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Synergistic influence of air temperature and vaccination on COVID-19 transmission and mortality in 146 countries or regions

Qifa Song*, Guoqing Qian*, Yuwei Mi*, Jianhua Zhu**, Chao Cao***

*Department of Critical Care Medicine, Ningbo City First Hospital, Ningbo, Zhejiang Province, China
**Department of General Internal Medicine, Ningbo City First Hospital, Ningbo, Zhejiang Province, China
***Department of Respiratory and Critical Medicine, Ningbo City First Hospital, Ningbo, Zhejiang Province, China

ARTICLE INFO

Keywords:
COVID-19
Weekly incidence
Time-varying reproduction number
Mortality
Vaccination
Air temperature

ABSTRACT

Objective: We aimed to determine the influence of vaccination and air temperature on COVID-19 transmission and severity.

Methods: The study data in 146 countries from January 6, 2020 to July 28, 2022 were aggregated into 19,856 weeks. Country-level weekly incidence, time-varying reproduction number (Rt), mortality, and infection-fatality ratio (IFR) were compared among groups of these weeks with different vaccination rates and air temperatures.

Results: Weeks with <15 °C air temperature and 60% vaccination showed the highest incidence (mean, 604; SD, 855; 95% CI, 553–656, unit, /100,000 persons; N = 1073) and the highest rate of weeks with >1 Rt (mean, 41.6%; SD, 1.49%; 95% CI, 39.2–45.2%; N = 1090), while weeks with >25 °C and <20% showed the lowest incidence (mean, 24; SD, 75; 95% CI, 22–26; N = 5805) and the lowest rate of weeks with >1 Rt (mean, 15.3%; SD, 0.461%; 95% CI, 14.2–16.2%; N = 6122). Mortality in weeks with <15 °C (mean, 2.1; SD, 2.8; 95% CI, 2.0–2.2, unit, /100,000 persons; N = 4365) was five times of the mortality in weeks with >25 °C (mean, 0.44; SD, 1; 95% CI, 0.41–0.46; N = 7741). IFR ranged between 2% and 2.6% (SD, 1.9%–2.4%; 95% CI, 2.0–2.7%) at < 20% vaccination level, 1.8% (SD, 2%–2.2%; 95% CI, 1.7–2.0%) at 20–60% vaccination level, and 0.7%–1% (SD, 1%–1.8%; 95% CI, 0.7–1.1%) at > 60% vaccination level and at all air temperatures (all P < 0.001).

Conclusions: Vaccination was insufficient to mitigate the transmission since the significantly elevated weekly incidence and >1 Rt rate in weeks with high vaccination, while IFR was reduced by high vaccination. Countries with long-term low air temperature were affected by high transmission and high mortality.

1. Introduction

The continuing novel coronavirus disease 2019 (COVID-19) pandemic caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has been threatening the world for more than two years. As of July 2022, there have been more than 300 million confirmed cases and approximately 6 million deaths worldwide (2020). Varied transmission and severity of COVID-19 have been described with the incidence and mortality of COVID-19 in different populations who are characteristic of distinctive demographic and environmental factors (Song et al., 2022). Among various environmental factors related to COVID-19 transmissibility, such as mobility, UV light, air pollution, and moisture, higher air temperatures significantly reduce COVID-19 transmission (Smith et al., 2021). In European countries, COVID-19 is characteristic of seasonal transmission (Zoran et al., 2022), indicating the massive influence of air temperature on COVID-19 transmission. Regarding governmental and medical interventions for COVID-19, vaccination is critical to alleviate COVID-19 infection with declining mortality in vaccinated people (Moghadas et al., 2021), although vaccination causes varied reductions in the transmission of SARS-CoV-2 variants with decreasing effects over time (Eyre et al., 2022). Moreover, emerging SARS-CoV-2 variants have been causing breakthrough
infections in vaccinated individuals, rendering uncertainty about the long-term and overall effect of vaccination globally (Lipsitch, 2022).

The transmission of COVID-19 disease can be reflected by incidence and time-varying reproduction numbers (Rt) (Del Aguila-Mejia et al., 2022). Rt is computed from the incidence and the serial interval which is the time between successive cases in a chain of transmission. Two types of mortality can be used to describe the severity and adverse outcomes of COVID-19 infection, which are infection-fatality ratio (IFR) and all-cause mortality or total mortality. IFR is a measure of the likelihood of an individual dying once infected with SARS-CoV-2 (Team, 2022), while total mortality estimates excess mortality attributable to COVID-19 in a population (Collaborators, 2022). It is difficult to compare IFRs among countries or across time due to the absence of a standardized report of confirmed cases and deaths that can be strongly affected by testing capacity and reporting policies, as well as by the time shift between infection and the occurrence of resulting mortality (Thomas and Marks, 2021), because IFR often varies substantially between locations (Team, 2022). However, IFR is a sensitive indicator of COVID-19 severity among infected individuals and is crucial for risk perception, policy making for epidemic control, and estimation of COVID-19 burden (Gu and Cao, 2022). In contrast, total COVID-19 mortality has been widely accepted as a more objective indicator of the COVID-19 death toll (Karlinsky and Kobak, 2021). It is more appropriate to reflect the overall health life loss from the COVID-19 pandemic in a population. Previous research reported that the global all-age rate of excess COVID-19 mortality was 120.3 deaths per 100,000 people (Collaborators, 2022). Therefore, tracking a simultaneous measurement of IFR and total COVID-19 mortality for each country and region can help understand the ongoing changes in the severity of COVID-19 cases and the pandemic’s impact on public health, respectively.

As a result of the emerging SARS-CoV-2 variants, ongoing vaccination, and seasonal variations in air temperature, understanding the incidence and mortality changes over the pandemic period can provide clues to the assessment of vaccination effects and environmental impacts on the variants, as well as better prepare for seasonal outbreaks. However, the synergistic effect of vaccination and air temperature on the global incidence and mortality of COVID-19 has not been adequately investigated, considering their lasting and widespread impact on COVID-19 transmission. Our study examined the weekly incidence, time-varying reproduction numbers, total mortality, and IFR of COVID-19 in each country or region during the entire period of the pandemic. We aimed to prove the hypothesis that the transmission and severity of COVID-19 were affected by the combined effects of vaccination and air temperature worldwide.

2. Methods

2.1. COVID-19 data and pretreatment

The study data were downloaded from the John-Hopkins Coronavirus Center data repository (https://coronavirus.jhu.edu/) using the R package COVID19 (Guidotti and Ardia, 2020). The original data were composed of the country-level daily cumulative numbers of confirmed cases, deaths, and vaccination rates. In this study, we included 146 countries with more than one million people and with the data for air temperature and COVID-19 available. The data were aggregated into weekly values. We computed the weekly incidence (unit, number of confirmed cases per 100,000 people throughout the study) using the number of weekly confirmed cases divided by the number of the population of each country or region. Daily Rt values of each country were computed using the R package EpiEstim (Corti et al., 2013) with a serial interval and its standard deviation (SD) which were 5 and 2 days, respectively (Li et al., 2020), which were further aggregated into weekly mean values. We computed the rates of weeks with over 1 Rt to represent the increasing transmission. The weekly total mortality was the number of weekly deaths divided by the population (unit, deaths/100,000 persons). The weekly IFR was computed using the number of deaths divided by the number of cases that required at least 1000 cases. The outliers of IFR were truncated by the inclusion range of the mean value plus four SDs. In each week, the percentage of vaccinated individuals was classified into three levels of <20%, 20%–60%, and >60%.

2.2. Meteorological data

Hourly air temperature data were downloaded from the National Oceanic and Atmospheric Administration (NOAA) via the R package worldmet (Carslaw, 2021). The meteorological stations were selected at a geometrical space interval of 5° latitude and 10° longitude for countries with more than one meteorological station. The hourly air temperatures were aggregated to create weekly air temperatures in each country. The weekly air temperatures were classified into three ranges of <15 °C, 15–25 °C, and >25 °C.

2.3. Data analysis

Weekly incidence, Rt values, and mortality of a country in each week were classified into groups using a combination of three levels of vaccination and three levels of air temperature and were compared among groups. Weekly incidence was expressed in mean and SD, while the mortality and rates of weeks with >1 Rt were expressed in prevalence and 95% confidence interval (95% CI). The trajectories of vaccination rates and air temperatures in every week of all countries were illustrated via a heatmap with country names on the column and dates on the row of the heatmap. The country names in the heatmap were clustered into three groups representing low, medium, and high levels of vaccination rates or air temperature by hierarchical cluster according to the profiles of different vaccination and air temperature levels, respectively (Maechler et al., 2012). The temporal trajectories of incidence, rates of weeks with >1 Rt, and mortality were demonstrated for three groups of countries that were classified by yearly mean air temperature. We conducted the sensitivity analysis using different grouping methods as the following: Besides the current classification of three groups by three air temperatures and three vaccination rates, we classified the weeks into five groups using quintiles and computed the P for trend of the groups (Bigdeli et al., 2021). As various underlying confounding factors, especially age and socioeconomic population composition, might affect our conclusions, we computed the median value of the percentage of population age 65+ years for 120 countries that had the demographic data of age profiles from the World Bank development indicators. We divided the 120 countries into two groups with more younger and more elder populations by the median percentage (median, 8%; 1st and 3rd quartiles, 5–13.78%) of population age 65+ years and compared the indicators as mentioned. We considered the association to be robust if the P for trend was all <0.05 despite the different classification. P values were 2-tailed, and statistical significance was set at a P value less than 0.05.

3. Results

The data covered 136 weeks between January 6, 2020 and July 28, 2022. A total of 146 countries or regions added up to 19,856 weeks with available data (Table 1). Vaccination was carried out in 10,940 weeks (53.9%), with a single-dose vaccination rate (mean, 36.2%; SD, 30.7%; 95% CI, 35–36.7%) in all weeks. The mean weekly incidence in 18,309 weeks was 188 (SD, 319; 95% CI 104–113; unit, /100,000 persons). There were 4640 weeks with Rt > 1, accounting for 24.1% of all weeks. The mean total mortality in 17,686 weeks was 0.98 (SD, 1.95; 95% CI, 0.95–1.01, unit, /100,000 people), while the IFR was successively computed in 10,300 weeks with more than 1000 cases and with a mean of 1.87% (SD, 2.12%; 95% CI, 1.83–1.91%). The mean weekly air temperature was 20.5 (SD, 9.6; 95% CI, 20.4–20.6; unit, °C) in 19,119
weeks.

Then, all weeks were stratified by a combination of three vaccination rates and three air temperatures to exhibit their impact on COVID-19 transmission and mortality. Weekly incidence was significantly inversely associated with air temperature among groups stratified by three vaccination rates ($P < 0.01$), while the incidence was significantly positively associated with vaccination rates among groups stratified by three air temperatures ($P < 0.01$) (Part A of Fig. 1). The group of 1073 weeks with $<15^\circ$C air temperature and $>60\%$ vaccination showed the highest incidence (mean, 604; SD, 855; 95% CI, 553–656, unit, /100,000 persons), while the group of 5805 weeks with $>25^\circ$C air temperature and $<20\%$ vaccination showed the lowest incidence (mean, 24; SD, 75; 95% CI, 22–26, unit, /100,000 persons). These two associations were clearly seen when the weeks were classified by individual vaccination rates or air temperature (Part A of Fig. 1).

Regarding the rates of weeks with $>1$ Rt among groups of weeks with similar stratification, similar associations existed with smaller differences in the exact values (Part B of Fig. 1). The group of 1090 weeks with $<15^\circ$C air temperature and $>60\%$ vaccination showed the highest rate of weeks with $>1$ Rt (mean, 41.6%; SD, 1.49%; 95% CI, 39.2–45.2%), while the group of 6122 weeks with $>25^\circ$C air temperature and $<20\%$ vaccination showed the lowest rate of weeks with $>1$ Rt (mean, 15.3%; SD, 0.461%; 95% CI, 14.2–16.2%).

Fig. 2 demonstrates the total mortality and IFR rates among groups stratified as above described. Mortality was significantly inversely associated with air temperature among the groups stratified by three vaccination rates ($P < 0.01$), which was present clearly among the three groups of weeks classified by vaccination rates (Part A of Fig. 2). The mortality in the group of 4365 weeks with $<15^\circ$C air temperature (mean, 2.1; SD, 2.8; 95% CI, 2.0–2.2, unit, /100,000 persons) was five times of the mortality in the group of 7741 weeks with $>25^\circ$C air temperature (mean, 0.44; SD, 1; 95% CI, 0.41–0.46, unit, /100,000 persons) ($P < 0.01$). However, the association between vaccination and mortality was not significant ($P > 0.05$), with the highest mortality in the group with 20–60% vaccination.

In the case of IFR, the profile of associations among the groups of weeks markedly differed from mortality (Part B of Fig. 2). IFR was significantly inversely associated with vaccination rate among the

Table 1
Weekly measurements of COVID-19 transmission and mortality in 146 countries from January 6, 2020 to July 28, 2022.

| Variable            | No. of weeks | Mean  | SD   | 95% CI        |
|---------------------|--------------|-------|------|---------------|
| Air temperature ($\degree$C) | 19,119       | 20.5  | 9.6  | 20.4–20.6     |
| Vaccination (%)     | 10,940       | 36.2  | 30.7 | 35.0–36.7     |
| Incidence (/100,000) | 18,309       | 108   | 319  | 104–113       |
| Rate of Rt $>1^a$   | 4640         | 24.1  | 23–25|               |
| Total mortality (/100,000) | 10,300     | 1.87  | 2.12 | 1.83–1.91     |

Note: IFR was computed only when there were more than 1000 cases in a week. The remaining measurements were computed when there were relevant data reported. The total number of weeks was 19,856.

$^a$ The rate of Rt $>1$ was computed with the number of weeks with Rt $>1$ divided by the total number of weeks.

Fig. 1. Upper part: Weekly incidence and the rates of weeks with $>1$ time varying reproduction number (Rt) in weeks stratified by a combination of three vaccination rates and three air temperatures. Lower part: Weekly incidence and Rt in weeks stratified by three vaccination rates or three air temperatures.
groups stratified both by vaccination rates and by combined factors \((P < 0.01)\). IFR ranged between 2% and 2.6% (SD, 1.9%–2.4%; 95% CI, 2.0%–2.7%) at < 20% vaccination level, 1.8% (SD, 2%–2.2%; 95% CI, 1.7%–2.0%) at 20–60% vaccination level, and 0.7%–1% (SD, 1%–1.8%; 95% CI, 0.7%–1.1%) at > 60% vaccination level and at all air temperatures.

Figs. 3 and 4 show the temporal and spatial trajectory of incidence, Rt values, total mortality, and IFR. The weeks with an incidence of over 100/100,000 were designated as high incidence weeks and labeled with “*”. The distribution of high-incidence weeks showed that most countries with higher vaccination rates and with lower air temperatures had more high-incidence weeks throughout the pandemic period (Figs. 3 and 4). Regarding the spatial trajectory of these measurements that were summarized for every country and shown on the columns of the heat-map, the rates of weeks with \(R_t > 1\) were highly related to its incidence and showed similar associations with vaccination rates and air temperatures. The mortality also had similar distribution profiles, whereas IFR manifested alike with smaller strength. Turning to the temporal trajectory of these measurements that were summarized for every week and shown on the rows, the incidence within one year was much higher than before, and the rates of weeks with \(R_t > 1\) fluctuated in the short term without an obvious trend. The mortality dropped remarkably after around April 2022, while IFR steadily declined during the whole pandemic period. The trajectory analysis revealed that > 25 °C countries had steadily low incidence, low rates of weeks with \(R_t > 1\), and low mortality compared to the remaining groups of countries throughout the period of the pandemic. The countries with lower mean air temperatures had higher vaccination rates (Fig. 4).

The sensitivity analysis revealed that the association between total mortality and vaccination was not robust because \(P\) for the trend of mortality was 0.05 for the quintile classification of weeks (Table 2), \(P\) for trend of IFR was 0.172 and 0.179 for the current and quintile classification of weeks by air temperature, respectively, indicating air temperature had no significant impact on IFR.

The results regarding the stratification by the percentage of population age revealed that vaccination and air temperature had very similar influence profiles on incidence and mortality despite the composition of population age. The Rt countries with more younger population (Column A and B in Fig. 6) were more affected in Rt by vaccination than the countries with older population. Low air temperatures led to a slightly increased Rt. With respect to IFR, vaccination decreased IFR significantly in all countries, with a larger decrease in countries with elder population (Column C). There was no association between IFR and air temperature despite composition of population age.

Collectively, these findings revealed that despite different vaccination levels, weeks with < 15 °C air temperature contributed to much higher transmission in terms of weekly incidence and Rt values, as well as to higher total morality than weeks with above 15 °C. When all countries were classified into three groups using yearly mean air temperatures, these associations were present throughout the whole pandemic period (Fig. 5). Vaccination predominantly resulted in a lower IFR that was not affected by air temperature in the three groups of countries.

Fig. 2. Upper part: Weekly total mortality and infection-fatality ratio (IFR) in weeks stratified by a combination of three vaccination rates and three air temperatures. Lower part: Weekly total mortality and IFR in weeks stratified by three vaccination rates or three air temperatures.
4. Discussion

In the current study, we analyzed the weekly incidence, the rates of weeks with $>1$ Rt, and the mortality of COVID-19 in 146 countries throughout the whole pandemic period and assessed the joint effects of two critical factors of vaccination and air temperature on the global transmission and severity of COVID-19. The results showed that vaccination was insufficient to mitigate the transmission given the significantly elevated weekly incidence and Rt were observed in the weeks of countries with high vaccination, while IFR was massively reduced by higher vaccination rates. There was a significant increase in transmission and total mortality in the countries with long-term low air temperatures.

The scientific determination of global factors that influence the transmission and severity of COVID-19 is meaningful for its accurate prediction and prevention on a global scale. A majority of previous studies used reproduction numbers ($R_0$ or $R_t$) to investigate the increasing transmissibility of SARS-CoV-2 variants. Estimation of reproduction number requires the exact serial interval for every epidemic, which is practically impossible for all countries in a

Fig. 3. Weekly vaccination rates and incidence of every country from January 6, 2020 to July 28, 2022. The “*” labels 1 in the cells indicate a high weekly incidence of $>100/100,000$. The barplots on the column reflect the means of measurements for every country, while the barplots on the right reflect the means of measurements for every week.

Fig. 4. Weekly air temperatures and incidence of every country from January 6, 2020 to July 28, 2022.
developing pandemic like COVID-19 (Li et al., 2021). Here we used the same serial interval that was commonly reported to be computed for all countries. Additionally, IFR among confirmed cases is inaccurate due to the great variations in test capacity and reporting policies in countries and periods. Our study computed the incidence and two types of mortality every week in each country, which associated the changing incidence and mortality precisely with the changing vaccination and air temperatures.

Previous studies have proved the effectiveness of vaccination on the containment of COVID-19 transmission (Moghadas et al., 2021; Shrotri et al., 2021; Waldman et al., 2021). However, most of those studies used regional short-term data to investigate the effectiveness of one type of vaccine (Cabezas et al., 2021). As large-scale vaccination is now continuously conducted in a number of countries whose unique factors, such as air temperature and population composition, may affect the vaccination effects, it is essential to investigate its dynamic effect on global transmission and mortality. Our study on the association between vaccination levels and changing incidence and mortality in all countries ensures the reliability of dynamic vaccination effectiveness. Figs. 1 and 3 illustrate a positive link between high vaccination and high transmission, indicating that high vaccination doesn’t necessarily warrant low transmission. This phenomenon is evident within the last year due to the widespread Omicron variants, which started at the end of 2021 and have partly frustrated the endeavor to reduce the transmission by vaccination (Fig. 3) (Suryawanshi et al., 2022). Despite the ineffectiveness of vaccination to contain the global COVID-19 transmission in our study, vaccination was proved to be effective to reduce the severity in terms of IFR which lowered from a mean of 2.3% at <20% vaccination rate to a mean of 0.8% at >60% vaccination rate. The declining trend in IFR was very steady, as shown by the temporal trajectory (Fig. 3). It is noteworthy that the current study identified an intriguing positive association between high vaccination rates and increased transmission. This association may be influenced by several potential factors. In the first instance, most high-vaccination countries are located in low-air temperature regions where SARS-CoV-2 can easily spread. Secondly, nonpharmaceutical interventions are liable to be lifted in high-vaccination countries. Furthermore, the Omicron variant of

| Measurements          | P for trend of vaccination impact | P for trend of air temperature impact |
|-----------------------|----------------------------------|--------------------------------------|
|                        | The present study                | Quintile                             | The present study | Quintile |
| Incidence (/100,000)   | <0.001                           | <0.001                               | <0.001             | <0.001   |
| Rate of Rt > 1*        | <0.001                           | <0.001                               | <0.001             | <0.001   |
| Total mortality        | <0.001                           | 0.05                                 | <0.001             | <0.001   |
| IFR (%)                | <0.001                           | <0.001                               | 0.172              | 0.179    |

Fig. 5. Weekly trajectories of incidence, rates of weeks with >1 Rt, total mortality, and IFR of three groups of countries stratified by yearly mean air temperatures.
SARS-CoV-2 is more transmissible and has spread globally in recent months when high levels of vaccination have been achieved. Nonetheless, it should be noted that the IFR is significantly lowered in vaccinated individuals, which results in unremarkable elevated total mortality despite a much higher incidence.

Another significant aspect of our study is the effect of air temperature on the transmission and severity of COVID-19. So far, the influence or causality of temperature in relation to COVID-19 has been heavily debated. There are studies that argued against the relationship (Hoogeveen et al., 2022), as well as studies indicating that both cold and dry environments likely facilitate the COVID-19 transmission (Fu et al., 2021). Moreover, it has been suggested that besides the direct effect, air temperature may produce a mediator effect on COVID-19 transmission through its relation to people’s mobility, UV radiation, humidity, and seasonal allergens (Hoogeveen et al., 2022; Nicastro et al., 2021). However, these factors usually tend to affect specific groups of people or in a limited period of time or under a special condition, like UV, mostly affecting surface and air, whereas air temperature and vaccination produce a much more lasting and broad impact on COVID-19 transmission. Although other factors like air pollution have been proven to have a positive association with the incidence and severity of COVID-19 (Marques and Domingo, 2022), we think this impact is not global.

It is a challenge to prove the association between air temperature and COVID-19 transmission, as the role of temperature in seasonal respiratory diseases was already doubted (Tamerius et al., 2011). This question can be solved by using enough population samples in a long enough period of time, owing to the wide range and time span of impacts from air temperature, as well as using objective measurements. As a result, our study analyzed COVID-19 data in almost all the countries during the whole pandemic period and applied the weekly incidence and rates of weeks with $>1$ Rt to reflect COVID-19 transmissibility.

According to our findings, air temperature was inversely associated with COVID-19 transmission, which was supported both by weekly incidence and rates of weeks with $>1$ Rt (Figs. 1 and 4). The incidence and rates of weeks with $>1$ Rt are much greater at temperatures at $<15 \, ^\circ\text{C}$ than $>25 \, ^\circ\text{C}$. Those countries with most weeks above $25 \, ^\circ\text{C}$ had a steadily lower incidence and total mortality despite their low vaccination (Figs. 3 and 4) and similar IFR, indicating air temperature played a greater role than vaccination. These findings explain why European countries have more severe outbreaks due to a longer period of low temperatures. Our perspective is that, as a consequence of a multitude of underlying factors that are confounded with air temperature, a robust...
conclusion about this question requires large population samples over a long enough period of time to investigate the wide range and time span of impacts of air temperature. The sensitivity analysis in the current study also proved that air temperatures affect incidence, Rt, and total mortality except IFR (Table 2).

Finally, we take into consideration the influence of vaccination and air temperature together. Our study revealed that low air temperatures increase COVID-19 incidence and total mortality in all populations with different vaccination rates, implying the inverse association between air temperature and transmission in the whole population regardless of vaccination levels. This impact exists throughout the entire pandemic (Fig. 5). The COVID-19 severity is largely reduced by high vaccination levels at different air temperatures, while air temperatures show no significant effect on the severity. Moreover, various confounding factors in different countries, such as age and social-economic profiles, and healthcare systems, might result in biased conclusions. We used the composition of population age to divide countries and investigate the metrics discussed above. This measure would greatly compensate for the underlying confounders from social-economic factors. The overall impact from vaccination and air temperature on metrics about transmission and severity of COVID-19 remained regardless of the composition of population age.

4.1. Limitations of the study

One limitation is that we computed Rt using the same serial interval, which might vary between countries and during different epidemic periods. Another is that we didn’t take into consideration the different population composition, as many countries, like European countries, have more elderly people, which might contribute to biased conclusions.

5. Conclusions and policy implications

Our study illustrates the dynamic influence of vaccination and air temperature on the transmission and severity of the global COVID-19. While a high vaccination rate can greatly reduce the severity of COVID-19, it is insufficient to reduce COVID-19 transmission worldwide. Air temperature is a critical factor negatively influencing transmission and total mortality. It is most likely that the transmission will be accelerated at temperatures lower than 15 °C. Low vaccination rates and low air temperatures contribute to high transmission rates and high mortality rates. Our findings imply the importance of future studies on the suitability of SARS-CoV-2 variants to air temperature.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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CRediT author statement

Qifa Song: Conceptualization, Methodology, Software, Formal analysis, Writing- Original draft preparation. Guoqing Qian: Methodology, Data curation, Formal analysis, Writing- Original draft preparation. Yuwei Mi: Investigation, Data curation, Writing- Reviewing and Editing. Jianhua Zhu: Resources, Supervision, Writing- Reviewing and Editing. Chao Cao: Resources, Visualization, Validation, Writing-Reviewing and Editing.

Ethics approval

This methodological study was waived for ethical approval by the Ethics Committee of Ningbo First City Hospital as no patients were involved.

Funding

Natural Science Foundation of Ningbo (No. 2021J270), and Public Welfare Fund of Zhejiang Province, China (No. LGF22G030010).