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RESEARCH ARTICLE

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Correlation between vaccine coverage and the COVID-19 pandemic throughout the world: Based on real-world data

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Abstract

The aim of the study was to examine the correlation between COVID-19 vaccine coverage rates and outcomes of the COVID-19 epidemic in the case of COVID-19 variants based on real-world data. The data came from Our World in Data, which is building the international COVID-19 vaccination data set and is an open-source data set for everyone to use. The vaccination data set uses the most recent official numbers from governments and health ministries worldwide. We assessed the correlation between COVID-19 vaccine coverage rates and outcomes of the COVID-19 epidemic with existing variants by performing temporal analysis and spatial analysis. Overall, new cases per million population, the reproduction rate of COVID-19, new deaths from all causes per million population, excess mortality attributed to COVID-19 pandemic, and hospital patients or intensive care unit (ICU) patients per million population were not decreased with the time course. However, at the same time point, new cases per million population, the reproduction rate of COVID-19, new deaths per million population, and hospital patients or ICU patients per million population gradually decreased as the rate of vaccination coverage increased. High coverage percentages of COVID-19 vaccination were negatively correlated with the reproduction rate of COVID-19 (correlation coefficient −0.116) and ICU patients per million of the local population (correlation coefficient −0.055). Currently, there is no effective treatment for the COVID-19 pandemic, and prevention of the COVID-19 pandemic mainly depends on vaccines, especially when the rate of COVID-19 vaccine coverage is over 60%. The benefits of preventing severe disease and preventing transmission of infection are likely to be obvious.

KEYWORDS
COVID-19, effectiveness, global health, vaccination

1 | INTRODUCTION

Current epidemiologic data indicate that COVID-19 appears to have the ability for sustained human-to-human transmission.[1] Transmission may be possible during the asymptomatic period, and infection-enhancing variants including B.1.1.7 (Alpha), B.1.351 (Beta), P1 (Gamma), and B.1.617.2 (Delta) show increased transmissibility and resistance toward vaccines and therapies,[2,3] which could present additional challenges in controlling the outbreak. Given the potential for the rapid spread of the virus internationally,[4] unprecedented measures have been instituted to try to contain the spread of COVID-19, including severe restrictions on millions of people in China and mass COVID-19 vaccination policies in some countries and regions.[4–7]

To date, there has been no effective drug to reduce the spread of COVID-19. Ideally, the COVID-19 vaccine would be the most effective way to prevent disease, prevent asymptomatic infection, and stop transmission. Global efforts to produce vaccines for COVID-19 have gained momentum.[8] Active or planned COVID-19 vaccine trials include more than 690 000 individuals across the globe, and this number will grow as further studies commence.[9] To ensure equitable global access to COVID-19 vaccines once these vaccines are available and to private donors and foundations to finance the manufacturing and distribution of vaccines for low-income and middle-income countries (LMICs), the COVID-19 Vaccines Global Access (COVAX) Facility provides participating countries an opportunity to secure early access to the vaccines.[10] However, vaccination across the world has progressed slowly in both high-income countries (HICs) and LMICs.[11] Both HICs and LMICs will likely encounter barriers and challenges to rolling out vaccines. Additionally, some worry that the emergence of COVID-19 variants may tip the scales in favor of infection enhancement.[2] In some regions, the proportion of citizens who seem inclined to receive the COVID-19 vaccine is probably too small to effectively stop the spread of the disease.[12] This situation requires fostering a climate of respectful mutual trust between science and society, where scientific knowledge is not only preached but also cultivated and sustained, thanks to the emphatic understanding of citizens' worries, needs of reassurance, and health expectations. Such evidence should be considered before more resources are allocated toward the deployment of these vaccines. Based on global data analysis,[13] we examined whether there is always a benefit to conducting a mass COVID-19 vaccination policy in reducing COVID-19 cases and fatalities and in preventing severe disease in the case of COVID-19 variants. We hope that our research can facilitate easy and quick decision-making for COVID-19 vaccination policies for global health administration.

2 | METHODS

The data come from Our World in Data, which is building the international COVID-19 vaccination data set and is an open-source data set for everyone to use.[13] The vaccination data set uses the most recent official numbers from governments and health ministries worldwide. In this article, six key indicators were used to detect the correlation between COVID-19 vaccine coverage rates and outcomes of the COVID-19 epidemic with the existence of COVID-19 variants, including the rate of vaccination coverage, new COVID-19 cases, reproduction rates, new deaths per million, excess mortality, hospital patients per million population, and intensive unit care (ICU) patients per million population. The rate of vaccination coverage represents the rate of people fully vaccinated per hundred population. The reproduction rate represents the average number of new infections caused by a single infected individual. If the rate is greater than one, the infection is able to spread in the population. If it is below one, the number of cases occurring in the population will gradually decrease to zero. New deaths per million represent new deaths from all causes. Excess mortality represents the number of deaths during the COVID-19 pandemic compared to the deaths we would have expected had the pandemic not occurred. In this study, excess mortality is measured as the percentage difference between the reported number of weekly or monthly deaths in 2020–2021 and the projected number of deaths for the same period based on historical deaths data from 2015 to 2019. This metric is called the *P*-score and we calculate it as (Reported Deaths - Projected Deaths)/Projected Deaths × 100. The reported number of deaths might not count all deaths that occurred due to incomplete coverage and delays in death reporting. Hospital patients per million population represent all hospitalized patients per million population. ICU patients per million population represent all ICU patients per million population. The population estimates used to calculate per capita metrics are all based on the last revision of the United Nations World Population Prospects. The international COVID-19 vaccination data set is updated each morning (London time) with data up to the previous day (last updated: August 20, 2021).

This study examines the correlation between COVID-19 vaccine coverage rates and outcomes of the COVID-19 epidemic in the case of COVID-19 variants by performing a temporal analysis and spatial analysis. Plots and correlation analyses were constructed to visualize whether there is always a benefit to conducting a mass COVID-19 vaccination policy in reducing COVID-19 cases and fatalities, in preventing severe disease, in preventing transmission of infection, and against variants. R 3.6.3 and RStudio 1.2.5019 were used for data analysis in this study. The analysis code in RStudio is presented in Appendix file S1.

3 | RESULTS

We have listed the COVID-19 epidemiology and vaccination rates on each continent from January 1, 2020, to August 20, 2021 (Table 1).

3.1 | COVID-19 vaccination practice on a global scale

The introduction of the COVID-19 vaccine on a global scale occurred in approximately early 2021 (Figure S1A). The compared distribution data among different continents are presented in Figure S1B.

TABLE 1 The global distribution of COVID-19 epidemiology and vaccination rates until the last update of August 20, 2021

Continent	Total cases per million	Total deaths per million	Excess mortality	People vaccinated per hundred (%)	People fully vaccinated per hundred (%)
Asia	37 460	382	-	45.66	32.66
Europe	84 649	1531	1.33	54.61	45.12
Africa	13 434	217	-	20.49	5.77
North America	33 800	652	-	48.18	39.07
South America	65 737	2070	29.36	45.23	30.19
Oceania	5253	110	-	42.53	23.19
Total	41 660	748	6.28	40.76	31.36

3.2 | Correlation between COVID-19 vaccine coverage rates and COVID-19 epidemic on a global scale

The new cases per million population and reproduction rate of COVID-19 did not decrease with the time measured (Figures S2A and 2B). However, at the same time point, new cases per million population and the reproduction rate of COVID-19 gradually decreased as the rate of vaccination coverage increased (Figures S2C and 2D), especially when the rate of COVID-19 vaccine coverage was over 60%. The comparison data of distribution among different continents are presented in Figure S3. Trends within region subgroups were generally consistent with the overall situation.

3.3 | Correlation between COVID-19 vaccine coverage rates and mortality on a global scale

New deaths from all causes per million population and excess mortality did not decrease with the time course (Figure 1A,B). However, at the same time point, new deaths per million population gradually decreased as the rate of vaccination coverage increased (Figure 1C), especially when the rate of COVID-19 vaccine coverage was over 60%. The comparison data of distribution among different continents are presented in Figure S4. Trends within region subgroups were generally consistent with the overall situation.

3.4 | Correlation between COVID-19 vaccine coverage rates and hospitalization on a global scale

Hospital patients per million population and ICU patients per million population did not decrease with the time course (Figure 2A,B). However, at the same time point, hospital patients or ICU patients per million population gradually decreased as the rate of vaccination coverage increased (Figure 2C,D), especially when the rate of COVID-19 vaccine coverage was over 60%. The comparison data of distribution among different continents are presented in Figure S5. Trends within region subgroups were generally consistent with the overall situation.

3.5 | Correlative analysis of the due factors for the outcome of the COVID-19 epidemic on a global scale

It was found that the new cases per million and new deaths per million increased as the rate of people fully vaccinated per hundred increased. The correlation coefficient between the rate of people fully vaccinated per hundred and new cases per million or new deaths per million was 0.233 or 0.057, respectively. However, the reproduction rate and ICU patients per million decreased as the rate of people fully vaccinated per hundred increased; the correlation coefficients were −0.116 and −0.055, respectively. There was no significant correlation between excess mortality and the rate of people fully vaccinated per hundred. At the same time, handwashing facilities were negatively correlated with excess mortality (correlation coefficient −0.127), and extreme poverty was positively correlated with excess mortality (correlation coefficient 0.328) (see Figure 3).

4 | DISCUSSION

Currently, there is no effective treatment for the COVID-19 pandemic throughout the world with infection-enhancing variants, and prevention of the disease mainly depends on vaccines. The previous social-epidemiological model suggests that the most effective vaccination strategy for interrupting transmission and reducing mortality due to COVID-19 depends on the time course of the pandemic in the population. Uniform or contact-based strategies prevent the most deaths compared with the strategies of prioritizing vulnerable age groups.[7] Studies of the epidemiology of COVID-19, particularly the temporal and spatial distributions, have played an important role in preventing infections. However, previous studies have neglected to analyze the correlation between the COVID-19 vaccine coverage rates and outcomes of the COVID-19 epidemic with temporal and spatial analyses. This study supplements evidence from real-world data in the area of the COVID-19

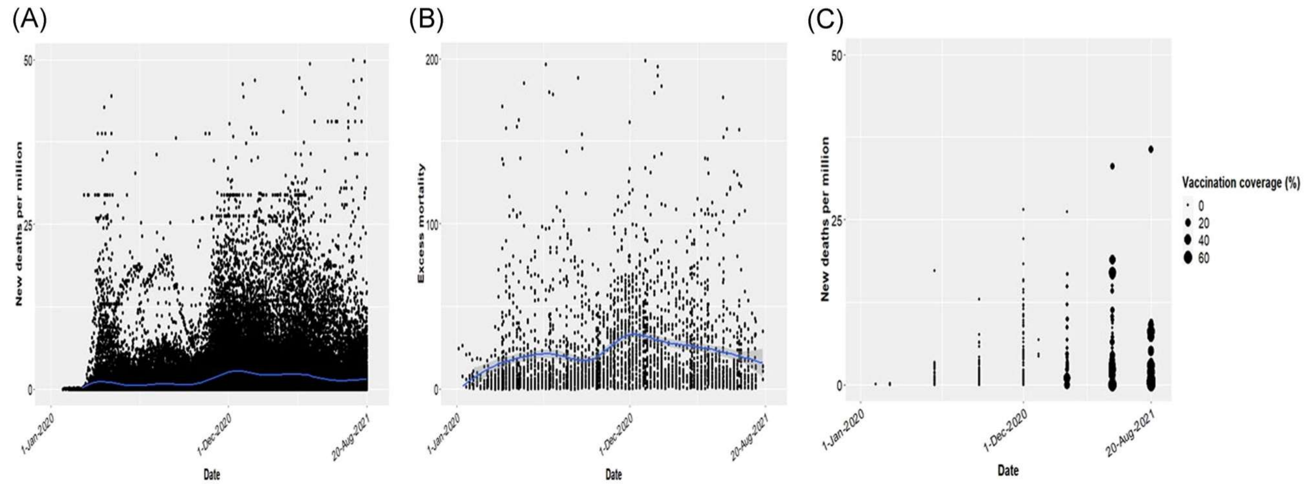

FIGURE 1 Correlation between COVID-19 vaccine coverage rates and mortality on a global scale. (A) New deaths per million represent new deaths from all causes; (B) Excess mortality is measured as the percentage difference between the reported number of weekly or monthly deaths in 2020–2021 and the projected number of deaths for the same period based on historical deaths data from 2015 to 2019. The chart here shows excess mortality during the pandemic for all ages using the *P*-score. *P*-score = (Reported Deaths - Projected Deaths)/Projected Deaths × 100. The reported number of deaths might not count all deaths that occurred due to incomplete coverage and delays in death reporting; (C) The number of new deaths per million changes along with the rate of COVID-19 vaccine coverage

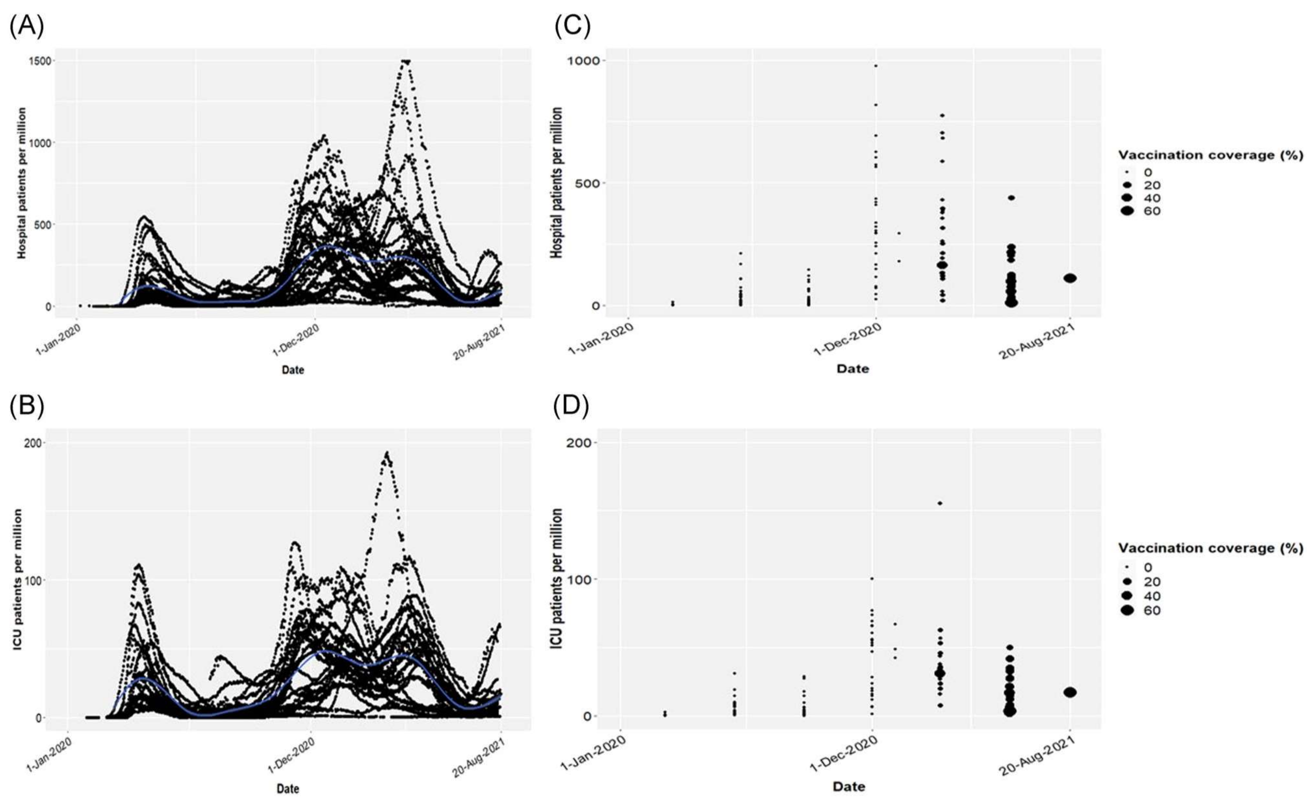

FIGURE 2 Correlation between COVID-19 vaccine coverage rates and hospitalization on a global scale. (A) Hospital patients per million population represent all hospitalized patients per million population; (B) Intensive care unit (ICU) patients per million population represent all ICU patients per million population; (C) The number of hospital patients per million population changes along with the rate of COVID-19 vaccine coverage; (D) The number of ICU patients per million changes along with the rate of COVID-19 vaccine coverage

epidemic by performing a temporal analysis and spatial analysis and determining the correlation between COVID-19 vaccine coverage rates and outcomes of the COVID-19 epidemic. The evidence provided insights into potential solutions to diminish the diseases. The results of data analysis suggested that a high rate of COVID-19 vaccine coverage was negatively correlated with the reproduction rate and ICU patients per

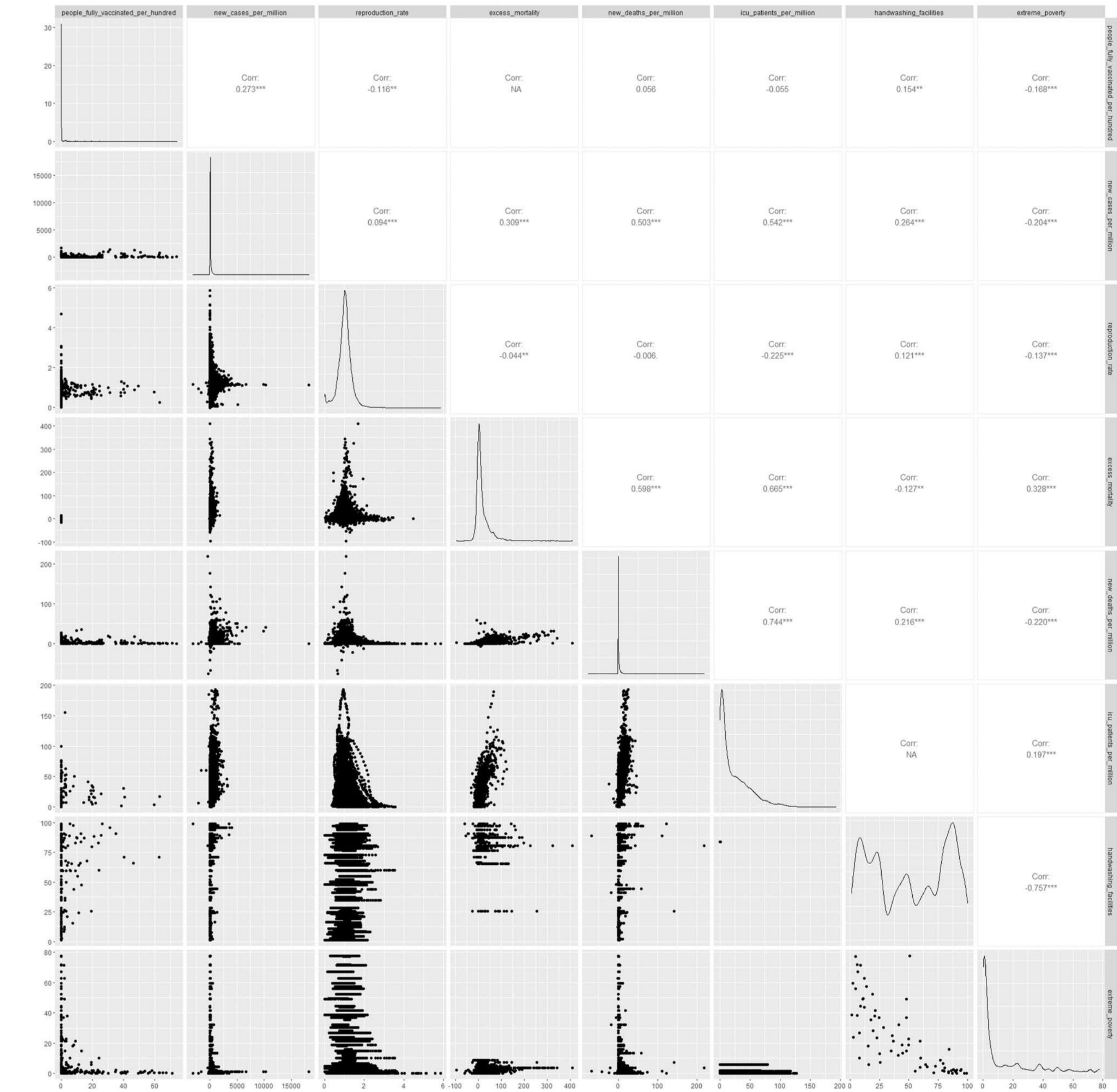

FIGURE 3 The correlation between potential factors and outcome of COVID-19 epidemic on a global scale

million and that COVID-19 vaccine coverage could prevent severe disease and prevent transmission of infection, especially when the rate of COVID-19 vaccine coverage was over 60%. The benefits of COVID-19 vaccines in preventing severe disease and preventing transmission of infection were likely to be obvious. It is worth noting that the trends of benefits from COVID-19 vaccines within regional subgroups were generally consistent with the overall situation. Meanwhile, handwashing facilities might be beneficial in decreasing the COVID-19 pandemic. Although the rate of COVID-19 vaccine coverage did not reveal a significant correlation with excess mortality, there were some factors with greater weight that greatly impacted excess mortality, such as extreme poverty.

Based on the results of our temporal and spatial analysis of the correlation between COVID-19 vaccine coverage rates and outcomes of the COVID-19 epidemic, our research mainly strengthens the belief that a mass COVID-19 vaccination policy would protect the health and wellbeing of everyone, especially when the rate of COVID-19 vaccine coverage is over 60% and the trends within region subgroups are generally consistent with the overall situation. However, to date, the average coverage rate of the COVID-19 vaccine has not reached 60% on any continent (see Table 1). The low average coverage rate of the COVID-19 vaccine is probably too small to effectively stop the spread of the disease. We hope that our research can facilitate easy and quick decision-making for COVID-19 vaccination policies for global health administration.

As outlined above, vaccination across the world has progressed slowly in both LMICs and HICs.[11] There are two key factors slowing the process of vaccine coverage: vaccine accessibility and public acceptance of COVID-19 vaccination. Some studies may help governments determine the best way to implement COVID-19 mass vaccination programs.[10,14] A systematic review and meta-analysis[14] found that factors contributing to the acceptance of COVID-19 vaccination included older age, male sex, female sex, marital status, high education, high income, health care workers, chronic diseases, high level of knowledge, perceived risk, perceived benefits, fear about COVID-19, encounters with COVID-19, flu vaccine during the previous season and trust in the health system. However, LMICs have been taken as an impact factor to decrease COVID-19 vaccine acceptance. Variations in the epidemiology of the infection in different geographical locations, which are still not fully understood, will make it necessary to weigh the balance between different risk factors in each geographical region.[10] There are very little data from LMICs regarding who is most at risk of a severe COVID-19 outcome. The epidemiology of the infection may differ considerably in LMICs from that in HICs, as the demography, household transmission dynamics, comorbidities by age group, and access to life-saving treatment, such as oxygen and intensive care, will be different. When vaccine supply cannot meet demand, the decision on who to vaccinate needs to be equitable and highly contextualized based on the properties of the vaccine and whether the reduction of severe disease, interruption of transmission, or both are desired.[10] Most importantly, health departments should implement urgent health promotion services and disseminate more reliable information.[14] Deciding how much priority to give to direct protection or to the indirect effects and allowing everyday activities to resume with consequent economic benefits to the whole community will be a challenge for public health authorities. Furthermore, decisions on which vaccine to use will depend on the vaccine's properties in terms of efficacy against severe disease and transmission and whether the desired public health outcome is to prevent severe disease and/or to prevent transmission. Governments need to make decisions based on their own local epidemiology, priorities, and societal values and then take action to ensure that people have enough information, have healthy attitudes, and have positive opinions about COVID-19 vaccines.[10–12]

This study had some limitations. First, limited testing and challenges in the attribution of the cause of positive COVID-19 cases and outcomes mean that the number of confirmed positive COVID-19 cases and outcomes may not be an accurate count of the true number of positive COVID-19 cases and outcomes from COVID-19. The reported number of positive COVID-19 cases and outcomes might not count all positive COVID-19 cases and outcomes that occurred due to incomplete coverage and delays in positive COVID-19 cases and outcome reporting. Second, due to some confounding factors, the quantitative contribution of COVID-19 vaccine coverage to outcomes cannot be determined.

5 | CONCLUSIONS

Based on the results of our temporal and spatial analysis of the correlation between the COVID-19 vaccine coverage rates and outcomes of the COVID-19 epidemic, we provide additional evidence that a mass COVID-19 vaccination policy would protect the health and wellbeing of all, especially when the rate of COVID-19 vaccine coverage passes 60% and the benefits to preventing severe disease and preventing transmission of infection are likely to become obvious.

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CONFLICT OF INTERESTS

The author declares that there are no conflict of interests.

ETHICS STATEMENT

Not applicable.

AUTHOR CONTRIBUTIONS

Rong Peng conceptualized and designed the study. Rong Peng and Chao Huang put forward the outline of the article. Rong Peng, Lijun Yang, Jia Pan made data analysis, draw pictures, and drafted the manuscript. Xiaomei Xu revised the article. All authors read and approved the final manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in [repository name “A global database of COVID-19 vaccinations”] at https://ourworldindata.org/covid-vaccinations, reference number.[13]

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SUPPORTING INFORMATION

Additional supporting information may be found in the online version of the article at the publisher's website.

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