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Impacts of income inequality and the mediation role of reporting delays on COVID-19 deaths during 2020 and 2021 in Hong Kong: an observational study

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ABSTRACT

Objective To estimate the impacts of demographic factors and income disparities on the case fatality rate (CFR) of COVID-19 in Hong Kong, taking into account the influence of reporting delays (ie, the duration between symptom onset and case confirmation).

Design Retrospective observational longitudinal study.

Participants A total of 7406 symptomatic patients with residence information reported between 23 January 2020 and 2 October 2021.

Main outcome measures The study examined the disparity in COVID-19 deaths associated with the factors such as age (≥65 vs 0–64 years old groups), gender and the income level of districts (low income vs non-low income). The severe reporting delay (>10 days) was considered as the mediator for mediation analysis. A Cox proportional hazards regression model was constructed.

Results We found that CFR was 3.07% in the low-income region, twofold higher than 1.34% in the other regions. Although the severe reporting delay was associated with a hazard ratio (HR) of about 1.9, its mediation effect was only weakly present for age, but not for gender or income level. Hence, high CFR in Hong Kong was largely attributed to the direct effects of the elderly (HR 25.967; 95% CI 14.254 to 47.306) and low income (HR 1.558; 95% CI 1.122 to 2.164).

Conclusion The disparity in COVID-19 deaths between income regions is not due to reporting delays, but rather to health inequities in Hong Kong. These risks may persist after the discontinuation of test-and-trace measures and extend to other high-threat respiratory pathogens. Urgent actions are required to identify vulnerable groups in low-income regions and understand the underlying causes of health inequities.

STRENGTHS AND LIMITATIONS OF THIS STUDY

- ⇒ This study used a comprehensive data set of COVID-19 patients in Hong Kong including demographic, socioeconomic and location-based aspects.
- ⇒ The mediation impact of severe reporting delay (indicating the low efficiency of testing and tracing) on the death risk was assessed in one of the regions with the highest per capita testing capacity in the world.
- ⇒ Individual-level data were collected from COVID-19 patients who were reported between January 2020 and October 2021, encompassing an extended study duration.
- ⇒ Limitations of the data include the absence of individual socioeconomic and household-related data, as well as details on other comorbidities related to COVID-19 deaths.
- ⇒ The disparities among the case fatality rate in different groups of people could be confounded by other factors that were not covered in this study.

INTRODUCTION

COVID-19-related health inequities, such as differences in the risk of being infected, the risk of developing severe illness, the access to health resources or services, are of great concern.[1 2] During the early spread, when COVID-19 tests were scarce, individuals in more socioeconomically disadvantaged neighbourhoods had higher risks of morbidity and mortality.[3–7] For example, many of the people in lower-income regions were associated with longer delays in testing and treatment, resulting in higher mortality rates in Chile and Brazil.[5 6] Deprivation was found to be positively associated both with test positivity and with prevalence in England.[3] On the other hand, health inequities can also stem from disparities in health beliefs and behaviours across various sociodemographic groups. For example, age and gender may influence people's willingness to seek medical services, thereby affecting delays in the diagnosis of both short-term infectivity and long-term underlying health conditions in Hong Kong, China.[8] Especially age can play a vital role in cases of health inequalities as the case fatality rate (CFR) and susceptibility for COVID-19 symptomatic cases were much higher among the elderly population compared with the other age groups.[9]

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While the public health emergency is over, the virus still circulates. It remains unclear whether the inequity will disappear after compulsory testing and tracing measures are discontinued. If severe disparities in COVID-19 mortality resulted from unequal access to testing services, they should be less likely to persist after discontinuing these services. Conversely, if these disparities were not caused by unequal access to testing services, they are more likely to persist.

Hong Kong, located on China's southern coast near Southeast Asian and East Asian countries, was highly susceptible to COVID-19 due to its dense population, large elderly population and the risk of importation. In Hong Kong, numerous measures were implemented to address the COVID-19 pandemic, including compulsory testing, app-based contact tracing and immediate hospitalisation or isolation regardless of symptoms. There were about 5.2 hospital beds per 1000 people in 2015, which was the top 3 in Asia.[10] Persons subject to compulsory testing could find free testing sites in all 18 districts.[11] Until the massive outbreak during the Omicron wave, all COVID-19 cases were admitted to public hospitals without charges, immediately after their confirmation. By implementing these mitigation strategies, Hong Kong was capable of having rapid and successful control or delay of the pandemic wave during the first COVID-19 emergence.[12]

Hong Kong consistently had the highest ratio of tests performed to cases globally (eg, more than 5000 tests per case).[13] Unexpectedly, Hong Kong experienced about twofold higher CFR than many neighbouring countries (such as Singapore, Japan, South Korea and Thailand) even though the percentage of the elderly population (ie, people aged 65 or above) was almost 10% lower than that of Japan.[13] On the other hand, the city faced significant income inequality (with the highest Gini coefficient, a measure of income inequality, in Asia).[14] According to the 2021 Population Census,[15] the variation of median household incomes across the total districts was notably high. Whether the risks of deaths were associated with income levels through the efficiency of testing and tracing remains unknown. This efficiency can be assessed by the proportion of cases with reporting delays, under zero-COVID strategies.[16]

This study aimed to quantify the impacts of income disparities and demographic factors on COVID-19-related deaths taking into account their influence through delays in case reporting during the provision of enhanced and equitable testing and hospital services. A better understanding of these health inequities helps to inform policies to mitigate the impacts of high-threat respiratory pathogens on these vulnerable groups in the future.

METHODS

Data processing

Individual-level data of a total of 12 232 COVID-19 patients reported between 23 January 2020 and 2 October 2021 were collected from the Centre for Health Protection.[17] The deaths mainly happened during the two significant epidemic waves (figure 1A). Individual symptom-onset date, reporting date and the date of discharge or death were extracted. The reporting date was assumed to be the start of being isolated at hospitals (including temporary isolation centres). Among all, 41 patients who were not

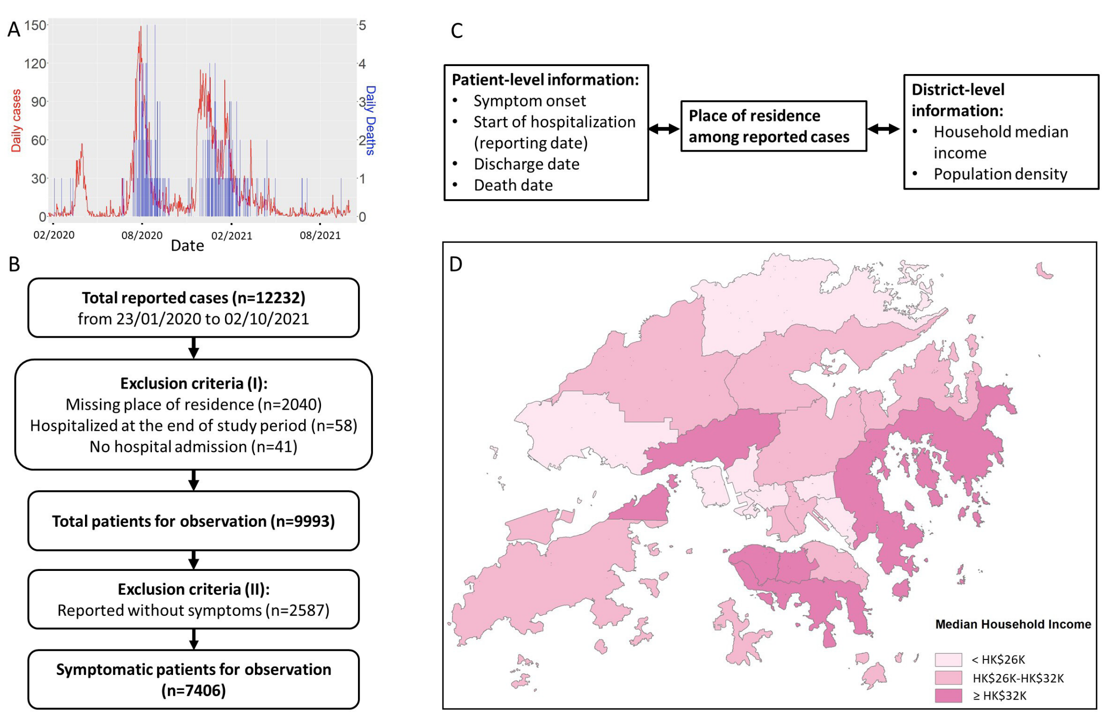

Figure 1 The map of Hong Kong and data processing. (A) Distributions of daily reported cases and deaths. (B) The flow chart of data processing. (C) Relational schema of data sources. (D) Districts in Hong Kong with household income levels.

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admitted to the hospital were excluded; and 58 patients whose statuses were hospitalised at the end of the study period were also removed because we did not know their disease outcomes. The place of residence (at district level) of each confirmed individual was extracted from the archives of list of buildings with confirmed/probable cases of COVID-19.[18] Before the rise of the Omicron strain, residence information of most reported cases was available to the public in order to improve the performance of test and trace. Among these patients, 2040 cases whose residence information was unknown were excluded, leaving 9993 observations. Among them, 2587 were such cases which were reported without symptoms. Hence, excluding the asymptotic cases, the rest of the 7406 patients who were reported as symptomatic were used for further observational analyses (figure 1B).

The district-level socioeconomic data (eg, median monthly household income and population density in each district) were obtained from the Census and Statistics Department, Hong Kong[15] (online supplemental table S1). The confirmed patients were linked to district-level information, such as median monthly income and population density (figure 1C). All the 18 districts have been classified into 3 categories (6 districts for each group) according to their median monthly household income namely low, middle and high income (ie, low-income region with <HKD$26 000, middle-income region with HKD$26 000–HKD$31 999 and high-income region with ≥HKD$32 000). The reporting delay was calculated as the duration between symptom onset and reporting date. We assumed all patients were immediately admitted to hospitals or isolation facilities. The duration of survival for each patient was determined using the interval between the time of hospital admission and the date of discharge or death. Patients discharged alive or still admitted at the end of the study period were treated as censored observations. Because we are interested in the survival within the first 100 days, the Kaplan-Meier curves for the first 100 days were shown. Only 0.47% of patients were discharged or died after 100 days.

Statistical analysis

To evaluate the differences among epidemiological and sociodemographic variables between the discharged and deceased cases of symptomatic patients, the Mann-Whitney-Wilcoxon test and χ^2 test have been used. The p values of these test statistics show the significance of the difference between several groups of subjects. The correlation matrices were generated to analyse the relationship between the epidemiological, demographical and income variables of symptomatic patients based on the district level as well as individual patient data. A Cox proportional hazards regression was used to estimate the effect of several variables (ie, age group, gender, reporting delay, income level of districts where patients lived) on the time discharge from the hospital or death happened. Meanwhile, Kaplan-Meier curves were used to observe the survival probability of different variables. Before the regression was performed, the proportional hazard assumption was tested by using the scaled Schoenfeld residuals to check the independence between residuals and time.[19] This is a prediagnostic test to check whether the relative hazard of covariate remains constant over time. We found that using a threshold of 10-day delay as a risk factor can satisfy this test. In addition, we found that an increasing trend of CFR reached a plateau when delays were larger than this threshold (see Results). Hence, in the study, we defined >10 days as a severe delay. Then, the Cox model was built and used as follows for mediation analysis following the traditional approaches[20]:

$$log(hr) = c_1 Age + c_2 Gender + c_3 IncomeRegion + bReportingDelay \quad (1)$$

$$P(ReportingDelay) = a_1 Age + a_2 Gender + a_3 IncomeRegion \quad (2)$$

$$log(hr') = c_1' Age + c_2' Gender + c_3' IncomeRegion \quad (3)$$

where the logarithm of the hazard ratio (HR), *hr*, is the dependent variable. c_i is the coefficient that measures the effect on hr of each independent binary variable, including *Age*: the elderly group ≥65 years old (compared with non-elderly group), *Gender*: male (compared with female) and *IncomeRegion*: low-income region (compared with high-income and middle- income regions). *b* is the coefficient for the mediator, *ReportingDelay*: the severe reporting delay. a_i is the coefficient that measures the effect of each independent binary variable on the severe reporting day. Equation 1 is the mediation model and equation 3 is the total effect model. The difference between c_i and $\acute{c}_i$ is the mediation effect, whereas equation 2 is the logistic regression against the mediator. Here, we have used age as a confounder category specifying 65 years and older as the 'elderly group' since this age group had experienced significantly higher COVID-19 mortality compared with the other age groups across many countries during 2020.

In addition to the mediation analysis based on Cox model, an alternative method was used to validate the above approaches. Survival regression based on a parametric accelerated failure time model was adopted to validate the effects of the same predictors in equation 1 on survival time. By adding the results from the survival regression and equation 2, causal mediation analysis proposed by Tingley *et al*[21] was performed to test the statistical significance of the total effect and direct effects of age and income regions, as well as their separate indirect effects via reporting delay (see mediation analysis in online supplemental material).

We used individual age, gender and regional income groups as the primary independent variables to estimate their individual effects and mediating pathways via reporting delay. All the analyses were performed in R (V.4.2.1). The source code and data for the work are publicly available.[22]

Patient and public Involvement

Patients and/or the public were not involved in the design, or conduct, or reporting, or dissemination plans of this research.

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Table 1 Demographic distribution, income region, delays in reporting and case fatality rate of symptomatic patients

Variable	Total (N=7406)	Discharged (N=7256)	Deceased (N=150)	P value	CFR (%)
Age (years)				<0.0001*	
0–44	3374 (45.56%)	3373 (46.49%)	1 (0.67%)		0.03
45–64	2672 (36.08%)	2661 (36.67%)	11 (7.33%)		0.41
≥65	1360 (18.36%)	1222 (16.84%)	138 (92%)		10.15
Gender				0.018*	
Female	3842 (51.88%)	3779 (52.08%)	63 (42%)		1.64
Male	3564 (48.12%)	3477 (47.92%)	87 (58%)		2.44
Income region				<0.0001*	
High (≥HKD$32K)	1798 (24.28%)	1777 (24.49%)	21 (14%)		1.17
Middle (HKD$26K–HKD$32K)	2673 (36.09%)	2634 (36.30%)	39 (26%)		1.46
Low (<HKD$26K)	2935 (39.63%)	2845 (39.21%)	90 (60%)		3.07
Delayed reporting time (days)					
0–10	6934 (93.63%)	6801 (93.73%)	133 (88.67%)		1.92
>10	472 (6.37%)	455 (6.27%)	17 (11.33%)		3.60
Mean (SD)	4.83 (3.52)	4.82 (3.49)	5.33 (4.39)		–
Median (IQR)	4 (2–6)	4 (2–6)	4 (2–7)	0.795†	–
Hospitalisation time (days)					
Mean (SD)	16.53 (17.60)	16.29 (16.57)	28.35 (43.47)		–
Median (IQR)	13 (10–18)	13 (10–18)	17 (10–33)	<0.001†	–

The p values of the difference between discharged and deceased cases were calculated. SD represents the standard deviation and IQR represents the interquartile range.
*P values were obtained using χ^2 test.
†P values were obtained using Mann-Whitney-Wilcoxon test.
CFR, case fatality rate.

RESULTS

Demographic distribution in deceased groups

Among 7406 hospitalised symptomatic patients admitted to the hospital, 2.03% (150 individuals) were deceased (table 1). Most deceased patients were ≥65 years old or above (92%). The gender proportion in the symptomatic patients was nearly equal (48.12% in males vs 51.88% in females), but deceased patients were more likely to be males (58%). The CFRs were 2.44% for men and 1.64% for women, and 10.15% for the elderly.

Among 18 districts, which were classified into low-income, middle-income and high-income levels (see the Methods section and figure 1D), many of the deceased patients lived in the region with low income. The CFRs were 1.17% for symptomatic cases in the high-income region and 1.46% in the middle-income region. The value increased to 3.07% in the low-income region, twofold higher than 1.34% in the non-low-income region. If reported asymptomatic cases were included, the CFRs were 0.95%, 1.47% and 2.89% in the high-income, middle-income and low-income regions, respectively (online supplemental table S2).

The reporting delay of the deceased group was slightly higher than discharged groups but the difference was not significant (Mann-Whitney-Wilcoxon test was used because the data was skewed). Compared with patients without the severe delay (>10 days), CFR increased from 1.92% to 3.60% for patients with the severe delay. The median hospitalisation time (ie, the length of stay in the hospital) of the symptomatic patients was 13 (IQR 10–18) days, significantly lower than the deceased group at 17 (IQR 10–33) days. Overall, the elderly and male patients residing in the low-income region, or the patients with the severe reporting delay might have contributed to their higher risks of death.

District-level analysis

To further understand whether income and population density were associated with disease transmission and severity, we examined the cumulative incidence (CI) and the CFR during the study period across 18 districts.

No correlation was found between income level and CI (figure 2A and online supplemental figure S1). On the other hand, a higher income level was clearly associated with a lower CFR (figure 2B). The highest three CFR districts (ie, Tun Mun, Sham Shui Po and Wong Tai Sin) all belonged to low-income group. Vice versa, the lowest three CFR districts (ie, Sai Kung, Tai Po and Southern), all belonged to high-income or middle-income group (see online supplemental table S1).

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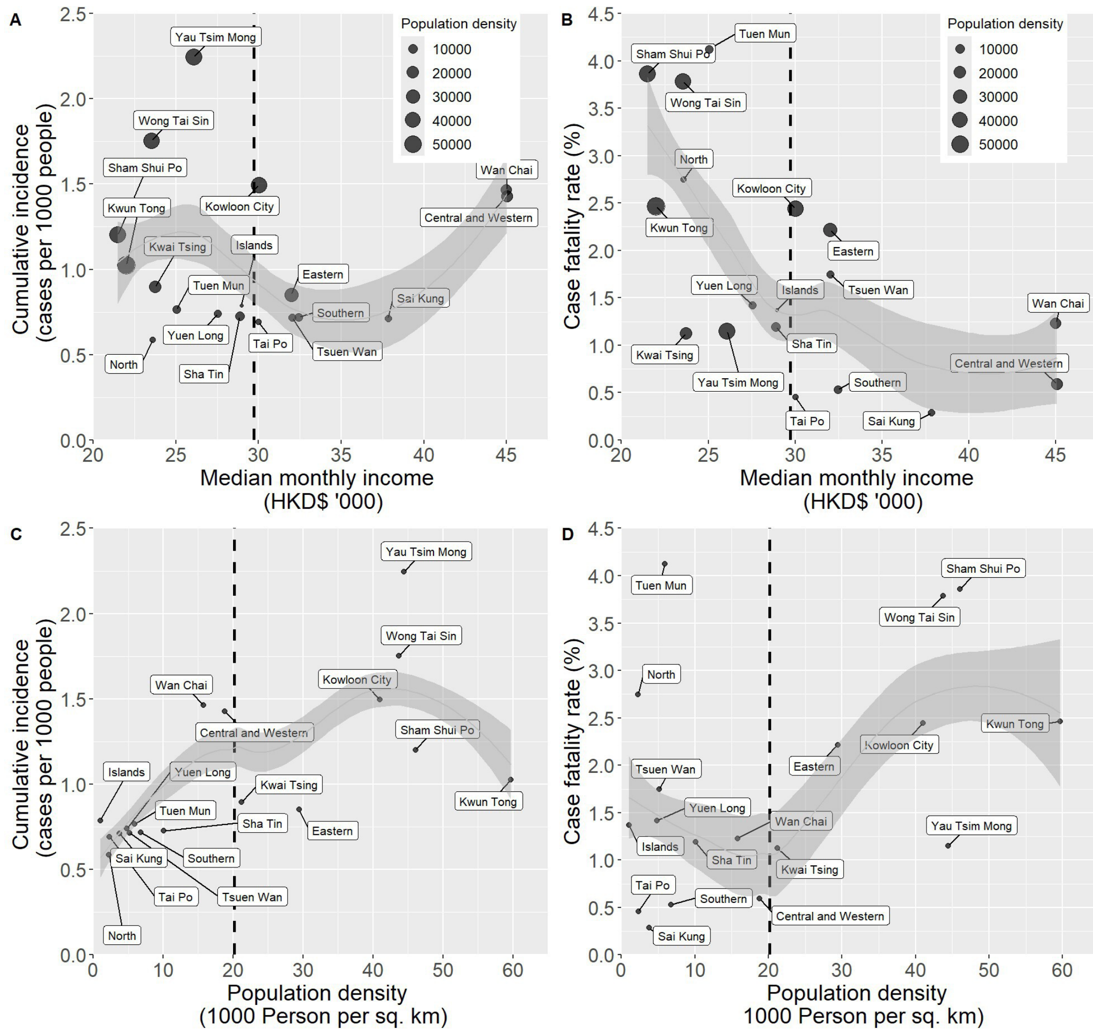

Figure 2 CI and CFR for districts using symptomatic patients. (A) CI of symptomatic patients across district by median monthly household income. (B) CFR of symptomatic cases across district by median month income. (C, D) same as (A, B) but are distributed by population density. Vertical lines represent the average values of the observed data. The trends were plotted using locally weighted scatterplot smoothing (LOESS) with span=0.8 and the interquartile range. CFR, case fatality rate; CI, cumulative incidence.

A greater population density was generally associated with a higher CI (figure 2C). The highest three CI districts (Yau Tsim Mong, Wong Tai Sin and Kowloon City) all had population density greater than the average value. Conversely, the lowest nine CI districts all had population density lower than the average (see online supplemental table S1). However, the relationship between population density and CFR appeared to be positive within a narrower range and with a larger confidence interval (figure 2D). The correlation of CFR with income level was found to be more significant than with population density (online supplemental figure S1).

To control the effect of age, we checked the distribution of CFR by districts in elderly patients only (online supplemental figure S2A,B). The results were consistent with the total symptomatic cases. The patterns were similar if imported cases were excluded (online supplemental figure S3).

Associations of reporting delays with demographic factors and income regions

Among all groups (age, gender and income region) in our study, the elderly males in the low-income region had the highest CFR, 15.98%. The CFR reduced as the income level increased in the elderly males (ie, 8.65% in the middle-income region and 6.52% in the high-income region) (figure 3A). Severe reporting delay was very high among the middle-income and low-income elderly male populations (figure 3B). The CFR increased as the value of the minimal reporting delay became longer among the symptomatic patients after analysing individual data (figure 3C). An increasing trend of CFR starting from about 1.8% to a plateau of about 4% was found between delays >2 and >10 days. When this rate was plotted versus the corresponding delayed time periods, we found two optimal values occurred when the delay was less than 4 days and greater than 9 days (figure 3D). It was likely

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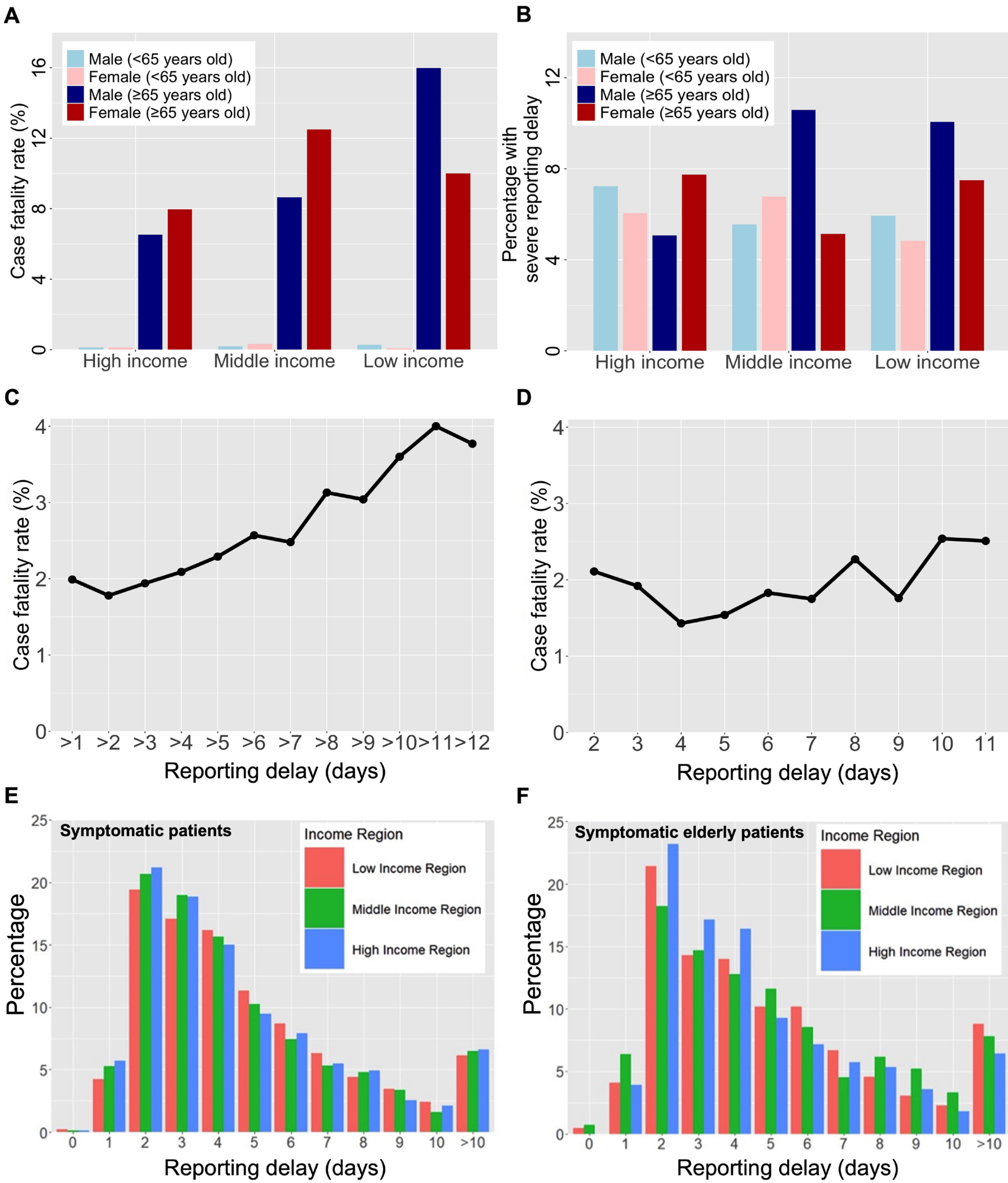

Figure 3 Relationships between CFR, reporting delay and other risk factors. (A) CFR of symptomatic cases by age and income groups. (B) Percentage of symptomatic patients with severe delay (>10 days) by age and income groups. (C) CFR of cases with different thresholds of reporting delay. (D) CFR of cases with delays in reporting. The curve is the sliding average (3-day window, centred on the second day). (E) Percentage of symptomatic patients with delays in reporting in different income groups. (F) Percentage of symptomatic elderly patients (≥ 65 years old) with delays in reporting in different income groups. CFR, case fatality rate.

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that some of the death cases quickly developed severe outcomes, resulting in early identification after their symptom onsets.

Further analysis was performed in order to understand which groups of elderly experienced severe reporting delays. Among total symptomatic patients, the proportions of the patients in the low-income, middle-income and high-income regions that were reported with delays greater than 10 days were of no clear difference (6.13%, 6.47% and 6.62%, respectively; figure 3E). Age and reporting delay appeared to be positively correlated (online supplemental figure S4A). Moreover, the proportion of the older patients with such severe delays in the low-income region was 8.81%, clearly higher than the high-income region (6.43%; figure 3F) or the average level in the elderly (6.37%; table 1).

We found a slightly negative correlation between hospitalisation time and reporting delay (online supplemental figure S4A). This can be explained by that in mild cases who were detected late, viral load had already begun to decrease. Many of them were recovered and soon eligible for discharge criteria, shortening the length of stay. However, no correlation between them was found in deceased patients (online supplemental figure S4B). In addition, between different income regions, there were no apparent differences in hospitalisation time of symptomatic patients who were later discharged (online supplemental figure S5A) or deceased (online supplemental figure S5B).

Survival analysis

No significant difference was observed between genders (figure 4A). However, up to 50 days of hospitalisation, when about 98% of the patients were either discharged or died), the elderly (≥65 years old) and the low-income region had clearly lower survival probabilities than their reference groups (figure 4B,C). Patients who were reported with severe delays had a slightly lower survival probability than those without severe delays, especially during the first 30 days since reporting (figure 4D).

We built a Cox proportional hazards regression model to assess the impacts of demographic factors and level of income in each region, after the proportional hazards assumption was validated (online supplemental table S3). In the total effect model, elderly group and low-income region were significantly associated with higher HR (table 2). After severe reporting delay was incorporated as a mediator for causal mediation analysis, we found the severe delay was associated with higher death risk (HR 1.859; 95% CI 1.109 to 3.115) (table 2).

However, further analyses showed that mediating effect of severe reporting delay was weak. First, severe reporting

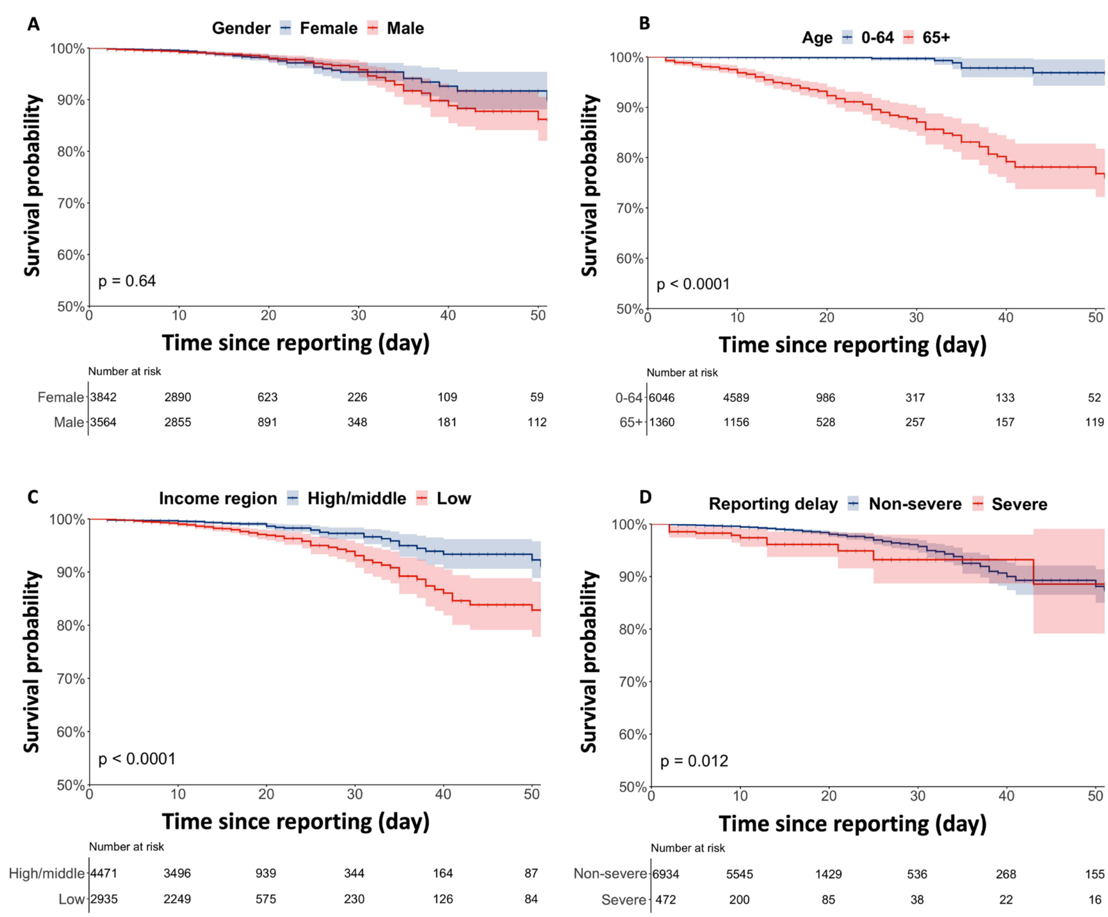

Figure 4 Kaplan-Meier plot of symptomatic patients. The plots are stratified by gender (A), age (B), monthly median income (C) and severe reporting delay (D).

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Table 2 Parameter estimates of the Cox regression model for symptomatic patients

	Mediation effect model		Total effect model	
Parameter	HR (95% CI)	P value	HR (95% CI)	P value
Age group				
≥65	25.967 (14.254 to 47.306)	<0.0001	26.116 (14.333 to 47.586)	<0.0001
Gender				
Male	1.022 (0.736 to 1.419)	0.898	1.040 (0.750 to 1.444)	0.814
Income region				
Low (<HKD$26K)	1.558 (1.122 to 2.164)	0.008	1.589 (1.145 to 2.205)	0.006
Reporting delay				
>10 days	1.859 (1.109 to 3.115)	0.019	–	–

delay had minimal mediating role for income region or gender due to the absence of significant associations between severe reporting delay and income or gender (online supplemental table S4). Next, although old age was associated with a higher risk of severe reporting delay (OR 1.373; 95% CI 1.094 to 1.712; online supplemental table S4), the little difference between the total effect of being ≥65 years vs <65 (HR 26.116; 95% CI 14.333 to 47.586) and the direct effect (HR 25.967; 95% CI 14.254 to 47.306) indicated that the high CFR in elderly was only marginally attributed to the reporting delay.

We replicated the analyses based on the parametric accelerated failure time model for survival time analysis and found consistent results. The survival time ratios were significantly lower in old age at 0.054 (95% CI 0.028 to 0.105), low income at 0.677 (95% CI 0.503 to 0.911) and severe reporting delay at 0.621 (95% CI 0.392 to 0.983) (online supplemental table S5). As previous results, causal mediation analysis showed a statistically significant but weak indirect effect through severe reporting delay for old age (proportion mediated=0.44%; 95% CI 0.01% to 1.07%), but the effect was not significant for low-income (online supplemental table S6).[21]

Sensitivity analysis

To evaluate whether the findings were the same if asymptomatic cases were included, we performed the same approach using total patients, including asymptomatic cases. The CI and CFR using total patients among individual districts showed a similar pattern as the symptomatic patients (online supplemental figure S6). Using the Cox regression model, we found that the HRs were consistent with the results using symptomatic patients (table 2 and online supplemental table S7). We also changed the levels of various income regions (eg, low income with <HKD$28K, moderate income with HKD$28K–HKD$36K and high income with >HKD$36K) to evaluate the consistency of the estimated results of the Cox regression analysis for the symptomatic patients. The HRs for the mediation effect and total effect models yielded the same results (table 2 and online supplemental table S8), even when the income variable was reformulated. Furthermore, the OR obtained from the logistic regression analysis remained consistent before and after changing the categories of different income levels (online supplemental tables S4 and S9).

DISCUSSION

Concerns of health inequity in Hong Kong have been raised, especially after the pandemic began.[7 23 24] Our results found that despite of intensive testing and isolation services under zero-COVID period, CFR of symptomatic cases in low-income neighbourhoods was nearly threefold higher than high-income neighbourhoods (table 1). Furthermore, this disparity was not associated with unequal delays in reporting time, an indicator of testing and tracing efficiency,[16] across regions with different income levels (online supplemental table S4). This can explain the absence of correlation between CI and income levels across different districts. Otherwise, if longer delays happened in certain districts with low-income level, their incidence could be higher.

A higher death risk in lower-income neighbourhoods in Hong Kong can likely be attributed to health conditions related to other chronic diseases. Certain places with high CFR have previously been reported to have major chronic diseases.[25] As pre-existing but poorly managed chronic condition is one of the major risk factors for COVID-19 severity, the observed health inequities in elderly and low-income region may be linked in part to the unequal access to primary care in Hong Kong during normal time (ie, before the pandemic).[26]

Our results showed that although the severe delay was associated with higher death risk, the mediation effect of which was weak (table 2). On the other hand, the delays reflect a lower willingness to comply with mandatory testing during the infectious disease control period.[27] Similar attitudes or behaviours may occur while seeking healthcare during normal time, leading to poorly managed chronic conditions.[8] According to a previous study, poor adoption of certain preventive measures was found in some older people.[28] Furthermore, patients with low income were associated with being worried about job lost,[24 29] which can delay seeking healthcare services. This

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is particularly likely to happen in elderly men, who may need to contribute income resources in families but are approaching or at retirement age. These may explain why the older male patients in the low-income region generally had both a higher CFR and a larger proportion of serious delays.

How to improve the use of primary care services by the elderly becomes critical in an ageing society. As the primary care and outpatient services are largely driven by the private sector with relatively high out-of-pocket fees, older patients with lower socioeconomic status could hardly enjoy the fast-track private services but tend to rely on the almost free public outpatient services with long waiting time. Such situation became even worse under the COVID-19 pandemic as most non-emergency and non-essential services in public outpatient clinics were suspended, which inevitably exacerbated the inequities in service access and hence their chronic disease management.[8 26]

Hence, our findings lead to an expectation that there might be a certain number of elderly males living in poor neighbourhoods who have underlying health conditions but are less willing to seek medical services in Hong Kong. A recent study found that the mortalities for certain chronic diseases, such as cardiovascular diseases and cancer, were lower in Hong Kong than in many other high-income countries.[30] However, poor health-seeking behaviour among elderly people in deprived communities can potentially lead to both health issues and inaccurate documentation of causes of death in the future. If this happens, the prevalence of chronic conditions might be underestimated in certain vulnerable groups.

Identifying vulnerable people, especially those who are not aware of their health risks, is essential for reducing future burdens of infectious disease outbreaks and has impacts on non-pharmaceutical interventions and vaccine prioritisation. During the pandemic, the app-based contact tracing intervention strategy along with compulsory testing appeared to be useful in reducing the inequality in the transmission but not in the disease severity in Hong Kong. To live more peacefully with viruses, testing strategy shall not need to be completely discontinued. Instead, it can be implemented with a focus on early detection and early treatment mainly for specific vulnerable groups. To know who should be prioritised for testing or vaccination, a better understanding of how some health conditions interact with COVID-19 in certain socioeconomic contexts is needed.[2 31]

There are some limitations of this study. First is the lack of data on the other indicators of socioeconomic inequalities such as individual income, educational and occupational class, and household sizes since it was a population-based study and the information was collected through the established government website. Also, individual vaccination statuses are unknown. However, most of the infections in our study occurred before April 2021, when the vaccine roll-out just began, with less than 1% of vaccine coverage for the second dose.[32] Furthermore, crowded housing or poor housing conditions may impact health,[33] but housing conditions are not available. In addition, the effects of income and age can be substitutional because of the absence of other unobserved comorbidities in the analysis to affect the COVID-19 CFR, such as drinking, smoking, obesity, diabetes, cardiovascular diseases, psychological stress and other chronic illness histories are not available. Apart from the reporting delay, there might be other strong mediators affecting the inequalities in CFR. In addition, sampling biases due to the exclusion of a significant number of sample observations can influence the overall predictions.

CONCLUSION

We found a significantly higher CFR in low-income neighbourhoods compared with other regions. Our causal mediation analysis indicated that income and age had a strong direct effect on COVID-19 death but with minimal influence through delays in reporting. These findings highlighted the existence of underlying health inequities during the pandemic, which may persist and extend to other high-threat respiratory pathogens in the postpandemic period. Addressing these disparities is crucial for improving overall public health, especially in a rapidly ageing society.

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REFERENCES

1 Etienne CF. COVID-19 has revealed a pandemic of inequality. *Nat Med* 2022;28:17.
2 Bambra C, Riordan R, Ford J, *et al*. The COVID-19 pandemic and health inequalities. *J Epidemiol Community Health* 2020;74:964–8
3 Padellini T, Jersakova R, Diggle PJ, *et al*. Time varying association between deprivation, ethnicity and SARS-Cov-2 infections in England: a population-based ecological study. *Lancet Reg Health Eur* 2022;15:100322.
4 Magesh S, John D, Li WT, *et al*. Disparities in COVID-19 outcomes by race, ethnicity, and socioeconomic status: a systematic-review and meta-analysis. *JAMA Netw Open* 2021;4:e2134147.
5 Mena GE, Martinez PP, Mahmud AS, *et al*. Socioeconomic status determines COVID-19 incidence and related mortality in Santiago, Chile. *Science* 2021;372:eabg5298.
6 Cobre A de F, Böger B, Fachi MM, *et al*. Risk factors associated with delay in diagnosis and mortality in patients with COVID-19 in the city of Rio de Janeiro, Brazil. *Cien Saude Colet* 2020;25(suppl 2):4131–40.
7 Chung GKK, Chan S-M, Chan Y-H, *et al*. Socioeconomic patterns of COVID-19 clusters in low-incidence city, Hong Kong. *Emerg Infect Dis* 2021;27:2874–7.
8 Xin H, Wu P, Wong JY, *et al*. Hospitalizations and mortality during the first year of the COVID-19 pandemic in Hong Kong, China: an observational study. *Lancet Reg Health West Pac* 2023;30:100645.
9 Kang SJ, Jung SI. Age-related morbidity and mortality among patients with COVID-19. *Infect Chemother* 2020;52:154–64.
10 Census and Statistics Department, Hong Kong Government. Medical institutions with hospital beds by area and type of institution. *Annual Digest of Statistics* 2021:396–7.
11 Info.gov.hk. Mobile specimen collection stations and community testing centres provide free testing for persons subject to compulsory testing (6 JAN 2021). Available: https://www.info.gov.hk/gia/general/202101/06/P2021010600281.htm [Accessed 20 Apr 2023].
12 El Guerche-Séblain C, Chakir L, Nageshwaran G, *et al*. Experience from five Asia-Pacific countries during the first wave of the COVID-19 pandemic Mitigation Strategies and Epidemiology Outcomes. *Travel Med Infect Dis* 2021;44:102171.
13 Our World in Data. Coronavirus pandemic (COVID-19). Available: https://ourworldindata.org/coronavirus [Accessed 5 Dec 2023].
14 The World Factbook. Gini index coefficient – distribution of family income. Available: https://www.cia.gov/the-world-factbook/field/gini-index-coefficient-distribution-of-family-income/country-comparison/ [Accessed 5 Dec 2023].
15 Census and Statistics Department, Hong Kong Government. D203B median monthly domestic household income by district Council district and year. Available: https://www.census2021.gov.hk/en/main_tables.html [Accessed 1 Oct 2022].
16 Yuan HY, Blakemore C. The impact of contact tracing and testing on controlling COVID-19 outbreak without Lockdown in Hong Kong: an observational study. *Lancet Reg Health West Pac* 2022;20:100374.
17 Centre for Health Protection, Hong Kong Government. Archives of latest situation of cases of COVID-19. Available: https://www.chp.gov.hk/en/features/102997.html [Accessed 2 Oct 2021].
18 Centre for Health Protection, Hong Kong Government. List of buildings with confirmed / probable cases of COVID-19. Available: https://www.chp.gov.hk/en/features/102991.html [Accessed 2 Oct 2021].
19 Grambsch PM, Therneau TM. Proportional hazards tests and diagnostics based on weighted residuals. *Biometrika* 1994;81:515–26.
20 Baron RM, Kenny DA. The moderator-mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. *J Pers Soc Psychol* 1986;51:1173–82.
21 Tingley D, Yamamoto T, Hirose K, *et al*. Mediation: R package for causal mediation analysis. *J Stat Softw* 2014;59:1–38.
22 Yuan HY, Wong WH, Khairunnasa F, *et al*. Github repository: Hong Kong COVID-19 case fatality rate. 2023. Available: https://github.com/hy39/hk_covid19_cfr_inequality
23 Chung GKK, Robinson M, Marmot M, *et al*. Monitoring socioeconomic inequalities in health in Hong Kong: insights and lessons from the UK and Australia. *Lancet Reg Health West Pac* 2023;31:100636.
24 Siu JY. Health inequality experienced by the socially disadvantaged populations during the outbreak of COVID-19 in Hong Kong: an interaction with social inequality. *Health Soc Care Community* 2021;29:1522–9.
25 Yip PSF, Chan CH, Lee R, *et al*. A spatial analysis of elderly mortality, morbidities and mental health status in Hong Kong. Available: https://csrp.hku.hk/content/uploads/2022/07/csrp_spatial-analysis_elderly_health_report.pdf [Accessed 12 May 2023].
26 Chung GKK, Chan SM, Chan YH, *et al*. Differential impacts of Multimorbidity on COVID-19 severity across the socioeconomic ladder in Hong Kong: A Syndemic perspective. *Int J Environ Res Public Health* 2021;18:8168.
27 Info.gov.hk. Government conducts enforcement action on compulsory testing notice at building in wan Chai (20 Oct 2022). Available: https://www.info.gov.hk/gia/general/202210/20/P2022102000349.htm [Accessed 27 Jan 2023].
28 Chan EYY, Huang Z, Lo ESK, *et al*. Sociodemographic predictors of health risk perception, attitude and behavior practices associated with health-emergency disaster risk management for biological hazards: the case of COVID-19 pandemic in Hong Kong, SAR China. *Int J Environ Res Public Health* 2020;17:3869.
29 Chung RY-N, Chung GK-K, Marmot M, *et al*. COVID-19 related health inequality exists even in a city where disease incidence is relatively low: a telephone survey in Hong Kong. *J Epidemiol Community Health* 2021;75:616–23.
30 Ni MY, Canudas-Romo V, Shi J, *et al*. Understanding longevity in Hong Kong: a comparative study with long-living, high-income countries. *The Lancet Public Health* 2021;6:e919–31.
31 Mendenhall E, Kohrt BA, Logie CH, *et al*. Syndemics and clinical science. *Nat Med* 2022;28:1359–62.
32 Hong Kong Government. Hong Kong vaccination dashboard. Available: https://www.covidvaccine.gov.hk/en/dashboard [Accessed 9 Feb 2022].
33 World Health Organization (WHO). WHO housing and health guidelines, recommendations to promote healthy housing for a sustainable and equitable future. 2018. Available: https://www.who.int/publications/i/item/9789241550376