Post-pandemic excess mortality of COVID-19 in Hong Kong: a retrospective study

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Summary

Background As the COVID-19 pandemic shifted into the post-pandemic period in early 2023, following the COVID-19 normalization with relaxation of stringent control measures and high vaccination coverage in Hong Kong, its long-term impact on mortality remains challenging with necessary needs of data-driven insights. This study examined the pattern of post-pandemic excess mortality in Hong Kong.

Methods We analyzed weekly inpatient death data from public hospitals from January 1, 2013, to June 1, 2024, using a mixed model with over-dispersed Poisson regression. Expected mortality was estimated as the difference between observed mortality and baseline derived from pre-pandemic data. Age-stratified analyses of overall and cause-specific mortality were conducted across the pre-Omicron pandemic, Omicron, and post-pandemic periods.

Findings In the post-pandemic period, the excess mortality declined but remained six-fold higher (37.66 [95% CI: 32.72–42.60] per 100,000) than pre-Omicron level, maintaining significance after adjusting for age (32.79 [95% CI: 28.13–37.46] per 100,000). The older population experienced sustained excess mortality, with crude estimates of 100.51 and 586.74 per 100,000 among those aged 65–79 years and ≥80 years, respectively, primarily due to respiratory diseases. Younger population showed near-zero overall excess mortality, whereas increased excess mortality among them occurred in heart disease, cerebrovascular disease, and injuries.

Interpretation Our findings highlight the lasting mortality impact of pandemic among vulnerable populations, specifically the older population, possibly due to the post-COVID conditions and circulating COVID-19, suggesting the need for targeted interventions for this group.

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Keywords: Long COVID; Excess death; Excess burden; Omicron

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Research in context

Evidence before this study

We conducted a PubMed search for research articles published between June 2020 and December 2024, using the search terms ("excess mortality" OR "excess deaths" OR "COVID-19 mortality") AND ("post-pandemic" OR "post-COVID" OR "after COVID-19 pandemic" OR "long-term impact"). Existing literature has extensively documented global excess mortality during the acute phases of the COVID-19 pandemic, revealing significant regional variations influenced by healthcare capacity, public health policies, and vaccination rates. However, after excluding studies that did not report excess mortality from 2022 to 2024, which is regarded as post-pandemic period, we found limited studies addressing post-pandemic excess mortality, particularly those with detailed cause-specific analyses. Two international studies reported modest levels of post-pandemic excess mortality across countries in 2023, with reduced regional disparities. One study conducted in England analyzed excess mortality stratified by age and cause, identifying significant excess deaths among middle-aged individuals, particularly due to cardiovascular diseases. These studies concentrated on Europe or global trends, providing limited evidence from the Asia–Pacific region, especially in highly vaccinated settings such as Hong Kong. Additionally, there is a notable absence of comprehensive analyses examining age-specific and cause-specific excess mortality patterns during the post-pandemic period in such populations.

Added value of this study

This study is among the first to analyze post-pandemic excess mortality in Hong Kong, a highly vaccinated city in the Asia–Pacific region, using time-series data from 2013 to 2024. Our findings revealed that overall excess mortality declined after the Omicron wave but remained significantly higher than pre-Omicron levels throughout the post-pandemic period, with notable disparities in sex-specific and cause-specific excess mortality. Specifically, females over 65 years old experienced significantly higher excess mortality than the males. Significant cause-specific excess mortality was found in deaths from pneumonia, along with modest excess mortality in cerebrovascular diseases, with the older populations (≥65 years) being disproportionately affected by pneumonia. Notably, younger populations experienced significant excess mortality from heart disease, cerebrovascular diseases, and injuries, underscoring the need for targeted interventions and greater public health attention on the pandemic's impact on less vulnerable groups. These findings highlight the enduring impact of COVID-19 on mortality patterns, even in a highly vaccinated population.

Implications of all the available evidence

Our findings highlight the urgent need for sustained public health efforts to address the long-term impacts of the COVID-19 pandemic, particularly among the population aged over 65 years. The continued lower-than-expected mortality in non-pneumonia respiratory diseases suggests that stringent control measures, such as mask-wearing and social distancing, may have had lasting benefits. However, the significantly increased mortality risk from heart disease, cerebrovascular diseases, and injuries among younger populations, even in a highly vaccinated setting, emphasize the need for more targeted interventions to address post-COVID conditions and the potential long-term effects of both mild and severe COVID-19 infections.

Introduction

The COVID-19 pandemic started to stabilize in 2023, following the end of the extensive outbreak of the new SARS-CoV-2 Omicron BA.2.2 variant (abbreviated as Omicron) in late 2022.[1] Although new variants have emerged and circulated globally from 2023 to 2024, their impacts are clearly weakened, as shown by the decreasing COVID-19 hospitalizations and deaths worldwide.[2] As of 2023, COVID-19 is being managed as a common respiratory infectious disease with recurrent outbreak risks, rather than receiving targeted control measures. With the declaration of WHO in May 2023, the COVID-19 pandemic has switched into an ongoing health issue.[3]

With the relaxation of policy responses, effectively monitoring COVID-19 impacts has become challenging due to the non-compulsory testing and reduced surveillance, and biases may be introduced when the resource allocation is no longer concentrated on COVID-19 prevention and control. Excess mortality, a measure of the difference between observed and expected mortality, can be captured to reflect the indirect deaths attributed to COVID-19 and mitigate the reporting bias caused by non-compulsory testing.[4] Previous studies revealed that excess mortality is usually higher than the reported COVID-19 deaths during the rapid transmission phase and lower-than-expected excess mortality occurred in regions conducting a zero-COVID-19 policy.[5–8] In addition, vulnerable populations disproportionately affected by the COVID-19 pandemic can be identified by analyzing population-specific and cause-specific excess mortality, which facilitated the design of adaptive responses in controlling COVID-19.

Several studies indicated the notable ongoing excess mortality during the post-pandemic period from 2023 to 2024. A modest excess of a hundred thousand deaths was found across 29 European countries in 2023, with the highest number of excess deaths in Italy and the highest excess rate expected in Bulgaria.[9] Pearson-Stuttard et al. reported an 8.6% excess in deaths in England during the first half of 2023, which primarily affects the middle-aged population and cardiovascular-

related deaths.[10] A global study by Ioannidis et al. observed a modest decline in the excess-to-expected death ratio among more vulnerable nations, alongside a slight narrowing of between-country disparities in 2023 compared to previous years.[11] These findings underscore the importance of ongoing surveillance of excess mortality trends to understand the full spectrum of long-term burden and indirect impact of the COVID-19 pandemic on public health.

In Hong Kong, stringent COVID-19 control measures were eventually lifted following the rapid and widespread Omicron outbreak in the first half of 2022, which resulted in a significant increase in excess mortality, particularly among the older population.[12] By late 2022, more than 90% of the population had been vaccinated,[13] prompting the gradual relaxation of border controls to facilitate international travel and support the transition to normalized practices in the post-pandemic era. However, it remains uncertain whether excess mortality has returned to pre-pandemic levels or shifted to a demonstrated pattern in this highly vaccinated setting. During COVID-19 normalization, limited evidence exists to assess the indirect mortality impact of the pandemic, shaped by a combination of stringent health interventions, prior infections, and high vaccination coverage. Building on this context, we examined the pattern of post-pandemic excess mortality in Hong Kong, specifically from January 1, 2023, to June 1, 2024, after all the control measures were relaxed and the establishment of hybrid immunity.

Methods

Our retrospective study applied the time series analysis on weekly death data during the post-pandemic period (January 1, 2013, to June 1, 2024), to calculate the excess mortality from January 23, 2020, through June 1, 2024. We also carried out subgroup analysis to manifest the disparities of excess mortality pattern: 1) age groups (0–19, 20–34, 35–49, 50–64, 65–79, and ≥80 years), 2) age groups and sex, and 3) causes of death. The causes include 10 causes of interest (four respiratory and six non-respiratory diseases) that are selected according to Hong Kong's leading causes of death from 2001 to 2023.[14] We presented our analysis in four defined periods: the overall period (January 23, 2020–June 1, 2024), the pre-Omicron pandemic (January 23, 2020–December 31, 2021), the Omicron pandemic (January 1, 2022–December 31, 2022), and the post-pandemic period (January 1, 2023–June 1, 2024).

Aggregated data grouped in ages and causes were collected from Census and Statistics Department (Hong Kong), that centralized electronic database for anonymized death records from 43 public hospitals in Hong Kong. For each anonymized death, the diagnosis was coded in the International Classification of Diseases, Ninth Revision (ICD-9),[15] and we categorized the causes of death records by checking their ICD-9 codes match with any in predefined lists of ICD-9 codes corresponded to causes (the ICD-9 code lists of 10 causes of interest are displayed in Table S1). Annual mid-year population estimates in Hong Kong from 2013 to 2024 as denominators for calculating mortality rates, are collected from the official website of the Census and Statistics Department.

Excess deaths during the January 23, 2020–June 1, 2024, were estimated by measuring the difference between observed deaths and expected deaths. The expected deaths and corresponding 95% confidence intervals (CIs) are modeled by a mixed model using over-dispersed Poisson regression that accounted for the trend effects including long-term secular changes, seasonal trends, and natural variability, using the pre-pandemic mortality data from January 1, 2013, to December 31, 2019.[16] We did not exclude any abnormal interval during the baseline period (2013–2019) as none were detected. Specifically, let Y_{it} represent the number of deaths on day t for sub-analysis group i; we assume Y_{it} follows a Poisson distribution with mean μ_{it} that denotes the expected number of deaths for sub-analysis group i at day t, and $f_i(t)$ is the changes of deaths between the observed and μ_{it}, ε_{it} is an auto-correlated random variable accounts for natural variation, leading to the following model formulation:

$$Y_{it}|\varepsilon_{it} \sim Poisson\left(\mu_{it}\left[1+f_i(t)\right]\varepsilon_{it}\right), for\ t \in (0, T) \quad (1)$$

$$\mu_{it} = N_{it}\ exp\{\alpha_i(t) + s_i(t) + w_i(t)\} \quad (2)$$

$$s_i(t) = \sum_{k=1}^{K}\left\{a_k\ cos\left(\frac{2\pi kt}{365}\right) + b_k\ sin\left(\frac{2\pi kt}{365}\right)\right\},\ K = 2 \quad (3)$$

To model temporal dependencies, $\alpha_i(t)$ is a smooth function of time with 1 knot per 7 years that represents the linear effect of long-term changes in mortality, $s_i(t)$ is a harmonics model with two terms that accounts for annual seasonal trends, and $w_i(t)$ denotes the impact associated with the day of the week.[16] Here, N_{it} is the mid-year population for the calendar year in which day t occurred for group i. The model computes the number of excess deaths for a single time point t by estimating $\mu_t f(t)$, where $f(t)$ is the natural cubic spline with 12 internal knots used to generate smooth estimates of $\widehat{\mu}_t\widehat{f}(t)$. From there, $[t_0, t_1]$ the estimate of excess deaths during a period is given by Equation (4).

$$\widehat{\Delta}_{[t_0,t_1]} = \sum_{t=t_0}^{t_1}\widehat{\mu}_t\widehat{f}(t) \quad (4)$$

Demographic changes over time introduce age as a confounding factor in expected mortality estimations, as

crude mortality may be inflated in aging populations due to the naturally higher mortality among older individuals.[17] To address this bias, we present both crude and age-adjusted metrics for excess mortality, where the crude estimates indicate the absolute burden of the COVID-19 pandemic, while the age-adjusted estimates provide a more accurate assessment of its impact and enhance the reliability and comparability of excess mortality estimates across different populations and regions.[18] We implemented an age-stratified approach to achieve the age adjustment of excess mortality. In this approach, we divided the population into 5-year age strata, ranging from 0 to 85 years, with individuals aged over 85 years grouped into a single stratum. For each age stratum i, we estimated the excess deaths Δ_i and corresponding estimated standard error $SE(\widehat{\Delta}_i)$ during 2020–2024 using pre-pandemic mortality data (2013–2019) as the baseline, modeling expected mortality with an over-dispersed Poisson regression as described in Equations (1)–(3). To calculate the age-adjusted excess deaths $\Delta_{[0,T]}$ over a given period $t \in [0, T]$, we first computed the excess deaths for each age stratum as $\widehat{\Delta}_{i,[0,T]}$. The overall age-adjusted excess deaths for a population that included m age strata were then derived from the summation of estimated excess deaths across all age strata, shown as Equation (5):

$$\Delta_{[0,T]} = \sum_{i=1}^{m} \widehat{\Delta}_{i,[0,T]} \tag{5}$$

As Equations (1) and (4) showed, the $f_i(t)$ indicates the changes of deaths between observed and mean deaths for strata i at time t. We assume the $\widehat{f}_i(t)$ follows the normal distribution and is independent across age strata within the Poisson regression framework. Following the variance addition rule, the standard error of age-adjusted excess deaths $\Delta_{[0,T]}$ is given by $SE(\Delta_{[0,T]}) = \sqrt{\sum_{i=1}^{m}[SE(\widehat{\Delta}_{i,[0,T]})]^2}$, and 95% confidence interval is constructed by $\Delta_{[0,T]} \pm 1.96.SE(\Delta_{[0,T]})$.

Age adjustment by 5-year strata in excess mortality estimation was applied in the age-specific analysis, whereas in the cause-specific analysis, age adjustment was conducted using 15-year strata since dividing death data by 5-year strata for specific causes produces sparse data for each stratum. In such cases, over-dispersed Poisson regression may have unreliable estimates when fitting excessive zero counts.[19] Moreover, our adaptive age adjustment strategy in cause-specific analysis adjusts strata based on death count size, with insufficient death counts typically occurring in the younger age groups. The details of strata division for age adjustment in cause-specific analysis are presented in Table S2.

All the analysis is performed in R, version 4.0.2, and R package *excessmort* was used to fit the time series modeling.[16] The package is publicly available on the R Comprehensive Archive Network (CRAN).

Ethics approval

Ethics approval was obtained from the Joint Chinese University of Hong Kong and New Territories East Cluster Clinical Research Ethics Committee (2022.197). As this study was a retrospective analysis using secondary data without any personal information, the requirement for obtaining informed consent was waived.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

All-cause excess mortality

During the COVID-19 pandemic and post-pandemic period (2020–2024) in Hong Kong, 186,098 deaths in total were recorded, corresponding to an all-cause mortality rate of 572.81 per 100,000 individuals. As shown in Table 1, excess mortality peaked during the Omicron wave, with crude excess mortality reaching 118.59 (95% CI: 112.72–124.47) per 100,000 and age-adjusted excess mortality at 107.54 (95% CI: 101.96–113.12) per 100,000, compared to a low level of 6.51 (95% CI: 2.35–10.67) and 0.32 (95% CI: −3.61, 4.26) during the pre-Omicron period, respectively. In the post-pandemic period, the excess mortality declined but remained six-fold higher (crude excess mortality: 37.66 [95% CI: 32.72–42.60] per 100,000; age-adjusted excess mortality: 32.79 [95% CI: 28.13–37.46] per 100,000) than pre-Omicron level.

Age-stratified excess mortality displayed changed population vulnerability across the periods (Table 1). Excess mortality in the population in all age groups elevated substantially during the Omicron wave. However, in the post-pandemic period, the elder population continued to experience significant excess mortality, with a crude estimate of 100.51 (95% CI: 86.16–114.86) and 586.74 (95% CI: 517.56–655.92) per 100,000 among those aged 65–79 years and ≥80 years, respectively. Particularly, individuals aged ≥80 years had 9.27% (95% CI: 8.09–10.45) of age adjusted excess deaths relative to baseline deaths. In contrast, the younger population groups (i.e., <65 years) showed near-zero excess mortality during the post-pandemic period. Within the specific age groups, no statistically significant age-adjusted excess mortality was observed in individuals aged 20–34 and 35–49 years. Among individuals aged 65–79 years, a notable difference between crude (100.51 per 100,000) and age-adjusted (15.73 per 100,000) estimates occurred. While excess deaths among the

	Observed deaths	Observed mortality per 100,000	Excess deaths	Age adjusted excess deaths	Excess mortality per 100,000 (95% CI)	Age adjusted excess mortality per 100,000 (95% CI)	% of age adjusted excess deaths to baseline deaths (95% CI)
Overall	186,098	572.81	13675.46	11448.84	42.09 (39.30, 44.89)	35.24 (32.59, 37.89)	6.56 (6.06, 7.05)
Pandemic (before Omicron)	76,434	528.45	941.95	46.91	6.51 (2.35, 10.67)	0.32 (−3.61, 4.26)	0.06 (−0.68, 0.81)
Pandemic (Omicron)	47,579	647.68	8712.03	7900.11	118.59 (112.72, 124.47)	107.54 (101.96, 113.12)	19.91 (18.88, 20.95)
Post pandemic	62,085	581.40	4021.47	3501.81	37.66 (32.72, 42.60)	32.79 (28.13, 37.46)	5.98 (5.13, 6.83)
0–19 years	532	11.38	1.40	34.12	0.03 (−0.94, 1,00)	0.73 (−0.21, 1.67)	6.85 (−1.98, 15.69)
Pandemic (before Omicron)	230	10.87	−22.08	−10.40	−1.04 (−2.51, 0.43)	−0.49 (−1.94, 0.95)	−4.33 (−17.04, 8.39)
Pandemic (Omicron)	125	11.99	7.56	15.08	0.73 (−1.31, 2.76)	1.45 (−0.54, 3.43)	13.72 (−5.08, 32.52)
Post pandemic	177	11.68	15.92	29.44	1.05 (−0.59, 2.69)	1.94 (0.36, 3.52)	19.95 (3.73, 36.18)
20–34 years	734	12.97	−20.67	−27.13	−0.37 (−1.32, 0.59)	−0.48 (−1.44, 0.48)	−3.56 (−10.67, 3.54)
Pandemic (before Omicron)	303	11.55	−47.87	−50.27	−1.83 (−3.22, −0.43)	−1.92 (−3.32, −0.51)	−14.23 (−24.66, −3.80)
Pandemic (Omicron)	162	12.95	−4.04	−5.81	−0.32 (−2.34, 1.69)	−0.46 (−2.50, 1.57)	−3.47 (−18.6, 11.67)
Post pandemic	269	15.08	31.24	28.95	1.75 (0.06, 3.45)	1.62 (−0.08, 3.33)	12.06 (−0.60, 24.72)
35–49 years	4016	52.85	−97.80	−166.59	−1.29 (−2.95, 0.37)	−2.19 (−3.86, −0.52)	−3.98 (−7.01, −0.95)
Pandemic (before Omicron)	1782	51.95	−123.47	−144.27	−3.60 (−6.10, −1.09)	−4.21 (−6.71, −1.70)	−7.49 (−11.96, −3.02)
Pandemic (Omicron)	938	54.78	18.06	−0.53	1.05 (−2.43, 4.54)	−0.03 (−3.54, 3.48)	−0.06 (−6.46, 6.34)
Post pandemic	1296	52.76	7.60	−21.78	0.31 (−2.57, 3.19)	−0.89 (−3.78, 2.01)	−1.65 (−7.05, 3.75)
50–64 years	21,557	271.55	172.40	391.16	2.17 (−1.44, 5.78)	4.93 (1.30, 8.55)	1.85 (0.49, 3.21)
Pandemic (before Omicron)	9437	266.51	−238.18	−212.36	−6.73 (−12.17, −1.28)	−6.00 (−11.49, −0.51)	−2.20 (−4.21, −0.19)
Pandemic (Omicron)	5207	287.55	352.38	405.79	19.46 (11.92, 27.00)	22.41 (14.84, 29.98)	8.45 (5.60, 11.31)
Post pandemic	6913	267.24	58.19	197.73	2.25 (−4.02, 8.52)	7.64 (1.37, 13.91)	2.94 (0.53, 5.36)
65–79 years	52,116	1058.53	4565.99	1960.44	92.74 (83.88, 101.60)	39.82 (30.75, 48.89)	3.91 (3.02, 4.80)
Pandemic (before Omicron)	20,859	1044.96	648.56	179.04	32.49 (18.24, 46.74)	8.97 (−5.40, 23.34)	0.87 (−0.52, 2.25)
Pandemic (Omicron)	13,031	1143.47	2120.62	1500.21	186.08 (167.74, 204.43)	131.64 (112.86, 150.43)	13.01 (11.15, 14.87)
Post pandemic	18,226	1019.53	1796.80	281.18	100.51 (86.16, 114.86)	15.73 (0.79, 30.67)	1.57 (0.08, 3.05)
≥ 80 years	107,127	6269.00	10153.25	9256.84	594.16 (554.48, 633.85)	541.70 (503.03, 580.38)	9.46 (8.78, 10.13)
Pandemic (before Omicron)	43,815	5785.82	621.27	285.19	82.04 (22.28, 141.81)	37.66 (−20.49, 95.81)	0.66 (−0.36, 1.67)
Pandemic (Omicron)	28,112	7221.17	6232.99	5985.37	1601.08 (1518.33, 1683.82)	1537.47 (1456.74, 1618.20)	27.05 (25.63, 28.47)
Post pandemic	35,200	6260.50	3298.98	2986.27	586.74 (517.56, 655.92)	531.12 (463.64, 598.61)	9.27 (8.09, 10.45)

Pandemic (before Omicron): 2020-01-23–2021-12-31; Pandemic (Omicron): 2022-01-01–2022-12-31, Post pandemic: 2023-01-01–2024-06-01. Mid-year population sizes were used to be the denominators of mortality rates. There are 16 missing records of age during 2020-01-23–2024-06-01.

Table 1: **Excess all-cause mortality by age group in Hong Kong (January 2020–June 2024).**

younger population fluctuate within expected levels, those aged ≥65 years showed modest increases characterized by clear wave patterns (Fig. 1).

In the post-pandemic period, younger females aged 0–49 years experienced no substantial excess mortality (Fig. 2). However, compared to male individuals, the excess mortality rates of females were generally higher among the elder groups during the post-pandemic period (males vs females: 50–64 years: −4.86 [95% CI: −15.94 to 6.21] vs 10.25 [95% CI: 3.28–17.22]; 65–79 years: 87.74 [95% CI: 63.20–112.27] vs 119.61 [95% CI: 104.33–134.88]; ≥80 years: 470.38 [95% CI: 361.50–579.26] vs 661.07 [95% CI: 580.04–742.10] per 100,000).

Cause-specific excess mortality

The patterns of cause-specific excess mortality shifted between the pandemic and post-pandemic periods. According to Table 2, excess mortality of respiratory diseases during the post-pandemic period still maintained at a higher level of 37.33 (95% CI: 34.47–40.20) per 100,000, which is ten-fold higher than that in the pre-Omicron period (3.47 [95% CI: 1.10–5.85] per 100,000). Pneumonia, which covered a major proportion of COVID-19 cases, exhibited the highest crude and age-adjusted excess death during the post-pandemic period, at 17.54 (95% CI: 14.99–20.10) per 100,000, and 23.06 (95% CI: 20.79–25.33) per 100,000, respectively. Particularly, the excess mortality due to pneumonia among individuals aged ≥65 years reached 58.87 (95% CI: 47.16–70.57) per 100,000 during the post-pandemic period, which is much higher than the 0.13 (95% CI: −0.58 to 0.84) per 100,000 observed among younger individuals (Fig. 3). Similar to the pandemic period, the crude and age-adjusted excess mortalities from influenza, chronic obstructive pulmonary disease, and lung diseases due to external agents remained negative during the post-pandemic period.

In contrast, excess mortality for non-respiratory diseases declined significantly, stabilizing near pre-Omicron levels with a crude estimate of −0.86 (95% CI: −4.57–2.86) per 100,000 and an age-adjusted

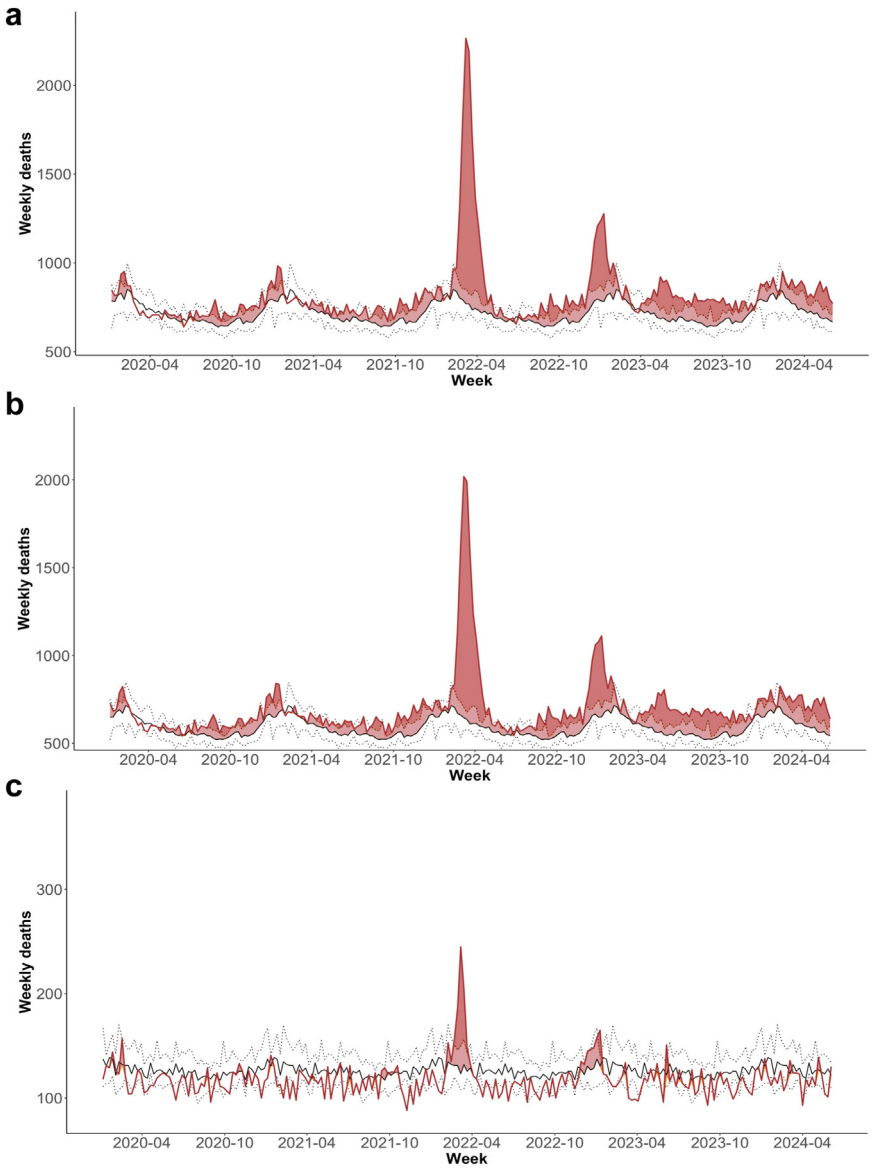

***Fig. 1*: Overall weekly all-cause deaths for (a) all individuals, (b) individual aged ≥65 years, and (c) individual <65 years in Hong Kong (2020–2024)**. Red lines represent the observed weekly deaths from 2020 to 2024, the black lines and dashed lines refer to the estimated average baseline deaths and the corresponding maximum upper and lower bounds of the 95% confidence interval.

estimate of 3.70 (95% CI: 0.04–7.36) per 100,000 (Table 2). During the post-pandemic period, the excess mortality rates of heart disease, neoplasms, nephritis and nephrosis, dementia, and injury generally approached or fell below the pre-pandemic baseline. While excess mortality from cerebrovascular disease declined following the Omicron pandemic, its post-pandemic excess mortality remained to be slightly positive at 1.55 (95% CI: 0.58–2.51) per 100,000 during the post-pandemic period, specifically among those aged ≥65 years. Similarly, we observed positive excess mortality rates of heart disease and injury among the younger individuals during the post-pandemic period (Fig. 3).

Discussion

Our study demonstrated the shifted excess mortality patterns in the post-pandemic period in a setting with high vaccination coverage. All-cause mortality, which remained around the expected levels in the pre-Omicron pandemic, surged sharply during the Omicron wave in

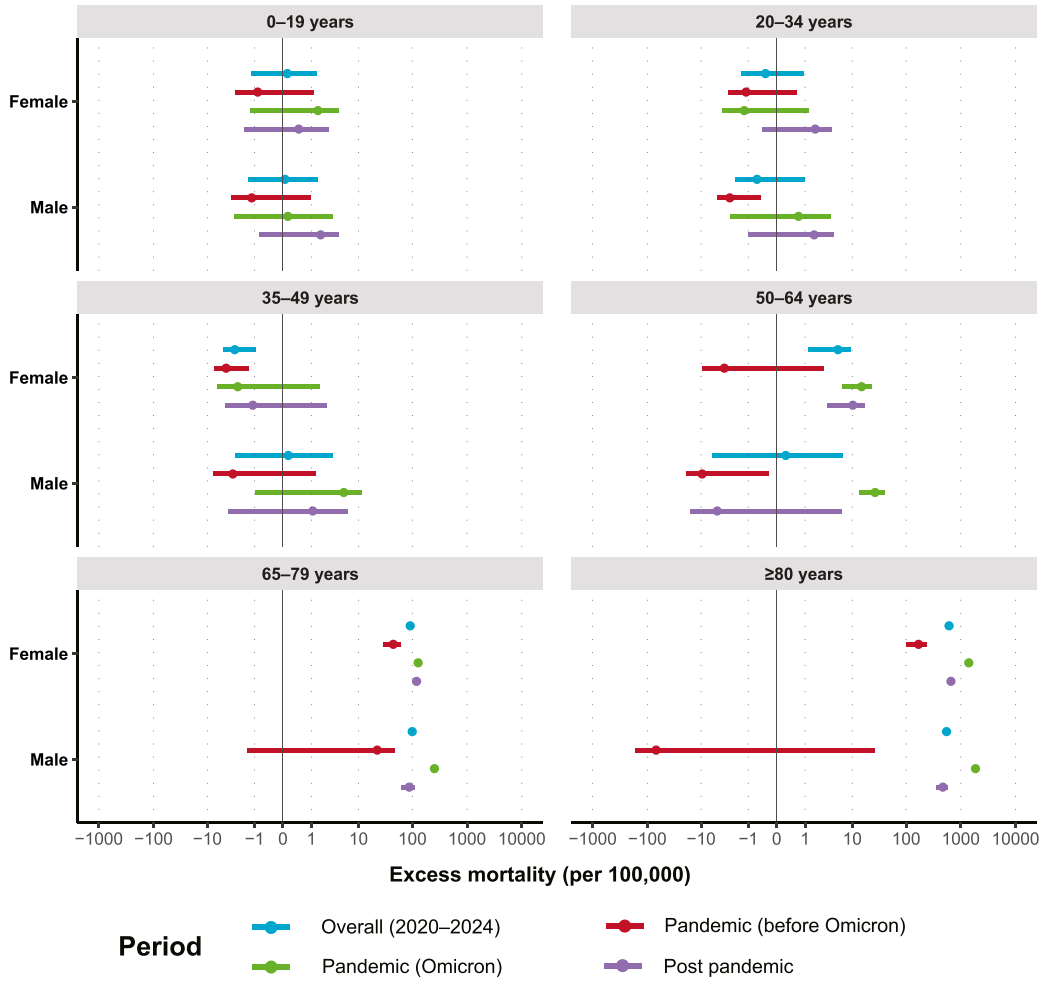

Fig. 2: **Sex-specific all-cause excess mortality by age groups in Hong Kong (2020–2024).**

early 2022 and subsequently declined to 37.66 per 100,000 during the post-pandemic period, which is still at a level significantly higher than pre-pandemic baselines. Particularly, the older population continued to experience significant excess mortality. The totality of our findings suggests that the COVID-19 pandemic continues to have lasting influences on mortality and population health, even though the acute impacts of COVID-19 surges have receded.

Throughout the post-pandemic period, substantial age-related disparities in excess mortality persisted, although the gap between age groups narrowed. The population aged ≥65 years experienced significant excess mortality, while the younger population exhibited normal mortality levels. Although Hong Kong's healthcare system has recovered to full functionality and capacity with high vaccination coverage, the sustained vulnerability of the older population still manifests, which can be attributed to several factors. One straightforward explanation is the prolonged exposure to COVID-19 due to the ongoing circulation of COVID-19 activity and the relaxation of control measures, which are usually underestimated due to the reduced testing and reporting. According to the sewage surveillance data, the sewage virus load of SARS-Cov-2 in the community after 2023 (around 300,000 copies/L), when normalization of COVID-19 started, are persistently higher than the pre-Omicron levels (below 10,000 copies/L).[20] Moreover, considering a gap in vaccination rates between the younger and older populations, the susceptibility and severity of COVID-19 among the older population may exceed the pre-Omicron conditions, as their immune systems are weakened not only by age-related decline but also by the long-term health effects from previous infections.[21] Studies also reported that female had a higher acute symptom severity after a SARS-CoV-2 infection[22] as well as a higher risk of developing long COVID than male,[23,24] it may thus

	Observed deaths	Observed mortality per 100,000	Excess mortality per 100,000 (95% CI)	Age-adjusted excess mortality per 100,000 (95% CI)	% of age adjusted excess deaths to baseline deaths (95% CI)
Respiratory diseases	70,052	208.96	37.86 (36.26, 39.47)	41.10 (39.58, 42.62)	23.55 (22.68, 24.42)
Pandemic (before Omicron)	25,446	170.85	3.47 (1.10, 5.85)	3.93 (1.67, 6.19)	2.29 (0.97, 3.60)
Pandemic (Omicron)	20,783	282.91	106.34 (102.98, 109.71)	108.71 (105.52, 111.90)	62.41 (60.58, 64.24)
Post pandemic	23,823	222.81	37.33 (34.47, 40.20)	44.87 (42.19, 47.54)	25.21 (23.71, 26.71)
Influenza	377	1.12	−2.70 (−2.95, −2.44)	−2.74 (−2.99, −2.49)	−71.08 (−77.63, −64.54)
Pandemic (before Omicron)	30	0.20	−2.77 (−3.10, −2.44)	−2.79 (−3.12, −2.46)	−93.62 (−104.76, −82.49)
Pandemic (Omicron)	0	0.00	−3.65 (−4.16, −3.13)	−3.75 (−4.27, −3.23)	−102.80 (−117.08, −88.52)
Post pandemic	347	3.08	−1.94 (−2.46, −1.43)	−1.88 (−2.37, −1.40)	−67.96 (−85.40, −50.51)
Pneumonia	52,484	156.55	14.83 (13.41, 16.26)	17.81 (16.45, 19.16)	12.39 (11.44, 13.33)
Pandemic (before Omicron)	21,723	145.85	8.56 (6.46, 10.66)	9.03 (7.01, 11.05)	6.40 (4.97, 7.83)
Pandemic (Omicron)	12,421	169.08	23.25 (20.26, 26.24)	25.54 (22.68, 28.39)	17.79 (15.80, 19.78)
Post pandemic	18,340	162.52	17.54 (14.99, 20.10)	23.06 (20.79, 25.33)	16.54 (14.91, 18.16)
Chronic obstructive pulmonary disease	1850	5.52	−1.29 (−1.57, −1.00)	−1.25 (−1.53, −0.96)	−17.97 (−22.10, −13.84)
Pandemic (before Omicron)	756	5.08	−1.95 (−2.39, −1.52)	−1.96 (−2.40, −1.53)	−27.30 (−33.38, −21.22)
Pandemic (Omicron)	408	5.55	−1.23 (−1.83, −0.64)	−1.24 (−1.84, −0.64)	−18.25 (−27.03, −9.47)
Post pandemic	686	6.08	−0.42 (−0.91, 0.08)	−0.27 (−0.73, 0.20)	−4.23 (−11.56, 3.09)
Lung diseases due to external agents	1997	5.96	−1.16 (−1.46, −0.87)	−1.01 (−1.31, −0.72)	−14.17 (−18.23, −10.11)
Pandemic (before Omicron)	927	6.22	−1.07 (−1.51, −0.62)	−1.04 (−1.48, −0.59)	−13.94 (−19.91, −7.97)
Pandemic (Omicron)	478	6.51	−0.77 (−1.38, −0.15)	−0.64 (−1.25, −0.03)	−9.00 (−17.55, −0.44)
Post pandemic	592	5.25	−1.56 (−2.07, −1.06)	−1.17 (−1.64, −0.71)	−18.27 (−25.55, −10.99)
Non-respiratory diseases	115,186	343.59	3.48 (1.37, 5.59)	4.33 (2.23, 6.42)	1.23 (0.63, 1.82)
Pandemic (before Omicron)	50,646	340.04	2.70 (−0.45, 5.85)	1.87 (−1.26, 5.01)	0.53 (−0.36, 1.43)
Pandemic (Omicron)	26,584	361.88	11.32 (6.88, 15.76)	10.05 (5.63, 14.48)	2.83 (1.59, 4.08)
Post pandemic	37,956	357.86	−0.86 (−4.57, 2.86)	3.70 (0.04, 7.36)	1.05 (0.01, 2.08)
Heart disease	16,560	49.40	0.04 (−0.77, 0.85)	0.56 (−0.22, 1.34)	1.12 (−0.44, 2.68)
Pandemic (before Omicron)	7341	49.29	−0.86 (−2.09, 0.37)	−0.85 (−2.04, 0.33)	−1.66 (−3.97, 0.65)
Pandemic (Omicron)	3843	52.31	2.00 (0.30, 3.70)	2.27 (0.63, 3.91)	4.56 (1.27, 7.85)
Post pandemic	5376	47.64	−0.09 (−1.50, 1.32)	1.23 (−0.04, 2.51)	2.67 (−0.09, 5.43)
Cerebrovascular disease	8761	26.13	1.86 (1.31, 2.42)	1.97 (1.42, 2.51)	7.87 (5.69, 10.05)
Pandemic (before Omicron)	3930	26.39	1.82 (0.99, 2.66)	1.76 (0.93, 2.58)	6.91 (3.67, 10.15)
Pandemic (Omicron)	2007	27.32	2.39 (1.23, 3.56)	2.35 (1.20, 3.50)	9.41 (4.82, 14.00)
Post pandemic	2824	25.03	1.55 (0.58, 2.51)	1.88 (0.99, 2.77)	8.13 (4.29, 11.98)
Neoplasms	40,172	119.83	−8.21 (−9.46, −6.96)	−10.02 (−11.29, −8.76)	−7.50 (−8.45, −6.55)
Pandemic (before Omicron)	18,010	120.92	−8.20 (−10.07, −6.32)	−9.25 (−11.15, −7.35)	−6.91 (−8.33, −5.49)
Pandemic (Omicron)	8807	119.89	−11.84 (−14.46, −9.21)	−14.81 (−17.49, −12.14)	−11.00 (−12.98, −9.01)
Post pandemic	13,355	118.35	−5.73 (−7.90, −3.57)	−7.37 (−9.45, −5.28)	−5.86 (−7.52, −4.20)
Nephritis and nephrosis	5901	17.60	0.41 (−0.05, 0.87)	0.51 (0.05, 0.96)	2.87 (0.28, 5.46)
Pandemic (before Omicron)	2591	17.40	0.70 (0.03, 1.38)	0.65 (−0.03, 1.32)	3.74 (−0.18, 7.67)
Pandemic (Omicron)	1417	19.29	1.64 (0.68, 2.60)	1.63 (0.67, 2.59)	9.22 (3.77, 14.66)
Post pandemic	1893	16.78	−0.83 (−1.65, −0.01)	−0.43 (−1.20, 0.34)	−2.50 (−6.95, 1.95)
Dementia	1058	3.16	−1.00 (−1.23, −0.78)	−0.95 (−1.18, −0.73)	−22.66 (−27.96, −17.36)
Pandemic (before Omicron)	456	3.06	−0.56 (−0.88, −0.24)	−0.58 (−0.90, −0.27)	−15.61 (−24.05, −7.18)
Pandemic (Omicron)	269	3.66	−0.66 (−1.14, −0.18)	−0.63 (−1.10, −0.15)	−14.59 (−25.63, −3.55)
Post pandemic	333	2.95	−1.84 (−2.27, −1.42)	−1.59 (−1.98, −1.20)	−35.04 (−43.70, −26.39)
Injury	3356	10.01	0.28 (−0.06, 0.63)	0.23 (−0.11, 0.58)	2.29 (−1.13, 5.72)
Pandemic (before Omicron)	1491	10.01	0.62 (0.11, 1.13)	0.53 (0.02, 1.04)	5.44 (0.21, 10.66)
Pandemic (Omicron)	743	10.11	0.04 (−0.68, 0.77)	−0.06 (−0.79, 0.67)	−0.61 (−7.79, 6.58)
Post pandemic	1122	9.94	0.00 (−0.62, 0.61)	0.03 (−0.56, 0.61)	0.26 (−5.61, 6.13)

Pandemic (before Omicron): 2020-01-23–2021-12-31; Pandemic (Omicron): 2022-01-01–2022-12-31; Post pandemic: 2023-01-01–2024-06-01. Mid-year population sizes were used to be the denominators of mortality rates.

Table 2: **Cause-specific excess mortality in Hong Kong (January 2020–June 2024).**

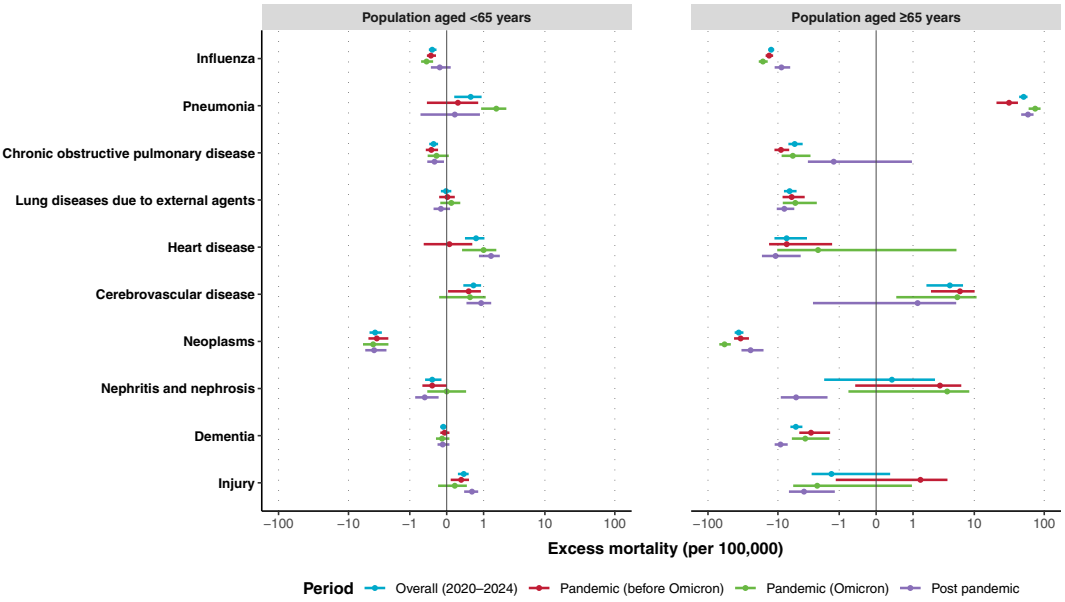

Fig. 3: **Cause-specific excess mortality by age groups in Hong Kong (2020–2024).**

explain female experiencing a greater excess mortality rate during the post-pandemic period in our study. Nevertheless, given inconsistent finding were reported in literature,[25] a careful interpretation of the sex-specific analysis is warranted.

Our study revealed varied post-pandemic recovery patterns in mortality attributed to different causes and populations. In the context of respiratory diseases, the population aged over 65 years was disproportionately affected by the pandemic compared to the younger group, experiencing the most sustained elevated and reverse excess mortality in pneumonia and influenza, respectively. Constantly increased risks in post-pandemic mortality were observed in the older population with pneumonia only, contrasting with other respiratory conditions that returned to pre-pandemic levels. Nevertheless, the significant excess mortality observed in pneumonia probably attributed to the COVID-19 deaths, which were categorized under the deaths of "pneumonia, organism unspecified" with ICD-9 code of "486" in the collected data, making delineating the non-COVID-19 pneumonia deaths challenging. Notably, significant reverse post-pandemic excess mortality was found in the influenza and lung disease due to external agents among the older population. This suggests lasting beneficial effects of COVID-19 control measures, such as social distancing and strict mask-wearing protocols during the pandemic, which effectively disrupted the transmission of respiratory infections and reduced exposure to airborne pollutants and pathogens.[26,27] However, one critical message from our findings is the resurgence of influenza activity in Hong Kong, where below-average mortality increased from −3.65 per 100,000 during the Omicron period to −1.94 per 100,000 in the post-pandemic period. This trend mirrors those observed in other countries and may be linked to reduced influenza vaccination coverage during the pandemic, while the co-circulation of influenza and COVID-19 likely exacerbated the risks of co-infections, leading to more severe complications.[28,29]

Post-pandemic mortality patterns diverged significantly between the older and younger groups in cerebrovascular disease, heart disease, and injuries with younger populations experiencing delayed impacts and heightened health risks in the post-pandemic period compared to the population aged ≥65 years. This suggests that the consequent pandemic impacts on non-respiratory diseases are more complex and shaped by both post-COVID conditions and the secondary effects of the pandemic. The abnormal rises in post-pandemic heart disease and cerebrovascular mortality among younger populations were also found in England,[10] underscoring the long-term monitoring of cardiac risks after the pandemic. Clinical studies have highlighted the significant thromboembolism risks and vascular damage in post-COVID physiological conditions. Delayed thrombotic events can occur months after the acute phase, even in individuals with mild or asymptomatic infections, while those with severe symptoms are substantially imposed with the risk of developing long-term thrombotic complications after the recovery.[30,31] For the cardiovascular risks, excessive incidences of major adverse cardiac events were found in both individuals with and without a prior history of heart disease during the COVID-19 hospitalization, as the virus can directly infect cardiac tissue and trigger an

inflammatory response, exacerbating endothelial dysfunction, myocarditis, and other complications.[32–34] Although younger populations initially had lower COVID-19 mortality due to stronger immune systems and fewer comorbidities, accumulated mild or asymptomatic infections may have increased their long-term cardiovascular mortality risk after the pandemic. Furthermore, younger individuals may experience more pronounced healthcare disruptions during the pandemic as they are more likely to delay or avoid routine medical management which is critical for timely screenings and early treatment for chronic conditions, due to their lower awareness of health risks compared to the older population.[35]

A similar increased mortality was also observed for injuries among younger populations after the Omicron wave. Specifically, excess mortality from injuries declined during the Omicron wave compared to the pre-Omicron pandemic, likely due to mobility restrictions, remote work arrangements, and reduced social interactions, which limited exposure to unintentional falls, traffic and occupational hazards.[36] However, in the post-pandemic period, excess mortality from injuries surged to twice the pre-Omicron level, coinciding with the resurgence of economic and social activities. Prolonged psychological and socioeconomic stress in younger populations induced by the pandemic, such as social isolation, job losses, and financial instability, may have exacerbated mental health symptoms, leading to increased substance abuse, suicides, and risky outdoor activities.[36,37]

Conversely, the older population exhibited reverse mortality patterns in most non-respiratory diseases until the post-pandemic period, plausibly explained by the harvesting effect which was particularly evident in countries with stringent COVID-19 control measure.[38] This suggests that the most vulnerable older individuals, who were predisposed to early mortality, died during the pandemic. As a result, the post-pandemic period saw a reduced pool of high-risk older individuals who might have otherwise died from chronic diseases. Notably, some studies have suggested that cancer patients infected with COVID-19 were at higher mortality risks.[39,40] However, our findings indicated a decline in neoplasm mortality among individuals aged 65 and older during the pre-Omicron pandemic, which was more pronounced during the Omicron wave but then slightly attenuated in the post-pandemic period. We speculate that early pandemic might cause delays in neoplasm diagnosis and treatment due to overwhelmed healthcare system, possibly resulting in a short-term reduction in reported deaths, but this could be offset by future increases due to disease progression. Indeed, the weekly diagnosis of gastric and colorectal cancers dropped by about half and one-third in Hong Kong between late 2019 and early 2020.[41] Additionally, this persistent decline in neoplasm mortality may in part result from COVID-19 acting as a competing cause of death in individuals with comorbidities during the pandemic, rather than reflecting a direct change in neoplasm mortality.[42]

Our study shows a notable difference between the crude and age-adjusted excess mortality among individuals aged 65–79 years, primarily due to a declining mortality trend in this group. Hong Kong is experiencing a rapid ageing population, with the highest life expectancy rate in the world. According to the local statistics,[43] the crude mortality rate for individuals aged 65–79 years decreased from approximately 53 per 1000 in 2013 to 48 per 1000 in 2019. This 10.3% drop is greater than the 6.9% decline observed in those under 65 years of age. As this age-specific trend is accounted for when determining the baseline expected mortality in the age-adjusted estimates, the difference between the crude and age-adjusted excess mortality is notably larger for this age group, given that they have been predominantly affected by the Omicron outbreak.

Several limitations of our study should be acknowledged. First, regarding data quality, our data did not include deaths that occurred in private hospitals or non-hospital settings. Nevertheless, most patients with life-threatening illnesses are sent to the hospital, even if they have passed away outside the hospital premises, including in nursing homes. One major reason for this is that the legal barriers hinder end-of-life care for the older population. For example, the procedure of death registration is highly complicated, and medical practitioners are often unwilling to certify an individual as deceased at home.[44] Even if the elderly died in nursing homes, they are still required to be transferred to a hospital after death. In addition, unlike outpatient services, inpatient services in private hospitals in Hong Kong are very expensive, and most patients prefer to receive care in public hospitals. As a result, more than 90% of all deaths in Hong Kong either occur in or are reported to public hospitals, excluding deaths occurring outside of Hong Kong. Second, data limitations in patients' principal diagnoses include the absence of initial primary causes of admission and specific ICD-9 coding for COVID-19 deaths. These may introduce the bias in understanding the underlying health conditions contributing to mortality and cause-of-death misclassification, particularly in the context of analyzing pneumonia-related mortality. Third, we had limited data on specific subgroups and did not explore how excess mortality varied by more detailed socioeconomic status or ethnicity. Including these factors could have provided a more detailed understanding of excess mortality disparities in Hong Kong. Forth, the dynamic nature of public health interventions, vaccination coverage, and vaccine effectiveness throughout the pandemic and post-pandemic period made it challenging to consistently measure the indirect mortality impact of COVID-19 in highly vaccinated setting. Prior to the Omicron outbreaks in early 2022, we assumed that immunity protection was primarily derived from

vaccination, as herd immunity afterwards became a combination of vaccine-derived and naturally acquired immunity. Furthermore, the selection of the baseline period for estimating expected mortality introduces sensitivity, as different reference periods can produce significantly different absolute excess mortality estimates.[45] Finally, our study could not capture the long-term health consequences of the pandemic, including delayed mortality from untreated conditions and the post-COVID long-term health effects.

Conclusion

Our investigation revealed a transition in excess mortality patterns from the pre-Omicron pandemic to the post-pandemic period. While overall post-pandemic excess mortality significantly declined from peak levels, it remained higher than pre-pandemic baselines, particularly among the population aged over 65 years. The variation in excess mortality trends across age groups and causes of death emphasize the need for targeted interventions, as well as sustained protective measures and management of post-COVID conditions in the older population.

Contributors

Study design and conceptualization: KL, YW, KCC. Data collection and pre-processing: SYL, KKL, CHKY, TYC, EKY. Data analysis and interpretation: KL, YW, KCC. Manuscript: KL, CTH, CKHW, XX, PKSC, SZ, ZG. Critical revision: GL, QC, CL, XJ, EKY, KCC. All authors contributed to the revision and review of the manuscript. KCC and EKY verified the data and had access to raw data. All authors were responsible for the decision to submit the manuscript for publication.

Data sharing statement

The sharing of mortality data is restricted by the Census and Statistics Department, Hong Kong.

Declaration of interests

All authors declare no competing interests.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lanwpc.2025.101554.

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