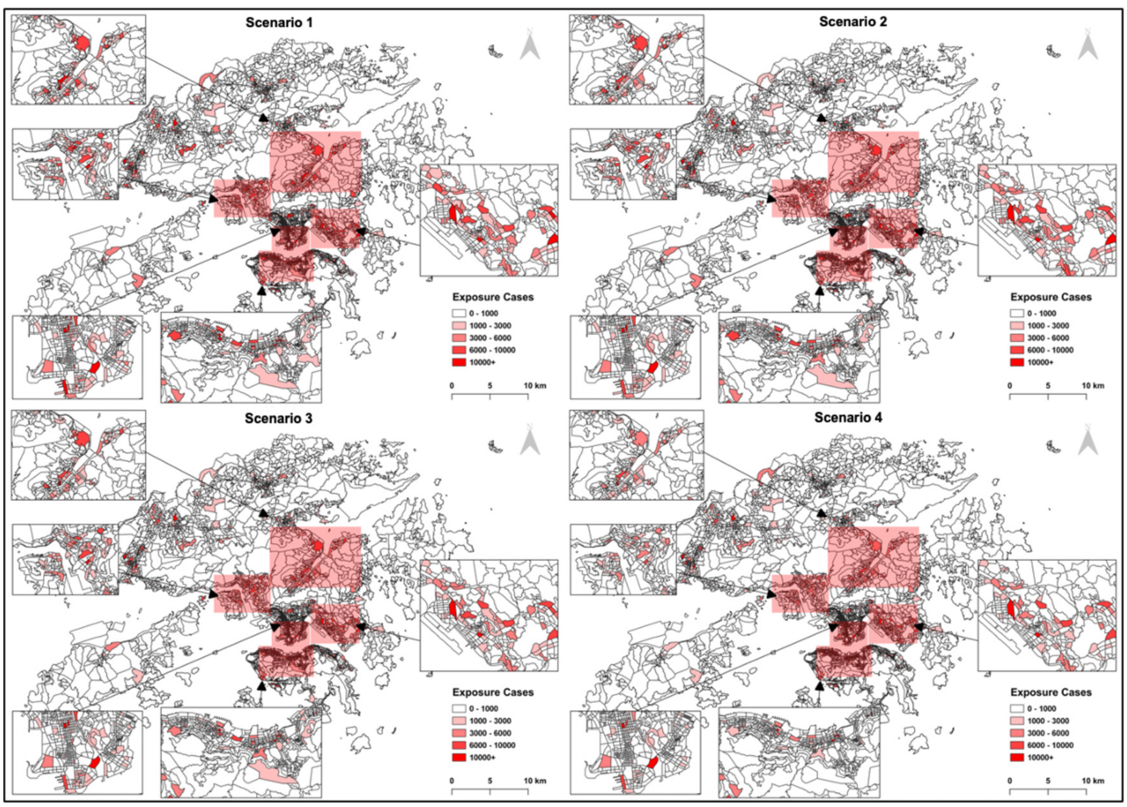

Figure 1. The estimated high-risk street blocks of Omicron exposure in Hong Kong

(2) **Scenario 2**: Under the same conditions as scenario 1, a CUT without a citywide lockdown would be implemented from March 26 to April 3. An additional 50,000 quarantine beds would be provided by March 31, 2022.

(3) **Scenario 3**: Under the same conditions as scenario 2, a CUT with a citywide lockdown (i.e., a 90% drop in mobility) would be implemented.

Table 1 summarizes the point estimates of major Omicron transmission indicators from our ABM. Scenarios 1-3 estimated that the Omicron wave would have reached its peak in the week of March 8-14, 2022. The total number of Omicron infections would be 1.7-2.5 million in the course of the year. The estimated total deaths were 1067-1450. Scenario 1 predicted another wave of the Omicron starting in November 2022 due to the potential waning level of vaccine protection over time and a higher incidence of infections (Wagner *et al.*, 2022). The Omicron wave would end in June-July 2022 in scenario 2-3.

In addition to scenarios 1-3, we ran scenario 4, assuming that there would have been the CUT with a lockdown during the estimated peak period from scenarios 1-3.

(4) **Scenario 4**: The same conditions as scenario 3, except for a different CUT schedule (during March 8-14).

Scenario 4 indicates that 1.3 million Hong Kong residents would be infected with Omicron. The total number of deaths estimated would decrease to 990. The Omicron wave would end by early June 2022. Many working-class neighborhoods in Kowloon and New Territories would be at higher risk for Omicron exposure, as illustrated in Figure 1.

Our results imply three messages to be further considered for Hong Kong's COVID-19 control. First, the Omicron interventions in Hong Kong were ineffective in minimizing fatalities. Hong Kong had 2,656 deaths from February 1 to March 9 (Hong Kong Food and Health Bureau, 2022)—this is 1.8 times higher than the estimate from scenario 1, which simulated the most similar conditions as the reality in February 2022. Second, a CUT with/without lockdown could be helpful to flatten the curve, but an implementation near the peak would be more effective, as scenarios 2-4 show. And finally, more resilient interventions and flexible exit plans from the current zero-COVID policy should be on the decision makers' table because newer variants of COVID-19, if any, could be more contagious yet less fatal than Omicron.

To conclude, this study exemplified the use of detailed geographic information to build an infectious disease ABM for an enhanced representation of reality as well as for more accurate estimates.

Author contributions

KK: conceptualization, methods, software, formal analysis, investigation, data curation, writing—original draft, writing—review and editing, supervision, project administration, and funding acquisition. **KCT**: conceptualization, methods, software, formal analysis, investigation, data curation, writing—review and editing, and visualization. **KA**: conceptualization, methods, writing—original draft, writing—review and editing, supervision. **BPYL**: conceptualization, methods, data curation, writing—original draft, writing—review and editing, supervision. All authors contributed to the article and approved the submitted version.

Conflicts of Interest

The authors have no competing interest to declare.

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Ethical Approval

Not applicable.

Data Sharing

All data used in this analysis is accessible from publicly available sources.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ijid.2022.06.042.

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