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Excess mortality during and after the COVID-19 emergency in Japan: a two-stage interrupted time-series design

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SUMMARY

Background The COVID-19 pandemic has had unprecedented impacts on mortality worldwide. This study aimed to estimate excess all-cause mortality in Japan from 2020 to 2023, stratified by age, sex and prefecture, to assess the evolving impact of the pandemic, particularly in the latter years. The study period extends beyond Japan ending the public health emergency.

Methods Using national vital statistics data from 2015 to 2023, we employed a two-stage interrupted time series analysis to estimate excess mortality during the COVID-19 pandemic (2020–2023) compared with the prepandemic period (2015–2019). Models were adjusted for seasonality, long-term trends, temperature and influenza activity. We calculated excess deaths during (14 January 2020 to 7 May 2023) and after (8 May 2023 to 31 December 2023) the COVID-19 emergency.

Results Japan experienced 219 516 excess deaths (95% empirical CI (eCI) 138 142 to 301 590) during the study period, corresponding to 3.7% (95% eCI 2.33 to 5.09) excess mortality. Excess mortality was negative in 2020 (−1.67%, 95% eCI −2.76 to −0.55), becoming positive in 2021 (2.19%, 95% eCI 0.9 to 3.49) and peaking in 2022 (7.55%, 95% eCI 5.96 to 9.13) before declining in 2023 (5.76%, 95% eCI 4.29 to 7.24). The <60 age group consistently showed the highest percentage excess mortality. Males had slightly higher excess mortality than females. By 2022, all prefectures exhibited positive excess mortality. The relative risk peaked in late 2022, with a smaller peak in summer 2023, coinciding with the post-emergency period. Comparing this post-emergency period with prior years shows the highest percentage excess mortality in 2022. Rural prefectures, and those with lower influenza cases, showed reduced excess mortality during the latter and post-emergency period.

Conclusion Despite initial success in mitigating excess deaths, Japan saw increasing excess mortality as the pandemic progressed, with continued elevation post-emergency. The varying impact across age groups and time highlights the complex factors affecting mortality. This study's findings underline the importance of continuous monitoring of excess mortality as a key indicator for public health dynamics.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ The available evidence highlighted negative excess all-cause mortality in 2020, becoming positive in early 2021. We found similar excess mortality studies globally but a lack of evidence for the latter stages of the pandemic and postpandemic.

⇒ Japan, in comparison to many countries globally, fared better in 2020 and 2021 with regards to excess mortality. However, the early evidence in Japan showed that this trend appeared to be changing as the pandemic progressed into 2021 and the pandemic period in its entirety needed assessment.

WHAT THIS STUDY ADDS

⇒ This study assesses excess mortality in Japan during and after the COVID-19 pandemic, providing new analysis for the pandemic period, including post-emergency, particularly identifying the increases in excess mortality and relative risk in 2022 and 2023 compared with previous years.

⇒ We found that all prefectures saw rises in excess mortality in the latter half of the pandemic, while males had slightly higher excess mortality compared with females. The younger population (<60 age group) consistently showed the highest excess mortality throughout the study period, which includes our post-emergency period.

⇒ This study also identified prefecture characteristics such as rurality and influenza cases that could influence excess mortality.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ These findings offer guidance for future public health strategies and cooperation during infectious disease outbreaks. The continued increase in excess mortality risk following Japan's initial negative excess deaths highlights the unpredictable and multifaceted nature of the pandemic.

INTRODUCTION

The WHO declared an end to the global Public Health Emergency for COVID-19 on 5 May 2023. Healthcare systems faced numerous challenges, compounded by the virus's evolving nature. COVID-19's cases,

morbidity, mortality and economic burden were unprecedented. Japan implemented multiple policies to mitigate its impact.[1 2] The pandemic led to widespread behavioural changes, including increased hygiene, social distancing and mask-wearing. Public trust in government guidance influenced preventative measures, while stay-at-home requests and contact tracing saw high adherence, reflecting a broader shift in public health awareness and response.[3] Whether the pandemic changes had an overall effect on mortality, compared with before and after the pandemic, can be crucial for future preparedness. The Japanese government downgraded the legal status of COVID-19 under the Infectious Disease Control Law to Class 5, the same level as influenza on 8 May 2023.[4] Assessing mortality during and after the emergency is vital to gain a better understanding of the disease and response, while also providing potential learnings on managing future infectious disease outbreaks.

Estimating excess deaths from the pandemic is important as it quantifies the overall burden compared with baseline levels. Previous studies examined shorter time frames. Onozuka *et al* reported reduced all-cause mortality in Japan in 2020, except for those aged <60 and 70–79.[5] Reduced deaths were observed for both sexes and in all age groups except those aged <60 and 70–79 years. Nomura *et al* studied excess deaths in Japan from January to June 2021 and found excess deaths occurring for the first time since 2020 in April 2021.[6] With nearly 4 years of data and COVID-19's emergency status downgraded, a more comprehensive assessment of its impact on mortality in Japan is now possible.

To provide insight on the potential impact of the COVID-19 pandemic from 2020 to 2023 on all-cause excess mortality in Japan, the aim of this study is to estimate all-cause excess deaths during this period by age, sex and prefecture, with particular focus on the latter years and post-emergency period, while also assessing associations with influenza cases. With numerous measures and events in the study period, there is a need to obtain further insight into how the pandemic impacted excess mortality, particularly as Japan's experience evolved over time. The changes since the first year of the pandemic, where Japan appeared to cope better than other countries, warrant detailed examination to understand longer-term patterns. We hypothesise that excess mortality would increase in the latter years of the COVID-19 emergency, especially post-emergency, as public measures shift. To better prepare for upcoming health emergencies, this analysis could direct both the creation of policies and the allocation of resources. Additionally, this study will incorporate nationwide and prefecture-level influenza data to explore potential associations with all-cause excess mortality, providing context for interpreting mortality trends. To the best of our knowledge, there are currently no studies looking at this extended time period in Japan. The primary objective of this study is to determine excess deaths from 2020 to 2023 in Japan, including the post-emergency phase, relative to mortality in the pre-COVID years of 2015 to 2019, stratified by sex, age group and prefecture.

METHODS

Data collection

Data for all-cause mortality from 2015 to 2023, with age and sex stratification, was obtained for the 47 prefectures of Japan from the Ministry of Health, Labour and Welfare's Vital Statistics system. Data included individual deaths, with details on: 'prefecture of residence', 'date of birth', 'date of death' and 'sex'. Daily totals were created from 1 January 2015 to 31 December 2023. Hourly temperatures from 1 January 2015 to 31 December 2023 were obtained from the Japan Meteorological Agency and then converted to average daily temperatures.[7] These data are from a weather station in an urban area of the prefectural capital for each of the 47 prefectures (except for Saitama and Shiga, where Kumagaya and Higone were used, respectively). Weekly influenza cases from January 2015 to December 2023 for all 47 prefectures were obtained using the sentinel surveillance data (Infectious Disease Weekly Record) provided by the National Institute of Infectious Diseases.[8] Weekly data were converted to daily data by dividing the weekly events by 7 days.

Statistical analysis

A two-stage interrupted time series was employed to estimate the time-varying excess mortality during our study period (14 January 2020 to 31 December 2023) relative to the pre-pandemic period (1 January 2015 to 13 January 2020).

The first stage used a quasi-Poisson regression model, as used in previous studies.[4 6]

$$\log\left[E\left(Y_{it}\right)\right] = \alpha + h_1\left(days\ from\ first\ COVID19\ case; \theta_i\right) + date + h_2\left(day\ of\ the\ year; \gamma_i\right) + dow_t + f\left(T_{it}, l; \beta_i\right) + flu_t$$

where $E\left(Y_{it}\right)$ represents expected daily deaths Y observed at time t in prefecture i; h_1 and h_2 represent spline functions of time with θ_i and γ_i as prefecture-specific coefficients, respectively; *date* represents continuous calendar time; *dow* denotes the day of the week; f denotes a cross-basis function for daily temperature T; l represents the number of lag days; β is a vector of fixed-effect coefficients; and *flu* represents daily influenza cases using 7 days moving average.

The component $h_1\left(days\ from\ first\ COVID19\ case; \theta_i\right)$ represents the spline function modelling temporal excess mortality associated with the COVID-19 outbreak. This was defined using a constrained quadratic B-spline curve, with df explored using Quasi-Akaike Information Criterion (qAIC), selecting the lowest value. Seven equally spaced knots were used to control smoothness for days from 14 January 2020 (first reported COVID-19 case in Japan) to 31 December 2023. The number of internal knots was tested from three to 10 knots, and 12 was determined on lowest qAIC. This is displayed in online supplemental table S1 and online supplemental figure S1.

To account for time-varying confounders, a cyclic cubic B-spline with seven df for day of year $h_2\left(day\ of\ the\ year; \gamma_i\right)$ which allows adjustment for seasonality, in addition to dummy indicators for day of the week (*dow*) for weekly mortality variation control. Choice of df for seasonality was based on the smallest qAIC, shown in online supplemental table S1 and online supplemental figure S2. We followed the three internal knots set at the 10th, 75th and 90th percentiles of prefecture-specific empirical distributions from previous studies using a cross-basis parameterisation.[5 9] The included term for mean daily temperature was defined through this DLNM over 0–21 lag days. To factor in the potential confounding of influenza epidemics and delayed effects, influenza terms 7 days moving average (*flu*) were included.

In the second stage, an intercept-only random effects meta-analysis model was used to pool the prefecture-specific estimates and obtain average estimates at the national level, following the methods of previous studies.[5 10] The best linear unbiased prediction was then used to estimate excess mortality for each of the 47 prefectures at prefecture level. The I^2 statistic was used to assess heterogeneity of pooled prefecture-level coefficients.

The relative risk (RR) of excess mortality for each prefecture on each day of the study period was computed using prefecture-level coefficients to arrive at national estimates. This is relative to the pre-pandemic period (1 January 2015 to 13 January 2020). The daily number of excess deaths was computed as $n^*[(RR - 1)/RR]$, where n is the daily number of deaths. Empirical CIs (eCIs) at 95% were computed using 1000 Monte Carlo simulations of the coefficients θ_i following a multivariate normal distribution. This method has been used in previous papers.[9 10] Age and sex stratified analyses were conducted using the same approach. Our age groups were defined as <60, 60–69, 70–79, 80–89 and ≥90 years. These are consistent with previous studies.[5 10] Percentage excess deaths were calculated by dividing the number of excess deaths by the number of observed deaths and then converting into a percentage. The sensitivity analysis and corresponding tables (online supplemental table S2–S8) and figures (online supplemental figure S3–S8) are provided in the Supplementary document.

Patient and public involvement

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

Software

Statistical analyses were performed using R 4.3.0 (R Core Team, R Foundation for Statistical Computing, Vienna, Austria).

RESULTS

Excess mortality

In the time period between 14 January 2020 and 31 December 2023, a total of 5 927 372 deaths were registered in Japan, with an excess from the estimated baseline of 219 516 (95% eCI 138 142 to 301 590). This results in a percentage excess of 3.7% (95% eCI 2.33 to 5.09). The estimates are adjusted for influenza, temperature, seasonality and temporal trends. This is summarised in online supplemental table S9). The yearly excess mortality breakdown, with percentage excess mortality, is shown in table 1. We can observe negative excess deaths in 2020 of −22 045 (95% eCI −36 562 to −7234), corresponding to a percentage of −1.67% (95% eCI −2.76 to −0.55). The years 2021, 2022 and 2023 have excess deaths of 31 791 (13 044; 50 699), 119 060 (95% eCI 94 015 to 144 034) and 90 710 (95% eCI 67 645 to 114 091) respectively. As a percentage, this amounts to 2.19% (95% eCI 0.9 to 3.49), 7.55% (95% eCI 5.96 to 9.13) and 5.76% (95% eCI 4.29 to 7.24), respectively.

This predominant trend is seen in both males and females. Males had higher percentage excess mortality than females in all years. In the age-stratified groups, only the <60 and 70–79 age groups show positive excess deaths in 2020 compared to 2003 (95% eCI 239 to 3758) and 4977 (95% eCI 420 to 9229), respectively. This corresponds to 2.42% (95% eCI 0.29 to 4.54) and 1.8% (95% eCI 0.15 to 3.34), respectively. In 2021, only the 60–69 and ≥90 age groups showed negative excess deaths, most negative in the 60–69 group with −2468 (95% eCI −8059 to 2985), corresponding to −2.21% (95% eCI −7.23 to 2.68). Excess deaths are positive for all sexes and age groups in 2022 and 2023, with all showing a percentage excess mortality increase from 2021 to 2022.

The <60 age group had the highest percentage excess mortality among all age groups in all 4 years of the study period (2020, 2021, 2022 and 2023) with 2.42% (95% eCI 0.29 to 4.54), 5.71% (95% eCI 3.43 to 7.93), 8.6% (95% eCI 6.46 to 10.7) and 8.19% (95% eCI 5.7 to 10.66), respectively. The 60–69 age group showed the lowest percentage excess mortality for each year. The largest year-on-year change seen was in the 80–89 age group from 1.66% (95% eCI −0.22 to 3.44) in 2021 to 8.06% (95% eCI 5.72 to 10.25) in 2022.

Table 2 outlines that the post-emergency period, commencing 8 May 2023 (when the status of COVID-19 was downgraded in Japan), shows positive excess mortality for all groups, but only higher compared with the yearly percentage excess mortality in 2023 for the 60–69 age group (0.43% (95% eCI −6.09 to 7.11)). For all groups, the post-emergency period in 2023 has greater excess mortality than the corresponding periods in 2020 and 2021, but lower than the corresponding period in 2022.

Relative Risk curves

Figure 1 illustrates the temporal change in RR of excess mortality across the study period. RR was negative in 2020 but gradually increased, becoming >1 in early 2021. This rise continued until mid-2021, followed by a plateau and slight decline in late 2021. However, RR sharply increased again until the end of 2022. This pattern was consistent across all 47 prefectures, with similar RR peaks observed in

Table 1 Yearly excess deaths and percentage excess mortality during the COVID-19 pandemic period (14 January 2020–31 December 2023). 95% empirical CIs (eCIs) are shown in parentheses

	Excess deaths (95% eCI) Percentage excess mortality (95% eCI)			
	2020*	2021	2022	2023
Overall	−22 045 (−36 562; −7234) −1.67% (−2.76; −0.55)	31 791 (13 044; 50 699) 2.19% (0.9; 3.49)	119 060 (94 015; 144 034) 7.55% (5.96; 9.13)	90 710 (67 645; 114 091) 5.76% (4.29; 7.24)
Sex				
Male	−6500 (−14 380; 1707) −0.95% (−2.11; 0.25)	20 563 (8687; 32 497) 2.76% (1.17; 4.36)	61 015 (49 159; 72 718) 7.59% (6.12; 9.05)	46 783 (35 540; 57 944) 5.84% (4.44; 7.23)
Female	−15 460 (−23 946; −7304) −2.41% (−3.73; −1.14)	11 284 (983; 21 731) 1.6% (0.14; 3.08)	58 126 (43 502; 72 801) 7.51% (5.62; 9.41)	43 890 (28 136; 59 726) 5.66% (3.63; 7.71)
Age				
<60	2003 (239; 3758) 2.42% (0.29; 4.54)	4981 (2992; 6922) 5.71% (3.43; 7.93)	7621 (5724; 9484) 8.6% (6.46; 10.7)	7207 (5011; 9379) 8.19% (5.7; 10.66)
60 to 69	−4384 (−7536;−1423) −4% (−6.87; −1.3)	−2468 (−8059; 2985) −2.21% (−7.23; 2.68)	1046 (−4559; 6692) 0.94% (−4.08; 5.98)	443 (−6089; 7127) 0.41% (−5.66; 6.62)
70 to 79	4977 (420; 9229) 1.8% (0.15; 3.34)	12 621 (6388; 18 563) 4.24% (2.15; 6.24)	21 960 (13 095; 29 699) 7% (4.18; 9.47)	14 824 (982; 27 022) 4.76% (0.32; 8.67)
80 to 89	−12 389 (−19 395; −5613) −2.61% (−4.09; −1.18)	8661 (−1160; 17 909) 1.66% (−0.22; 3.44)	45 990 (32 651; 58 478) 8.06% (5.72; 10.25)	37 784 (23 556; 50 816) 6.64% (4.14; 8.92)
≥90	−15 678 (−21 991; −9461) −4.13% (−5.79; −2.49)	−22 (−9092; 9493) −0.01% (−2.09; 2.19)	28 405 (13 519; 43 836) 5.77% (2.74; 8.9)	9831 (−5083; 24 936) 1.97% (−1.02; 5)

*Commencing 14 January 2020.

late 2022 (online supplemental figure S11). RR declined until spring 2023, followed by a summer peak coinciding with the post-emergency period (denoted in pink), and then dropped sharply below 1 in late 2023. Daily observed deaths also showed a gradual yearly increase, peaking in winter. In most years, RR peaks slightly preceded the observed death peaks, except in 2021, where RR peaked in summer before the winter mortality peak in early 2022.

The prefectural analysis displayed similar curves between the prefectures. Sex-stratified curves are available in online supplemental figures S12 and S13. The peak RR in females is marginally higher (1.15) compared with males (1.13) in 2022, and the low point is marginally lower (0.96 and 0.98), respectively, in 2020. Relative to their peaks in 2022, the peak in 2023 is relatively higher in males compared with females. Nevertheless, both sexes follow a similar pattern to the overall curve. Figure 2 shows the RR curves for each age group throughout the study period. The means are displayed, with the individual age group curves and CIs available in online supplemental figures S14–S18.

Table 2 Yearly percentage excess deaths in Japan during post-emergency period (8 May 2023–31 December 2023) and comparison with corresponding period in previous years. 95% empirical CIs (eCIs) are shown in parentheses

	Post-emergency period percentage excess mortality comparison (95% eCI)			
	2020	2021	2022	2023
Overall	−1.3 (−2.52; −0.07)	2.83 (1.67; 4)	9.5 (7.92; 11.1)	5.38 (3.98; 6.78)
Sex				
Male	−0.59 (−1.87; 0.71)	3.43 (2.12; 4.77)	9.34 (8.02; 10.62)	5.7 (4.3; 7.04)
Female	−2.06 (−3.58; −0.56)	2.19 (0.72; 3.69)	9.68 (7.84; 11.55)	5.04 (2.79; 7.24)
Age				
<60	4.03 (1.67; 6.42)	6.51 (3.62; 9.36)	9.67 (7.95; 11.4)	8.58 (5.14; 11.98)
60 to 69	−4.24 (−7.55; −0.82)	−1.99 (−7.01; 2.84)	2.59 (−2.44; 7.67)	0.43 (−6.09; 7.11)
70 to 79	2.36 (0.6; 4.02)	4.87 (2.85; 6.75)	8.28 (5.04; 11.12)	4.62 (−0.48; 9.09)
80 to 89	−2.42 (−4.11; −0.77)	2.28 (0.4; 4.02)	10.06 (8; 12.04)	6.34 (3.93; 8.56)
≥90	−3.9 (−5.72; −2.05)	0.68 (−1.32; 2.7)	8.39 (5.43; 11.45)	1.11 (−2.12; 4.35)

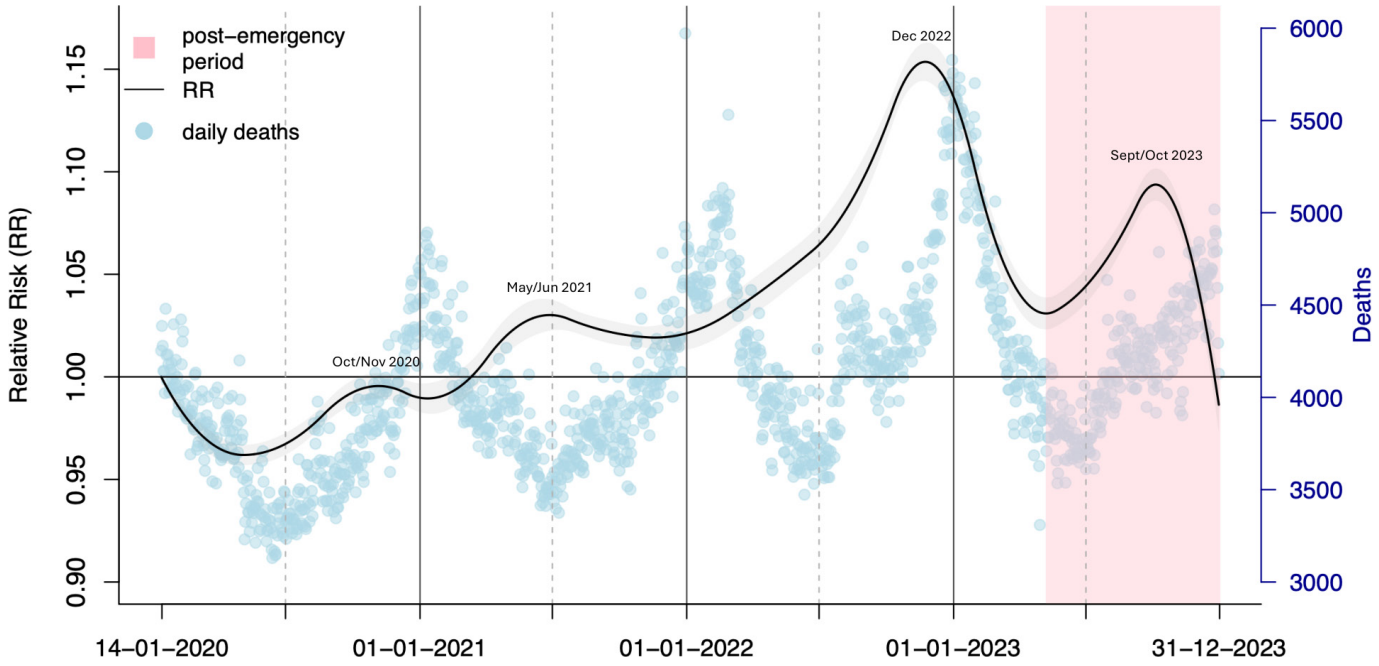

Figure 1 Overall relative risk of excess mortality in Japan throughout the COVID-19 pandemic period (14 January 2020–31 December 2023). Solid line indicates relative risk. Band corresponds to 95% empirical CIs. Blue dots indicate observed daily deaths. Pink shading denotes post-emergency period (8 May 2023—31 December 2023).

RR is <1 until mid-2020 in the <60 age group and then remains >1, increasing to peak RR at the end of 2022. The initial period of <1 RR is much shorter than the overall curve, becoming >1 around July 2020. This age group also saw peak RR in July/August 2023. The 60–69 age group, however, remains <1 until the second half of 2022. The peak for this age group is also at the end of 2022. This is followed by a rapid decrease of RR into <1 in 2023. The 70–79 age group is the only group not to show RR <1 during the early period of the pandemic.

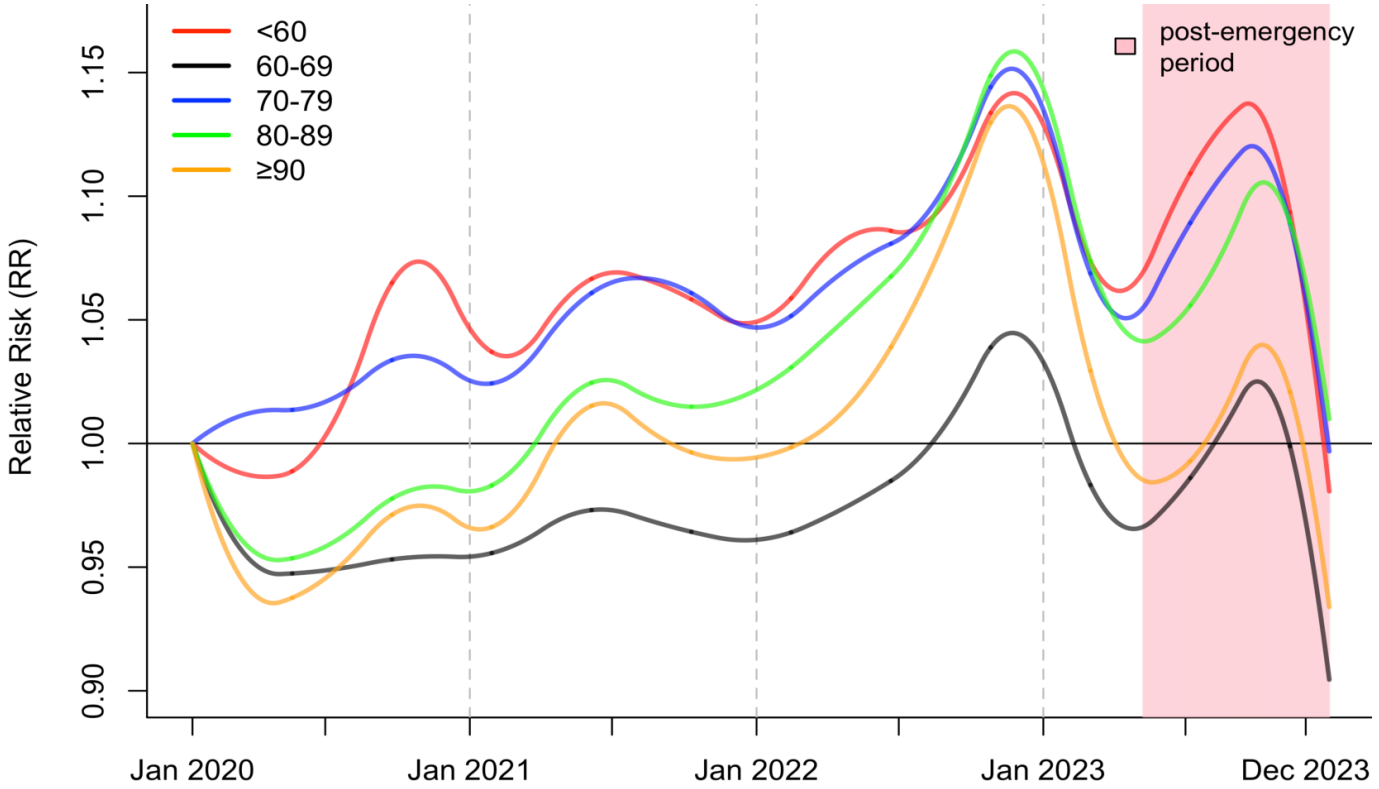

Figure 2 Age group risk curves throughout the COVID-19 pandemic period (14 January 2020–31 December 2023) for Japan. Pink shading denotes post-emergency period (8 May 2023—31 December 2023).

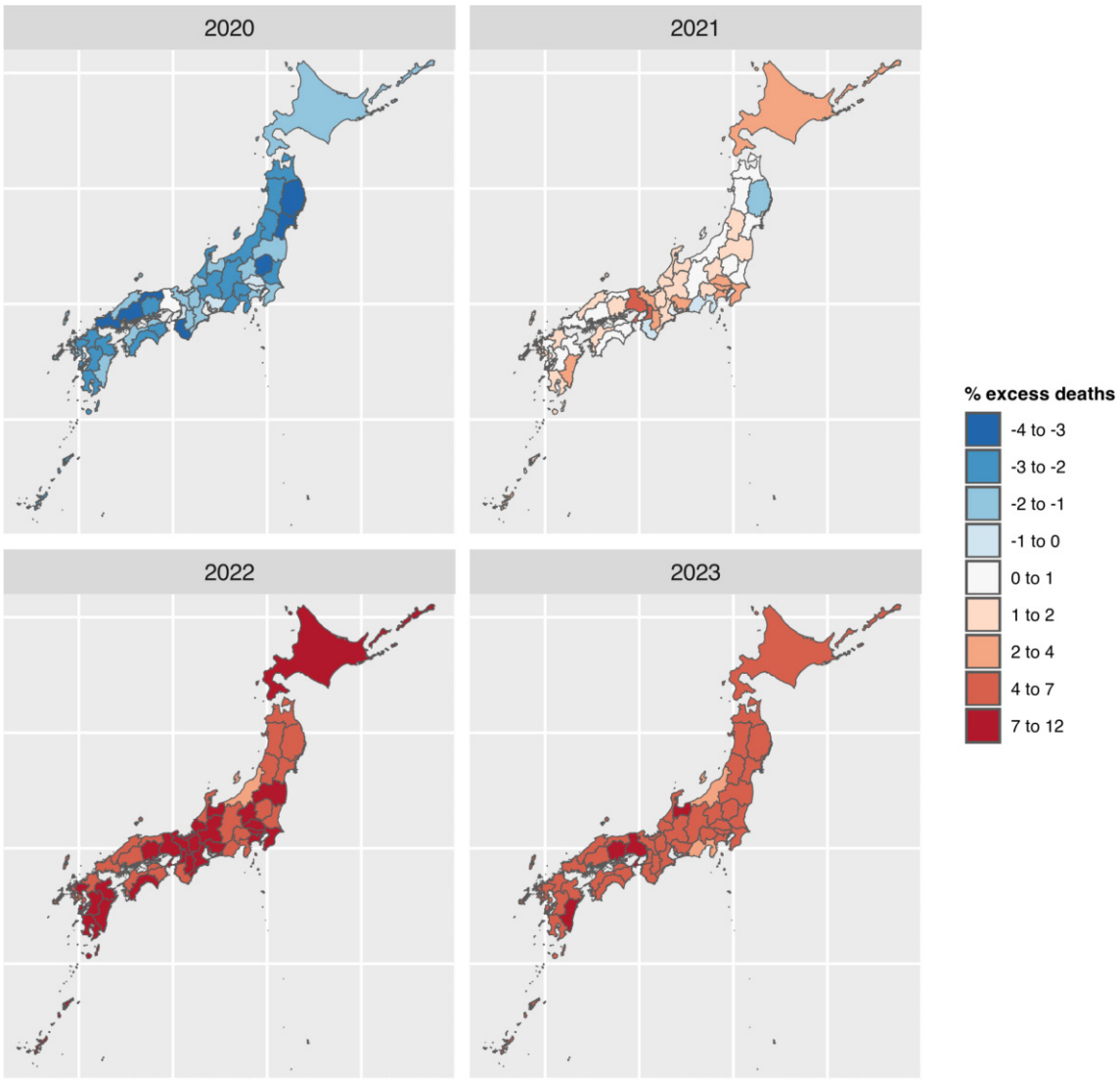

Figure 3 Yearly geographical distribution of percentage excess mortality during the COVID-19 pandemic across the 47 prefectures of Japan (14 January 2020–31 December 2023).

The 80–89 has a very similar temporal distribution of RR when compared with the overall curve. Its peak at the end of 2022, however, is the highest RR of all age groups. The ≥90 age group RR curve, while similar to the 80–89 group, has a lower relative peak in 2023 compared with 2022, closer to that of the 60–69 group.

Prefecture maps

The geographic distribution of the percentage excess in mortality by prefecture is illustrated in figure 3. In 2020, percentage excess deaths are negative for all prefectures apart from Hyogo with 0.46% (95% eCI −0.44 to 1.4). The prefecture with the lowest percentage excess deaths was Iwate with −3.83% (95% eCI −5.2 to −2.42). In 2021, only Wakayama with −0.22% (95% eCI −1.95 to 1.47), Shizuoka with −0.2% (95% eCI −1.51 to 1.07) and Iwate with −1.07% (95% eCI −2.84 to 0.65) have negative percentage excess deaths. Hyogo had the highest with 4.92% (95% eCI 3.84 to 6.01).

For both 2022 and 2023, all prefectures had positive percentage excess deaths. In 2022, Hyogo was the highest with 9.47% (95% eCI 8.1 to 10.78), and Niigata was the lowest with 3.64% (95% eCI 1.92 to 5.48). In 2023, Miyazaki was the highest prefecture with 8.01% (95% eCI 6.2 to 9.93). Niigata also had the lowest in 2023 with 3.12% (95% eCI 1.59 to 4.77). The prefecture maps by age and sex across the years of the study period are shown in online supplemental figures S19–S25. Nationwide all-cause mortality by age group and sex and total influenza cases for each year from 2015 to 2023 are shown in online supplemental table S10. Influenza cases by prefecture from 2015 to 2023 are shown in online supplemental figure S11. Compared with the prepandemic years, all prefectures showed lower influenza cases during 2020 to 2023, particularly 2021 and 2022.

DISCUSSION

Overview

This study used Vital Statistics data from 2015 to 2023 to estimate excess deaths throughout the study period and provided age, sex and prefecture breakdowns. The results show an increase in overall estimated excess mortality until 2022, with a reduction in 2023. The first year of the pandemic is the only year with negative excess mortality. The age groups with the highest percentage excess mortality are the <60 and 70–79 age groups. There is no significant difference between sexes, although males have slightly higher percentage excess mortality throughout the study period.

Yearly trends 2020–2022

Throughout our study period from 14 January 2020 to 31 December 2023, excess all-cause mortality has seen changes and fluctuations. When looking at the overall excess mortality, the negative excess mortality seen in 2020 is supported by other Japan studies.[5 11] This contrasts with many other countries, where positive excess deaths were observed in the first year of the pandemic.[12 13] Neighbouring South Korea and Taiwan did, however, exhibit negative excess deaths during this period.[14 15] In Japan, the voluntary restrictions on public events, transport, workplace and other social settings may have contributed to this.[16] Furthermore, the public understanding, uptake and compliance of measures likely further reduced excess deaths during this period. It is also mooted that fewer traffic accidents as a result of vehicle usage changes could also be a reason for negative excess mortality.[17] Moreover, other studies present notable decreases in deaths from infectious diseases excluding COVID-19 in 2020.[18] Reduction in influenza cases almost three-fold from 2019 to 2020 (1 876 083 to 563 488, respectively) reflects this, with record lows in 2021 with 1153 cases (online supplemental table S10).[19] The infection control measures, hygiene, social distancing and face mask wearing behaviours may have been contributing factors. The USA and Mexico have the highest excess deaths in the first 2 years. Both countries exhibit their pandemic peak of excess mortality in January/February 2021.[14] This is a reversal of the trend observed in Japan. This is likely due to stronger public health measures, prompt intervention in Japan compared with other countries, and public compliance leading to lower transmission rates and associated mortality. Japan, compared with the USA and Mexico, also has lower prevalence of certain comorbidities such as obesity and diabetes, which is suggested to influence pandemic excess mortality.[20]

However, in 2021, excess deaths became positive for the first time, and it can be speculated that Japan's healthcare system, which had managed well with the first year of the pandemic, had finally become unable to cope.[21] The fourth wave coincided with this (April 2021) and might be a contributing factor.[22] Peak RR in 2021 is observed around August 2021, with RR downtrending until the end of 2021. Events of note during this period include the delayed 2020 Summer Olympic and Paralympic Games, which was held on 23 July to 5 September 2021 in Tokyo, and other selected prefectures. A study looking at COVID-19 cases indicated that the daily average was significantly increased by the holding of the Olympic Games.[23] A global excess mortality study conducted by the WHO from January 2020 to January 2022 did find, however, that the global peak of excess deaths occurred in June 2021.[24] Therefore, the increase in excess mortality and RR is unlikely to be specific to Japan.

Excess mortality was significantly higher in 2022 than in the previous year, with the study period's peak RR occurring at the end of 2022. Japan's strict border controls began easing in spring 2022, ending fully on 8 May 2023, though evidence linking border measures to excess mortality is limited.[25] The Omicron variant became dominant in 2022, with BA.1/BA.2 driving the sixth wave in early 2022 and BA.5 dominating the seventh wave later in the year.[22] Omicron caused record infections in Japan, possibly contributing to increased excess deaths.[18] The sixth, seventh and eighth waves, the most significant in Japan, all occurred in 2022. Hong Kong and South Korea both observed an increase in excess mortality during this period.[26 27] For Japan, the healthcare system being overwhelmed by rising patient numbers is a possible cause of increasing RR of excess deaths during this period, with the backlog of patients who had deferred treatment during the early stages of the pandemic, potentially leading to more adverse health outcomes, and unmanageable demand on primary and hospital care.[28 29]

2023 and post-emergency period

In early 2023, we can observe a rapid fall in RR, followed by a rise during the second half of the year. As the peak RR of the study period occurs in late 2022, this severe fall in RR seen in early 2023 can be expected. Although the yearly peaks occur in the latter half, we can see that the peaks are higher in 2022 and 2023 compared with the first 2 years of the pandemic. Of note, influenza cases in the country increased rapidly during early 2023, following record low numbers during 2020 to 2022.[19] The increase in influenza cases could be due to decreased immunity in the population, ascribable to the COVID-19 protection measures for the first few years of the pandemic. South Korea follows the general yearly trends of Japan, with negative excess deaths in 2020, an increase until late 2022 and then a fall in 2023.[27 30] Both Hong Kong and Taiwan have increasingly positive excess deaths up to early 2023, but Hong Kong does exhibit the highest excess mortality among these East Asia nations.[14 26] This high mortality was largely attributed to low vaccination coverage among the elderly population in Hong Kong, significantly lower than Japan.[31] In Europe, the UK, France and Italy also show rising excess mortality at the end of 2022 and early 2023, but are lower than their peaks observed in 2020.[14 32] It should be noted that the European heatwaves during mid-2022 might have impacted excess mortality rises.[33]

The Japanese Government dropped its recommendation for mask wearing on 13 March 2023, with restrictions to encourage social distancing removed from 8 May 2023.[4] The rise in RR in 2023, and its subsequent peak in September/October, does coincide with this; however, it is difficult to draw concrete associations. Whether public behaviour changing following the announcement led to an increase in COVID-19 infections and deaths is debatable, as the daily counting of cases and deaths ceased from this point. However, studies suggest that lifting public health measures often correlates with increased transmission rates of respiratory infections, particularly in populations where risk perception declines following government policy shifts. September 2023 also saw significant rises in influenza incidence, leading to multiple school closures and class suspensions nationwide.[34] The typical influenza season starting in November and peaking in December occurred much earlier in 2023, with this year seeing Tokyo issuing its earliest influenza advisory since statistics were introduced in 1999.[8] The ninth wave of COVID-19 in Japan was also declared during this month, with weekly COVID-19 cases the highest since the downgrading of its status. The reduction of infection control measures may have contributed to both these surges, and the concurrent occurrence may have led to increased mortality. Further studies assessing cause-specific mortality in 2023 are required to provide insight on the mortality patterns of this year.

This post-emergency period in 2023, when compared with the corresponding periods in the first 2 years of the pandemic, has increased excess mortality. It could be argued that the change in public perception, following the downgrading of COVID-19 status, may have led to behaviour changes. The sharp increase in RR in 2023 following the status change is more severe than at other time points. Caution should be exercised when changing protocols or measures during pandemics, in particular those of novel diseases with unprecedented impacts. It is unclear whether the rise and peak of excess mortality are attributable to the relaxing of measures and recommendations or whether it would have been inevitable. However, it is important to note that for all groups, the corresponding period in 2022 remains marginally higher. Long COVID and hypertension-related disorders occurring in the later stage of the pandemic could play a role in increased excess mortality in 2022 and 2023, but current literature remains limited.[35] Further epidemiological studies are required to establish the magnitude of its impact and other chronic conditions on Japan's mortality trends.

Sex and age groups

When comparing the sexes, negative percentage excess deaths in 2020 were higher for females than males, consistent with previous studies.[5] Both sexes saw positive excess deaths in 2021 and 2022, with males having slightly higher excess. In 2023, percentage excess deaths were similar. The cause of the 2020 difference remains unclear. Increased suicides among females were observed early in the pandemic, reversing a previously decreasing trend, yet this contrasts with the excess mortality observed in our study.[36] It has been reported that globally, COVID-19 morbidity and mortality were greater in males, aligning with our findings in Japan.[37]

The age-stratified analysis reveals that the <60 age group had the highest percentage excess mortality throughout the study, followed by the 70–79 age group. Only the 60–69 age group exhibited negative excess deaths for the overall period, with high vaccine effectiveness in this group noted in Japan.[38] The difference between the 60–69 and 70–79 age groups is evident, with the RR curve remaining >1 for most of the study period in the latter, becoming <1 only in late 2023. The 70–79 group was also the only age group with an RR >1 in 2020. Studies in other countries have shown that individuals over 70 years are at higher risk of severe COVID-19 and mortality.[39] Social isolation, loneliness and mental health diagnoses have also increased in this group compared with prepandemic levels.[40 41] The <60 age group showed the highest percentage excess mortality across all years. The high excess mortality in this group coincides with rising suicide rates among younger populations during the pandemic.[42 43] Psychosocial challenges such as school closures, workplace layoffs and financial difficulties likely contributed.[44] The 80–89 and ≥90 age groups followed a similar trend throughout the study period, though 80–89 years consistently had higher percentage excess mortality. The RR curves for both groups were similar, but the ≥90 age group had a period where RR fell below 1 in late 2021–early 2022. This group also had a relatively lower RR peak in 2023 compared with 2022, while other age groups had similar peaks in both years. The prevalence of frailty in Japan's elderly declined following the change in COVID-19 classification, yet the higher RR magnitude in the 80–89 group in 2023 remains unclear.[45] Nevertheless, Japan's rapidly ageing population and the effects of social isolation applied to both groups.[46]

Prefectures

Drawing prefecture-specific conclusions is challenging due to various factors influencing percentage excess mortality, including healthcare availability, population density and socioeconomic differences. Pandemic-specific factors such as lifestyle changes, movement restrictions and cluster outbreaks also played a role.[47]

The overwhelmingly negative excess deaths in all but one prefecture (Hyogo) in 2020 suggest a uniform impact nationwide. Healthcare system changes during this period led to fewer hospitalisations.[48] Iwate and Wakayama had the lowest percentage excess mortality in 2020 and 2021, remaining the only prefectures with negative excess mortality in 2021, though the cause remains unclear. Iwate was the last prefecture in Japan to report a COVID-19 case (110 days after all other prefectures). This delay is attributed to proactive public health strategies by the local government, including the establishment of

dedicated medical facilities and strong community adherence to preventive measures.[49] Iwate is characterised by a predominantly rural landscape with a lower population density. Wakayama also features rural areas with lower population density, which may have similarly mitigated virus transmission rate, as reflected by its influenza case numbers (online supplemental table S11). The higher percentage excess mortality seen in areas such as Osaka and Tokyo in 2021 may be due to population density. During the fourth wave of COVID-19 in April 2021, Osaka experienced a significant surge in cases, leading to an overwhelmed healthcare system. The intensive care units faced excessive capacity from March to June 2021.[21] This is similar for Tokyo; hence, this strain likely resulted in increased mortality, both from COVID-19 and other conditions due to delayed or inaccessible care. All prefectures showed positive excess mortality in 2022 and 2023. It has been identified that patients in Japan may have refrained from seeking healthcare during the first year of the pandemic, which may have led to knock-on effects in the later years.[50] In 2023, lower excess mortality is mostly observed compared with 2022. Niigata had the lowest excess mortality in both years. Further investigation is warranted as studies are limited, but high COVID vaccination rates could be a factor.[51] In addition, this prefecture has relatively low influenza cases in 2022 for its population size (80 cases). Of the 47 prefectures, only Iwate, Ibaraki, Gunma, Niigata and Ishikawa had higher excess mortality in 2023 compared with 2022. Despite these prefectures being in East Japan, the increases are marginal and cannot be attributed to geographic or regional factors. The major metropolitan areas of Osaka and Tokyo showed more substantial decreases in excess mortality in 2023. However, it is important to reiterate that the excess mortality numbers in 2023 remain considerably higher than the first 2 years of the pandemic.

Implications and future study recommendations

This study estimates excess mortality throughout and after the COVID-19 pandemic in Japan. Year-on-year changes and subgroup variations provide insights for policymakers managing future outbreaks. As Japan cannot legally impose lockdowns, these findings can help guide public co-operation in similar crises. The continued rise in risk following Japan's negative excess deaths in 2020 suggests that the nature of COVID-19, delayed medical care or broader social challenges played unpredictable roles, highlighting the complexity of pandemic impact and the need for adaptive public health strategies. The measures that many individuals in Japan adhered to, such as social distancing, hand hygiene and facemask wearing, continue to be maintained, which differs from many other high-income countries. Future pandemics should follow similar measures that Japan employed during this time. Nevertheless, the trend in excess deaths and risk continued to rise until 2023, and although lower during the post-emergency period, excess mortality remained high. Future pandemic preparedness and response planning is essential. Investment and strategies regarding resource allocation planning could have limited the surges experienced in urban areas such as Tokyo and Osaka. High vaccination rates in certain prefectures resulting in lower excess mortality during this rise provide another possible measure that will likely improve outcomes in future outbreaks. Increasing emphasis on public communication is critical in achieving this. Further studies looking into government recommendations and the public response throughout the pandemic would provide useful insight and, in conjunction with the excess mortality findings in this study, can shed light on possible methods to counteract the rise in risk. This is in conjunction with cause-specific mortality studies, which are necessary to provide a more detailed picture. Much is reliant on prediction and pro-activeness with regard to limiting mortality during pandemics; thus, the development of early warning systems can provide an edge that was not present during the unprecedented COVID-19 pandemic. It is imperative to continue analysing and learning from this global event on what must be done to save lives and to ensure the losses suffered are minimal.

Limitations

This study has limitations, including the absence of individual data such as socioeconomic status and demographics, which could have provided deeper insight into excess mortality. Moreover, data on human mobility throughout the pandemic period would be beneficial to incorporate into prefectural analysis due to the nature of COVID-19 transmission, in addition to the change in travel and movement by individuals during the pandemic. We did, however, attempt to control for prefecture level variations by using a random effects model. Another consideration is the selection of reference period when estimating excess mortality. Similar studies have also included 5 years (2015–2019), which forms the basis of our choice. We decided to follow this for comparability and consistency. A longer reference period may identify underlying trends in mortality more reliably.[52] In the case of Japan, however, unusual mortality events such as the 2011 Great East Japan Earthquake will impact estimates. A further limitation is the applicability of the findings in Japan to other countries. Consideration for differences in government measures, public response and demographics is imperative, and can limit application in certain settings. These limitations highlight the importance of continuous research and data collection to refine our understanding of excess mortality and its influencing factors regionally and globally.

CONCLUSION

The COVID-19 pandemic has been unprecedented. This study found that although Japan coped well in terms of all-cause mortality during the first year of the pandemic, this gradually reversed with excess deaths and risk increasing until 2023. Prompt public health

measures, public compliance and health-conscious lifestyles in Japan could have factored in the initial low excess mortality. However, with healthcare facilities becoming increasingly overwhelmed, this was difficult to maintain. While numerous events occurred in Japan during the pandemic, it is difficult to draw associations on their impact on excess mortality, and it is likely highly multifactorial. Urban and rural prefectures may exhibit different patterns as identified, and the interaction with other infectious diseases, such as influenza, likely plays a role. Nevertheless, the results of this study highlight the significance of ongoing surveillance of excess mortality as a critical indicator for the dynamics of public health. While the pandemic's various actions and events may have contributed to excess mortality, more research is required to identify the precise factors causing these trends, with a particular emphasis on regional and demographic differences. For public health responses to be guided, and for a thorough understanding of the direct impact of interventions and behavioural changes in the Japanese context as it continues to navigate the post-emergency era, such targeted analysis is essential. Future cause-specific studies assessing pre-, during and post-COVID periods are necessary to provide a more detailed and conclusive picture on the impact of the pandemic on mortality in Japan.

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