Estimates of COVID-19 deaths in Mainland China after abandoning zero COVID policy

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Data statement: All data are in the manuscript and tables. Archives of Hong Kong (COVID-19 fifth wave) and South Korea COVID-19 data can be found in https://www.coronavirus.gov.hk/eng/5th-wave-statistics.html and https://ncov.kdca.go.kr/en/bdBoardList.do?brdId=16&brdGubun=161&dataGubun=&ncvContSeq=&contSeq=&board_id=

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ABSTRACT (247 words)

Background: China witnessed a surge of Omicron infections after abandoning "zero COVID" strategies on December 7, 2022. The authorities report very sparse deaths based on very restricted criteria, but massive deaths are speculated.

Methods: We aimed to estimate the COVID-19 fatalities in Mainland China until summer 2023 using the experiences of Hong Kong and of South Korea in 2022 as prototypes. Both these locations experienced massive Omicron waves after having had very few SARS-CoV-2 infections during 2020-2021. We estimated age-stratified infection fatality rates (IFRs) in Hong Kong and South Korea during 2022 and extrapolated to the population age structure of Mainland China. We also accounted separately for deaths of residents in long-term care facilities, which were prominent in Hong Kong.

Results: IFR estimates in non-elderly strata were modestly higher in Hong Kong than South Korea and projected 987,455 and 811,571 maximal COVID-19 deaths, respectively, if the entire China population was infected. Expected COVID-19 deaths in Mainland China until summer 2023 ranged from 64,573 to 691,219 assuming 25-70% of the non-elderly population being infected and variable protection of elderly (from none to three-quarter reduction in fatalities). The main analysis (45% of non-elderly population infected and fatality impact among elderly reduced by half) estimated 199,223-249,094 COVID-19 deaths until summer 2023. Large uncertainties exist regarding potential changes in dominant variant, health system strain, and impact on non-COVID-19 deaths.

Conclusions: The most critical factor that can affect total COVID-19 fatalities in China is the extent to which the elderly can be protected.

Keywords: COVID-19, China, mortality, Omicron, SARS-CoV-2

INTRODUCTION

China adhered to policies of "zero COVID" for almost three years during the COVID-19 pandemic with strictly enforced lockdowns and other aggressive restrictive measures. As of December 7, 2022, China decided to radically change course and adopt a "living with COVID" policy. Restrictive measures were lifted abruptly and, as expected, wide circulation of Omicron variants ensued across the country. A major question is what might be the COVID-19 death toll in China under these circumstances. Projections, expectations and interpretations of accumulating data have started to abound. The Institute of Health Metrics and Evaluation (IHME) projected (1) 300,000 deaths until April 1, 2023 and 1 million deaths during 2023, with substantially different outcomes depending on use of masks and social distancing. In non-peer-reviewed announcements, some scientists, companies, media and social media commentators have projected extremely high death tolls, possibly up to several million fatalities (2-4). Concurrently, the official data of COVID-19 deaths from China have recorded very few deaths after removal of lockdown measures. Only 7 COVID-19 deaths were reported in the first two weeks and in late December 2022 the authorities declared that they cease their daily COVID-19 reports. China is actually using a revised definition of COVID-19 deaths that requires the presence of pneumonia/respiratory failure due to SARS-CoV-2 infection and lack of comorbidities. This is a major change compared to previous recording of COVID-19 deaths, e.g. during the previous Shanghai outbreak practically all the recorded COVID-19 deaths occurred in people with comorbidities. This practice also deviates from COVID-19 recording practices in Western countries where both deaths 'with' and 'by' COVID-19 may be counted (5). Thus the official data from China and many speculations on COVID-19 deaths are becoming vastly divergent.

Here, we aim to offer estimates of the anticipated COVID-19 death toll in Mainland China from massive SARS-CoV-2 surges after the removal of lockdown measures. We

employ comparative data from Hong Kong and South Korea. Hong Kong and South Korea witnessed large waves with Omicron variants starting in January 2022 after following until then policies that had maintained minimal infections in the population. We estimate the infection fatality rate (IFR) estimates across granular age strata in Hong Kong and South Korea and then extrapolate to Mainland China considering differences in the age structure of the population pyramids and in residents of long-term care facilities (LTCFs). We discuss also other potential differences that may affect comparisons between Mainland China in 2023 versus Hong Kong and Korea in 2022.

METHODS

Modeling of China on Hong Kong and South Korea Omicron waves

We aimed to estimate the COVID-19 death toll in Mainland China following the removal of lockdown measures on December 7, 2022 and until summer 2023. We used Hong Kong and South Korea as prototypes to model the expected deaths in Mainland China after adjustment of the age-structure in the respective population pyramids. For Hong Kong where residents of LTCFs had particularly poor outcomes, we also took them separately into consideration.

Hong Kong witnessed a massive COVID-19 wave due to Omicron variants starting in January 2022. Seroprevalence data suggest that 45% of the community-dwelling population had been infected by mid-summer (6), 2.4 times the documented cases. We assumed the same ascertainment factor during 2022 with ascertainment factors per age strata informed by the seroprevalence study. Deaths of residents of LTCFs accounted for 54.5% of all COVID-19 deaths (7,8). As of December 27, 2022, after two new surges in the second half of 2022, the number of documented cases was 2,510,205 and the number of deaths was 11,349. BA.1 and BA.2 variants dominated until summer 2022 and BA.2 was gradually replaced by BA.5 and some BA.2.75, BQ1 and XBB variants later in the year (9).

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South Korea similarly had the first Omicron deaths documented on January 3, 2022. Until the end of 2021, only 1.2% of the population had been documented to have been infected, while the proportion increased to 38.2% by July 31, 2022. By December 27, 2022 there were 31,882 deaths and 28,772,196 confirmed infections. South Korea uses aggressive testing and thus has very low rates of under-ascertainment, as corroborated also by limited seroprevalence data (10). Therefore, we assumed the true number of infections is 1.25-times the number of documented cases for each age stratum. BA.1 and BA.2 variants dominated until summer 2022 and BA.2 was gradually replaced by BA.5 and some BA.2.75 and XBB variants later in the year (9).

In China, the wave started shortly after removal of restrictive measures on December 7, 2022. For the first weeks, sequencing data suggest that the dominant variants are BA5.2 and BF.7 (11).

Calculation of China COVID-19 deaths from age-stratified IFR estimates and population age structures

First, we projected the maximal COVID-19 fatalities in Mainland China, if the IFRs in different age groups (0-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79, 80-, 90-) were the ones seen in Hong Kong or in South Korea during their respective Omicron waves and if the entire population of Mainland China were infected. Then, we considered different attack rates in the non-elderly (0-59 years old) population in China (ranging from 25% to 70%) until summer 2023, and different ability to protect especially the elderly above 60 year old (ranging from none up to reducing the fatality impact among them by three-quarters). The fatality impact in the elderly may be reduced either by preferentially shielding them from infection (12) or by further reducing the IFR e.g. by higher vaccination rates. In the main analysis scenario, we used 45% of the non-elderly population being infected by summer and fatality impact reduced by half in the elderly strata. Both Hong Kong and South Korea had

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approximately 45% of their population infected in the respective time frame in their Omicron waves (6,10).

For the highest age-stratum (above 80 years old), data on COVID-19 deaths are not reported separately for more granular substrata. However, the relative proportion of people 80-89 and above 90 years old can make a substantial difference, because IFR typically increases steeply with age (13,14). Therefore, we used a separate IFR for the population 80-89 years old ($IFR_{80-}/(4-(3xP_{80-89}))$) where IFR_{80-} is the IFR in the entire above 80 (>=80) age-stratum and P_{80-89} is the percentage of those 80-89 years old among those above 80 years old) and for those above 90 years old ($IFR_{80-}/(1-(0.75xP_{80-89}))$)) in a way that the two estimates would differ 4-fold among them.

For Hong Kong, the majority of COVID-19 deaths during 2022 (54.5% of all COVID-19 deaths, 57% of COVID-19 in people above 60 years old).happened among the 76,091 residents of LTCFs (7,8) and their IFR was very high (probably because of very low vaccination rates in Hong Kong nursing homes) (15). Therefore, we generated separate IFR estimates for community-dwelling 60-69, 70-79, 80-89, 90- year old strata, and separately for residents of LTCFs. Assuming that 96% of deaths of residents of LTCFs are in people above 70 years old and the remaining 4% in people 60-69 years old, this corresponded to decreasing the community-dwelling IFR by 60% for people above 70 years old and by 25% for people 60-69 years old. For residents of LTCFs, we assumed that IFR was the same as the case fatality rate (9%) given the frequent, ubiquitous testing. For South Korea, LTCFs were better protected with much higher vaccination coverage and accounted for a much smaller share of deaths (no exact data available), so no separate IFRs were calculated. For China, it is estimated that there are 8.16 million beds for elderly people (16), but a large share of them are in day care facilities for overnight or short visits and the remaining are not fully occupied (17), therefore we assumed there are approximately 4 million residents of LTCFs.

Population pyramids

Population pyramids for Mainland China, Hong Kong, and South Korea for 2022 were obtained from pyramidnet.net (18).

RESULTS

Calculation of stratified IFR for Hong Kong and South Korea

Tables 1 and 2 present the calculations of stratified IFR for Hong Kong and South Korea, respectively. Among non-elderly age strata (up to 59 years old), the IFR estimates were modestly lower in South Korea than in Hong Kong. For Hong Kong where also separate IFRs were estimated for community-dwelling populations for elderly strata, IFR in residents of LTCFs was about 3.5 times higher than the IFR of community-dwelling elderly above 90 years old and 14-times higher than the IFR of community-dwelling elderly 80-89 years old.

China projections of maximal deaths based on Hong and South Korea stratified IFR

As shown in Table 3, if the entire population of China were to be infected with IFR estimates similar to those obtained in Hong Kong and South Korea during 2022, the total COVID-19 fatalities would be 987,455 and 811,571, respectively. This included 119,630 and 73,865 fatalities, respectively, among non-elderly (0-59 years old) and 867,825 and 737,706 fatalities among elderly, respectively.

China projections of expected COVID-19 deaths until summer 2023

As shown in Table 4, the range of expected COVID-19 deaths in China until summer 2023 ranged from 64,573 to 691,219 under different scenarios. The most optimistic estimate uses the South Korean stratified IFR estimates and assumes that only 25% of the non-elderly population of China gets infected and the fatality impact among the elderly is reduced by three-quarters (e.g. by combination of factors such as better protection to avoid infection and/or better vaccination coverage). The most pessimistic estimate uses the Hong Kong

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stratified IFR estimates and assumes that 70% of the population is infected with no ability to offer any extra protection benefit to the elderly as compared with the non-elderly. In the main analysis where 45% of the non-elderly population is infected and fatality impact among the elderly is reduced by half, we estimated 199,223 to 249,094 COVID-19 deaths until summer 2023.

DISCUSSION

An effort to estimate COVID-19 deaths in China until summer 2023 based on the respective experiences of Hong Kong and of South Korea during 2022 suggests a wide range of possibilities from ~65,000 to ~700,000, with values in the range of 200,000-250,000 for the main analysis. COVID-19 deaths in China are not a fixed, unavoidable calamity. How many people will die from SARS-CoV-2 depends primarily on the extent to which the elderly population can be protected and, to a much lesser degree, on the proportion of the non-elderly population that gets infected. It may also be further affected by whether the dominant variants during the epidemic wave have similar, lower, or higher fatality rates than the Omicron variants that dominated the 2022 outbreaks in Hong Kong and South Korea and by the functionality of the Chinese health system under strain.

The proportion of the population infected until summer 2023 in China may be higher or lower than the proportion of the population infected in the equivalent time span in 2022 in Hong Kong and South Korea (45%). The dominant variants in China as of end 2022 were BA 5.2 and BF.7 which may have become dominant because they are even more transmissible than the BA.1 and BA.2 variants that dominated in the first half of 2022 in Hong Kong and South Korea. This may lead to higher percentage of the population infected in China until summer 2023 and/or more explosive epidemic wave than may run its cycle faster. Conversely, differences in urbanicity and population density may point towards lower percentage of the population infected in China. Hong Kong is a highly densely populated

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metropolis and 81.4% of the population of South Korea is urban versus 64.7% in China. The extent to which restrictive measures, masks, and social distancing may be used in China (even without strict government mandates) adds to the uncertainty about the eventual attack rate.

The ability to selectively protect the elderly population is also uncertain. Evidence from seroprevalence studies from the first two COVID-19 waves suggests that some countries managed to offer substantial precision shielding to the elderly, but most countries had relatively similar infection rates among the elderly and non-elderly (19). With far greater sensitization about the extremely steep age risk gradient of IFR and with the past lessons of extremely high fatalities in LTCFs (20) elsewhere, including prominently in Hong Kong, one hopes that China avoids the past mistakes of other countries. Even though China has a smaller share of its population residing in LTCFs than Hong Kong and South Korea, a large share of avoidable deaths depends on whether these facilities can be effectively protected. An even larger share of avoidable deaths pertains to community-dwelling elderly people. Vaccination coverage among the elderly as of end-2022 in China is better than the respective coverage of Hong Kong elderly and LTCF residents in early 2022 (only 25% of people over 80 years old had been vaccinated by January 2022) (21), but not necessarily better than South Korea in early 2022. The ability to offer vaccine boosters to very high-risk people, the availability of effective treatments and the pragmatic effectiveness of the vaccines used in China (22-24) will further shape the eventual death toll. CoronaVac may be modestly less effective than mRNA vaccines (22,23).

It is unclear whether the currently dominant BA.5.2 and BF.7 subvariants in China are less lethal than the BA.1 and BA.2 variants that dominated in Hong Kong and South Korea during the first half of 2022. Case fatality rates have only decreased slightly in South Korea between the first and second half of 2022 (when BA.5 became dominant). Conversely, case

fatality rates have decreased substantially in Hong Kong during the second half of 2022 versus the first half. However, this may not be due to the dominance of BA.5, but due to better vaccination coverage and prior infections in a large segment of the population. The most likely scenario would be that for China as well, IFR may decrease during the course of 2023. However, long-term predictions are very uncertain, since the potential evolution towards new variants and the fatality thereof are unknown.

A comparison of stratified IFR estimates in Hong Kong, South Korea and China needs to consider also differences in the prevalence of risk factors for death after SARS-CoV-2 infection. China has a lower percentage of obesity in its population compared with Hong Kong and South Korea (25), but obesity has increased in recent years (26) and the difference may thus not be so prominent. Smoking rates (and thus respiratory disease) have been historically high in all three locations. The advantage of recent declines in smoking rates more prominently in Hong Kong probably do not translate yet to major decreases in severe respiratory disease. Transplants and other causes of medically-induced immunosuppression are less prevalent per population base in China. Overall, age-stratified IFR may be slightly or modestly lower in China than in Hong Kong and South Korea. If so, estimates of projected COVID-19 fatalities in China may be slightly or modestly overestimated.

Our main analysis estimates of COVID-19 deaths in China tend to be modestly lower than those proposed by IHME (1), but the range of possible outcomes with different scenarios amply overlaps. Our estimates are much lower than several non-peer-reviewed estimates that have been popular in media (2-4, 27). For example, one model endorsed by Wigram Capital Advisors anticipates 1.6 million COVID-19 deaths in China within 3 months of abandoning zero COVID policies (28). These high estimates are widely speculative and depend on questionable modeling assumptions rather than IFR standardization. Some inputs in such modeling may have exaggerated values.

A major limitation for our analyses is the difficulty of prefiguring the health system performance during a massive COVID-19 outbreak in China. It is unknown if the stress will be proportionally higher in China than in Hong Kong or South Korea, although both Hong Kong and South Korea were stressed during the peak of the Omicron waves. High system stress may translate to less favorable outcomes both for COVID-19 deaths and for non-COVID-19 deaths (29,30). In this regard, both Hong Kong and South Korea have probably more functional health systems than China overall – but there is substantial variability across China. This could be reflected eventually on escalating excess death counts in particular in China. Excess deaths are a useful summary metric of the composite impact of the pandemic, its indirect effects and of the measures taken. However, reliable calculation of excess deaths requires accurate data on fatalities, ideally stratified per age group, over time. Highly reliable data are available for South Korea, but not for Hong Kong or Mainland China. For example, in China a study conducted in 2018 found an average completeness of death registration of 72% with range from 2.4% to 100% across different counties (31). Even for South Korea, different modeling approaches yield different estimates of excess death. E.g. in 2020-2021, WHO estimates 6,288 excess deaths in South Korea (32), Economist estimates 7,558 excess deaths (33), while our calculations (using 2017-2019 as baseline) shows a death deficit (34). Economist projects 54,352 excess deaths as of November 14, 2022 (33), while our calculations based on age-stratified data (available until summer 2022) and using 2017-2019 as a baseline suggest a persistent death deficit until the summer of 2022. For China, uncertainties about excess deaths are likely to be even more prominent. E.g. Economist calculates over 700,000 excess deaths in China even before December 7, 2022 (33), i.e. with practically negligible COVID-19 deaths. Nevertheless, if COVID-19 deaths in China end up being in the range predicted by our main analysis, they would represent a very small

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percentage of overall mortality during the 2000-2023 period (<1% based on our main

analysis), given that there are more than 10 million deaths annually in China.

Our analysis has several other limitations. First, seroprevalence surveys and

estimation of ascertainment factors have uncertainty and potential biases (35,36). Second,

data on LTCFs are available with different definitions and levels of accuracy across the three

locations. Some imputations had to be made in the absence of detailed information.

Therefore, our estimates need to be seen with extra caution. Third, in principle long-term

projections for a dynamically evolving virus are highly precarious. Thus we discourage

estimates extending beyond the first half of 2023 and major surprises during even the first

half of 2023 are possible. Moreover, re-infections may have substantially lower IFR (37) and

transmission dynamics may change in a heavily previously infected population. Fourth,

relative estimates of effectiveness of various vaccines, e.g. the mRNA vaccines widely used

in South Korea and the China-produced vaccines, are uncertain as they are based on

observational data.

Finally, we used Hong Kong and South Korea as comparators for standardization, but

other countries in the vicinity of China may also be informative. Japan and countries in

Indochina already had substantial viral circulation and fatalities before 2022, in particular

with Delta variants, so comparisons are less relevant. Taiwan adhered to zero COVID policy

as well, but it abandoned this policy in late spring 2021 with its first massive Omicron wave

starting 4 months later than Hong Kong and South Korea. It is unclear whether shifting the

first massive exposure to the virus in late spring and summer rather than winter could make a

difference. As of late 2022, it is estimated that 71% of the population of Taiwan has been

infected (38) and 15,181 COVID-19 deaths have been reported as of December 28, 2022.

We could not find detailed stratified data to perform analyses similar to Hong Kong and

South Korea. However, the crude overall population IFR in Taiwan during 2022 (~0.07%) is similar to South Korea's.

Allowing for these caveats, our analysis provides a framework in which to attempt estimating COVID-19 deaths in China in the first half of 2023. Under most circumstances, the death toll may not be very high, but disparate estimates can emerge depending on the footprint of the epidemic wave on different population strata. The choice of China to report only a small subset of deaths compared to what has been reported by Western countries has drawn heavy criticism. It is unknown whether the intention is to reduce the potential for panic and the number of people who request healthcare attention, in particular in hospitals that may otherwise be overloaded with mildly symptomatic cases. Finally, while our analysis has an outlook of half a year, it is possible that in each city the duration of the epidemic wave will be much shorter, lasting only several weeks. The ability of the health system to absorb such acute waves without panic, the availability or not of resources and protection or lack thereof for the elderly and vulnerable may dictate the overall final outcomes of COVID-19 in China.

REFERENCES

1. Institute for Health Metric and Evaluation, report in

   https://1drv.ms/b/s!AuOyHP_aTIy72tRSHCDtJqOI5d_T9w?e=X2SMBb, last

   accessed December 26, 2022.

2. Sridhar D. https://www.theguardian.com/commentisfree/2022/dec/21/china-covid-surge-vaccination-data-infected, Guardian, last accessed December 26, 2022.

3. Bradsher K, Chien AC, Dong J.

   https://www.nytimes.com/2022/12/23/world/asia/china-covid-death-toll.html, New

   York Times, last accessed December 26, 2022.

4. https://www.airfinity.com/articles/china-risks-between-1-3-and-2-1-million-deaths-if-it-ends-its-zero-covid, last accessed December 26, 2022.

5. Ioannidis JPA. Over- and under-estimation of COVID-19 deaths. Eur J Epidemiol.

   2021 Jun;36(6):58188.

6. Lau JJ, Cheng SMS, Leung K, et al. Population-based sero-epidemiological estimates

   of real-world vaccine effectiveness against Omicron infection in an infection-naive

   population, Hong Kong, January to July 2022. medRxiv 2022.11.01.22281746; doi:

   https://doi.org/10.1101/2022.11.01.22281746

7. Chow L. Care homes and COVID-19 in Hong Kong: how the lessons from SARS

   were used to good effect. Age Ageing. 2021;50(1):21-24. doi:10.1093/ageing/afaa234

8. https://www.scmp.com/news/hong-kong/health-environment/article/3183212/number-coronavirus-cases-linked-hong-kong-nursing, South China Morning Post, last

   accessed December 26, 2022.

9. https://ourworldindata.org/grapher/covid-variants-bar?time=2021-12-06&country=USA~HKG~KOR~CHN, last accessed December 26, 2022.

10. Chun JY, Jeong H, Kim Y. Identifying susceptibility of children and adolescents to the Omicron variant (B.1.1.529). BMC Med. 2022;20:451.

11. https://www.globaltimes.cn/page/202212/1282775.shtml, Global Times, last accessed December 26, 2022.

12. Ioannidis JPAL Precision shielding for COVID-19: metrics of assessment and feasibility of deployment. BMJ Glob Health. 2021;6(1):e004614.

13. Pezzullo AM, Axfors C, Contopoulos-Ioannidis DG, Apostolatos A, Ioannidis JPA. Age-stratified infection fatality rate of COVID-19 in the non-elderly population. Environ Res. 2023 Jan 1;216(Pt 3):114655.

14. O'Driscoll M, Ribeiro Dos Santos G, Wang L, Cummings DAT, Azman AS, Paireau J, Fontanet A, Cauchemez S, Salje H. Age-specific mortality and immunity patterns of SARS-CoV-2. Nature. 2021 Feb;590(7844):140-145.

15. https://www.bloomberg.com/news/articles/2022-03-03/hong-kong-s-nursing-homes-are-unvaccinated-hotbeds-of-covid, Bloomberg, last accessed December 26, 2022.

16. https://www.statista.com/statistics/251917/number-of-beds-in-nursing-homes-for-elderly-in-china/, last accessed December 26, 2022.

17. Feng Z, Glinskaya E, Chen H, Gong S, Qiu Y, Xu J, Yip W. Long-term care system for older adults in China: policy landscape, challenges, and future prospects. Lancet. 2020 Oct 24;396(10259):1362-1372.

18. https://www.populationpyramid.net, last accessed December 26, 2022.

19. Axfors C, Pezzullo AM, Contopoulos-Ioannidis DG, Apostolatos A, Ioannidis JPA. Differential COVID-19 infection rates in children, adults, and elderly: systematic review and meta-analysis of 38 pre-vaccination national seroprevalence studies. J Glob Health (in press).

20. International data on deaths attributed to COVID-19 among people living in care homes, https://ltccovid.org/, last accessed December 26, 2022.

21. https://ourworldindata.org/covid-vaccinations, last accessed December 26, 2022.

22. McMenamin ME, Nealon J, Lin Y, Wong JY, Cheung JK, Lau EHY, Wu P, Leung GM, Cowling BJ. Vaccine effectiveness of one, two, and three doses of BNT162b2 and CoronaVac against COVID-19 in Hong Kong: a population-based observational study. Lancet Infect Dis. 2022 Oct;22(10):1435-1443.

23. Premikha M, Chiew CJ, Wei WE, Leo YS, Ong B, Lye DC, Lee VJ, Tan KB. Comparative Effectiveness of mRNA and Inactivated Whole-Virus Vaccines Against Coronavirus Disease 2019 Infection and Severe Disease in Singapore. Clin Infect Dis. 2022 Oct 12;75(8):1442-1445.

24. Leung K, Leung GM, Wu JT. Modelling the adjustment of COVID-19 response and exit from dynamic zero-COVID in China. medRxiv 2022.12.14.22283460; doi: https://doi.org/10.1101/2022.12.14.22283460

25. Global obesity observatory, https://data.worldobesity.org/, last accessed December 26, 2022.

26. Pan X-F, Wang L, Pan A. Epidemiology and determinants of obesity in China. Lancet Diabet Endocrin 2021;9:P373-392.

27. https://www.economist.com/china/2022/12/15/our-model-shows-that-chinas-covid-death-toll-could-be-massive, last accessed December 27, 2022.

28. https://www.ft.com/content/4e1f0062-279c-4390-86f8-4d331418a8f5, last accessed December 27, 2022.

29. Asch DA, Sheils NE, Islam MN, Chen Y, Werner RM, Buresh J, Doshi JA. Variation in US Hospital Mortality Rates for Patients Admitted With COVID-19 During the First 6 Months of the Pandemic. JAMA Intern Med. 2021 Apr 1;181(4):471-478.

30. French G, Hulse M, Nguyen D, Sobotka K, Webster K, Corman J, Aboagye-Nyame B, Dion M, Johnson M, Zalinger B, Ewing M. Impact of Hospital Strain on Excess Deaths During the COVID-19 Pandemic - United States, July 2020-July 2021. MMWR Morb Mortal Wkly Rep. 2021 Nov 19;70(46):1613-1616.

31. Zeng X, Adair T, Wang L, Yin P, Qi J, Liu Y, Liu J, Lopez AD, Zhou M. Measuring the completeness of death registration in 2844 Chinese counties in 2018. BMC Med. 2020;18:176.

32. Msemburi W, Karlinsky A, Knutson V, Aleshin-Guendel S, Chatterji S, Wakefield J. The WHO estimates of excess mortality associated with the COVID-19 pandemic. Nature. 2022 Dec 14. doi: 10.1038/s41586-022-05522-2.

33. https://ourworldindata.org/excess-mortality-covid#estimated-excess-mortality-from-the-economist, last accessed December 7, 2022.

34. Levitt M, Zonta F, Ioannidis JPA. Comparison of pandemic excess mortality in 2020-2021 across different empirical calculations. Environ. Res. 2022; 213:113754

35. Bergeri I, Whelan MG, Ware H, Subissi L, Nardone A, Lewis HC, Li Z, Ma X, Valenciano M, Cheng B, Al Ariqi L, Rashidian A, Okeibunor J, Azim T, Wijesinghe P, Le LV, Vaughan A, Pebody R, Vicari A, Yan T, Yanes-Lane M, Cao C, Clifton DA, Cheng MP, Papenburg J, Buckeridge D, Bobrovitz N, Arora RK, Van Kerkhove MD; Unity Studies Collaborator Group. Global SARS-CoV-2 seroprevalence from January 2020 to April 2022: A systematic review and meta-analysis of standardized population-based studies. PLoS Med. 2022 Nov 10;19(11):e1004107.

36. Arora RK, Joseph A, Van Wyk J, Rocco S, Atmaja A, May E, Yan T, Bobrovitz N, Chevrier J, Cheng MP, Williamson T, Buckeridge DL. SeroTracker: a global SARS-CoV-2 seroprevalence dashboard. Lancet Infect Dis. 2021 Apr;21(4):e75-e76.

37. Medić S, Anastassopoulou C, Lozanov-Crvenković Z, Vuković V, Dragnić N, Petrović V, Ristić M, Pustahija T, Gojković Z, Tsakris A, Ioannidis JPA. Risk and severity of SARS-CoV-2 reinfections during 2020-2022 in Vojvodina, Serbia: A population-level observational study. Lancet Reg Health Eur. 2022 Sep;20:100453.

38. Institute of Health Metrics and Evaluation, December 15 COVID-19 results briefing, Taiwan (province of China), https://www.healthdata.org/sites/default/files/covid_briefs/8_briefing_Taiwan_Province_of_China.pdf, last accessed December 28, 2022.

Table 1. Calculations of stratified infection fatality rates in Hong Kong:

Age	Population	Deaths	Cases	AsF	IFR	IFRc
0-19	1,277,620	18	325,661	3.3	0.000017	0.000017
20-29	798,498	19	288,699	2.4	0.000027	0.000027
30-39	1,104,277	31	418,923	2.1	0.000035	0.000035
40-49	1,141,564	79	414,715	2.3	0.000083	0.000083
50-59	1,169,327	329	397,424	2.3	0.000360	0.000360
60-69	1,122,469	969	352,545	2.5	0.001099	0.000825
70-79	608,372	1,869	170,189	2.5	0.004393	0.001757
80-89	288,088	7,979*	112,863*	2.5	0.016265	0.006506
90-	94,091			2.5	0.065060	0.026024

Population as of 2022; deaths and COVID-19 cases during 2022 (fifth wave) as of December 27, 2022; 56 deaths and 29186 cases are not included as their assignment to age group was pending at the time of the analysis (see detailed data at Government of Hong Kong coronavirus site dedicated to the fifth wave statistics

https://www.coronavirus.gov.hk/eng/5th-wave-statistics.html).

AsF: ascertainment factor (ratio of total infections over documented cases) based on seroprevalence study in late July 2022 (reference 6).

IFR: infection fatality rate.

IFRc: infection fatality rate among community-dwelling population (excluding residents of long-term care facilities).

*presented for all people aged 80 and over.

Table 2. Calculations of stratified infection fatality rates in South Korea

Age	Population	Deaths (in 2022)	Cases	IFR**
0-19	8,534,281	52	6,634,482	0.000006
20-29	6,410,012	65	4,196,212	0.000012
30-39	6,915,849	110	4,199,519	0.000021
40-49	8,022,763	354	4,386,635	0.000065
50-59	8,538,680	1,029	3,731,215	0.000221
60-69	7,044,982	2,791	3,104,523	0.000719
70-79	3,784,990	5,742	1,572,122	0.002922
80-89	1,788,653	16,176*	947,488*	0.009631
90-	289,695			0.038524

Population as of 2022; number of COVID-19 cases and deaths from the South Korea government Central Disease Control Headquarters as of December 27, 2022 (https://ncov.kdca.go.kr/en/bdBoardList.do?brdId=16&brdGubun=161&dataGubun=&ncvContSeq=&contSeq=&board_id=), subtracting the fatality impact per age group as of December 31, 2021 using historically archived data in Demography of COVID-19 database (https://dc-covid.site.ined.fr/en/data/korea/).

IFR: infection fatality rate.

*presented for all people aged 80 and over.

**assuming that cases in each age-stratum during the 5th wave is 1.25-times the number of cases recorded in the previous column.

Table 3. Calculation of expected maximal deaths in China using Hong Kong or South Korea stratified IFR estimates

Calculations using Hong Kong stratified IFR estimates

Age-group	IFR	China population*	Maximal deaths
0-19	0.000017	335,323,469	5,616
20-29	0.000027	175,108,854	4,802
30-39	0.000035	233,767,164	8,237
40-49	0.000083	202,957,964	16,810
50-59	0.000360	233,838,693	84,165
60-69 (com)	0.000825	154,777,903	127,626
70-79 (com)	0.001757	81,730,213	143,609
80-89 (com)	0.006506	23,834,546	155,068
90- (com)	0.026024	3,132,598	81,523
LTCFs	0.09	4,000,000	360,000
Total			987,455

Calculations using South Korea stratified IFR estimates

Age group	IFR	China population	Maximal deaths
0-19	0.000006	335,323,469	2,103
20-29	0.000012	175,108,854	2,170
30-39	0.000021	233,767,164	4,899
40-49	0.000065	202,957,964	13,103
50-59	0.000221	233,838,693	51,591
60-69	0.000719	155,777,903	112,037
70-79	0.002922	82,730,213	241,730
80-89	0.009631	25,334,546	243,997
90-	0.038524	3,632,598	139,942
			811,571

China population as per 2022.

Com: community-dwelling population (excluding residents of LTCFs).

IFR: infection fatality rate.

LTCFs: long-term care facilities.

*assuming 4 million residents of LTCFs distributed as 1 million 60-69, 1 million 70-79, 1.5 million 80-89, and 0.5 million above 90- years old.

Table 4. Expected COVID-19 deaths in China until summer 2023

Percent infected in non-elderly	HK, S=1	HK, S=0.5	HK, S=0.25	SK, S=1	SK, S=0.5	SK, S=0.25
25	246,864	138,386	84,147	202,893	110,680	64,573
30	296,237	166,063	100,976	243,471	132,815	77,487
35	345,609	193,740	117,805	284,050	154,951	90,402
40	394,982	221,417	134,635	324,628	177,087	103,317
45	444,355	249,094	151,464	365,207	199,223	116,231
50	493,728	276,771	168,293	405,786	221,359	129,146
55	543,100	304,448	185,122	446,364	243,495	142,060
60	592,473	332,126	201,952	486,943	265,631	154,975
70	691,219	387,480	235,610	568,100	309,903	180,804

HK: based on Hong Kong-inferred infection fatality rates.

SK: based on South Korea-inferred infection fatality rates.

S=1, no precision shielding preferentially for the elderly (above 60 years old).

S=0.5, fatality impact reduced by half for the elderly.

S=0.25, fatality impact reduced by three-quarters for the elderly.