

Vaccination associated with gross domestic product and fewer deaths in countries and regions

A verification study

Lin-Yen Wang, MD^{a,b,c}, Tsair-Wei Chien, MBA^d, Ju-Kuo Lin, MD^{e,f}, Willy Chou, MD^{g,h,*}

Abstract

Background: Vaccination can have a substantial impact on mitigating COVID-19 outbreaks. However, the vaccine rollout rates associated with the gross domestic product (GDP) and few deaths are required for verification. Three hypotheses were made:

1. the inflection point (IP) days on the cumulative number of confirmed cases (CNCCs) in 2021 are improved (i.e., shorter than 2021);
2. the vaccinations are associated with national GDP and fewer deaths; and
3. the association is weak between vaccinations and CNCC IP based on the argument that vaccinations are limited to protection against milder infection.

Methods: The corresponding CNCCs and deaths were downloaded from the GitHub website. Four variables, including IP days on CNCCs and deaths, GDP per capita, and vaccine doses administered per 100 people (VD100) in countries/regions, were collected. Correlation coefficients (CCs) between variables were computed to verify the association with vaccination rates. Four tasks were achieved:

1. determining IP days for each country/region;
2. drawing forest plots to identify the improvement in 2021;
3. using a pyramid plot to identify the improvement in US states; and
4. applying the Kano diagram to verify the three hypotheses mentioned above.

Results: We observed that

1. the IP days on CNCCs in 2021 were shorter than those in 2021 among continents and US states;
2. the CCs were 0.66 ($t=12.21$, $P<.01$) and -0.15 ($t=2.11$, $P<.01$) using the paired variables of [VD100, GDP] and [VD100, deaths IP], respectively; and
3. the CC between CNCC IP and deaths IP was 0.73 ($t=14.84$, $P<.01$), but a weak association with $CC=-0.01$ existed between CNCC IP and VD100.

Editor: Jinfeng Li.

The authors have no sources of funding to disclose.

All data were downloaded from the MEDLINE database at PubMed.com.

All data used in this study are available in Additional files.

The authors have no conflicts of interests to disclose.

Supplemental Digital Content is available for this article.

The datasets generated during and/or analyzed during the current study are publicly available.

^aDepartment of Pediatrics, Chi-Mei Medical Center, Tainan, Taiwan, ^bDepartment of Childhood Education and Nursery, Chia Nan University of Pharmacy and Science, Tainan, Taiwan, ^cSchool of Medicine, College of Medicine, Kaohsiung Medical University, Kaohsiung, Taiwan, ^dDepartment of Medical Research, Chi-Mei Medical Center, Tainan, Taiwan, ^eDepartment of Optometry, Chung Hwa University of Medical Technology, Jen-Teh, Tainan City, Taiwan, ^fDepartment of Ophthalmology, Chi-Mei Medical Center, Yong Kang, Tainan, Taiwan, ^gDepartment of Physical Medicine and Rehabilitation, Chi Mei Medical Center, Tainan, Taiwan, ^hDepartment of Physical Medicine and Rehabilitation, Chung San Medical University Hospital, Taichung, Taiwan.

* Correspondence: Willy Chou, Chi-Mei Medical Center, 901 Chung Hwa Road, Yung Kung Dist., Tainan 710, Taiwan (e-mail: ufan0101@ms22.hinet.net).

Copyright © 2022 the Author(s). Published by Wolters Kluwer Health, Inc.

This is an open access article distributed under the terms of the Creative Commons Attribution-Non Commercial License 4.0 (CCBY-NC), where it is permissible to download, share, remix, transform, and build up the work provided it is properly cited. The work cannot be used commercially without permission from the journal.

How to cite this article: Wang LY, Chien TW, Lin JK, Chou W. Vaccination associated with gross domestic product and fewer deaths in countries and regions: a verification study. *Medicine* 2022;101:4(e28619).

Received: 28 June 2021 / Received in final form: 10 December 2021 / Accepted: 23 December 2021

<http://dx.doi.org/10.1097/MD.00000000000028619>

Conclusion: Our results indicate that vaccination has a significant effect on mitigating COVID-19 outbreaks, even with limited protection against infection. Continued compliance with nonpharmaceutical interventions is essential to the fight against COVID-19 in the future.

Abbreviations: CC = Correlation coefficients, CNCCs = cumulative number of confirmed cases, FDA = Emergency Use Authorization, GDP = gross domestic product, IP = inflection point, OC = ogive curve, QR = quick response, VD100 = vaccine doses administered per 100 people.

Keywords: correlation coefficient, COVID-19, GDP, inflection point, vaccine doses administered per 100 people

Highlights

- Google Maps are particularly used to show dashboards on study results. This approach is rarely seen in previous papers.
- The IP days were used to measure the effective control of COVID-19, which is novel and modern in the literature.
- Three types of presentations using forest plots, pyramid plots, and Kano diagrams were used to display study results that are easy and clear to understand using visualizations.

1. Introduction

The novel coronavirus severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) has caused more than 1 million deaths in the first six months of the pandemic^[1] and 0.9 billion confirmed cases worldwide in 2020. They were still growing until safe and effective vaccines ended the COVID-19 pandemic. This is because vaccination can have a substantial impact on mitigating COVID-19 outbreaks, even with limited protection against infection.^[2]

1.1. Vaccination on mitigating COVID-19 outbreaks

Among all continents, the cumulative number of confirmed cases (CNCC) in Europe, North America, and Asia has exceeded 21 million, and the number of new confirmed cases in a single week in North America, South America, and Asia has increased. The CNCC in 18 countries, including the United States, India, and Brazil, was more than 1 million, accounting for 77.04% of the total CNCC in the world.^[3] As such, the COVID-19 pandemic was a major issue of the campaign in the 2020 United States presidential election.^[4] President-elect Joe Biden received his first dose of the Pfizer Covid-19 vaccine on December 20, 2020.^[5] The inauguration of Joe Biden as the 46th president of the United States took place on January 20, 2021,^[4] and announced the COVID-19 Vaccination Program and the Effort to Defeat COVID-19 Globally (e.g., the goal to the US Administer at least one vaccine shot to 70% of the U.S. adult population by July 4, 2021.^[6] The first research question is thus raised: whether vaccination has a substantial effect on mitigating COVID-19 outbreaks.

1.2. Challenges to the efficacy of vaccines against COVID-19

An efficacious vaccine is considered essential to prevent further morbidity and mortality.^[7] More than 44 candidate COVID-19

vaccines are in clinical development, and 151 are in preclinical development.^[8] In December 2020, the Pfizer vaccine was the first COVID-19 vaccine given Emergency Use Authorization (EUA), and the second FDA-approved vaccine was the Moderna mRNA-1273 vaccine introduced a week later.^[9]

Both Pfizer and Moderna vaccines (administered in 104 and 54 countries, respectively) are mRNA-based vaccines and are estimated to have an efficacy rate of more than 94%.^[9] In addition, a number of vaccines have been developed and approved by various regulatory authorities around the world.^[1,10,11]

Nonetheless, we were still facing some challenges, such as the global shortage of vaccines, the public's willingness to vaccinate, and equity in the distribution of vaccines^[12] (e.g., most countries have focused their early vaccination efforts on priority groups like the clinically vulnerable; people in their 60s, 70s, and older; and front-line workers, like doctors and nurses).

Even more than 2.66 billion vaccine doses have been administered worldwide (i.e., approximately 35 doses for every 100 people; for example, 118, 113, and 112 in Israel, Chile, and the United Kingdom, respectively) as of June 22, 2021. There is still a stark gap between vaccination programs in different countries, with some yet to report a single dose (e.g., <0.1 in Congo and Chad).^[13] For example, as of 7 April 2021, the cumulative number of doses administered per 100 people ranges from 118 per 100 in the case of Israel to <0.1 doses per 100 in countries that have just begun their vaccination campaigns, such as Mali, Namibia, and Brunei.^[14] The procurement, allocation, distribution, administration, and uptake of vaccines will be essential steps in the process^[10] (e.g., developing countries are likely to face challenges at each step in the process since a majority of the global population resides in these nations). The second research question is to investigate whether vaccinations are associated with income group classifications in countries/regions.

1.3. Effective containment referred to inflection points on curves of COVID-19 confirmed cases

The effective containment of COVID-19 refers to the inflection point (IP) days that stand for a point on a smooth plane curve where curvature changes sign from an increasing concave (concave downward) to a decreasing convex (concave upward) shape, or vice versa.^[15-17] The CNCC in a country/region can thus be modeled on an ogive curve (OC) to search for the IP days. The IP is defined at the moment of the outbreak to decrease after a peak.^[18] A shorter IP means more effective containment of COVID-19.^[16,17] Conversely, IP deaths can deflect efficacious vaccines to prevent further morbidity and mortality.^[17]

In addition to vaccinations, the effective containment of measures on COVID-19 includes physical distancing, early detection, self-isolation, and outbreak control, which should be continually emphasized as important preventive interventions. As

such, our concerns about the virus and vaccines may interfere with public health measures to control COVID-19.^[12]

1.4. COVID-19 vaccine doses administered: global inequalities in vaccine access

Vaccines, when available, will prove to be crucial in the fight against COVID-19.^[12] The problem we face is the acute dilemmas in allocating scarce life-saving resources in the form of vaccines for COVID-19 mentioned in Section 1.2.

The rollout of COVID-19 vaccines in developing countries is critical to protecting lives and stimulating economic recovery. The current crisis is exacerbating inequalities throughout the world, and without access to vaccines, the gap will widen further.^[1]

Based on data on COVID-19 vaccine doses administered by country income group,^[19,20] 21.8% of the world population has received at least one dose of a COVID-19 vaccine, particularly in high-income countries. In contrast, only 0.9% of people in low-income countries have received at least one dose. The major concern in this study was to inspect whether vaccinations were associated with the gross domestic product (GDP) and fewer deaths in countries and regions.

1.5. Study aims

Based on the statements in the previous sections, that is,

1. vaccine doses administered by country income group,^[20]
2. vaccination with limited protection against milder infection^[2] and
3. an efficacious vaccine merely preventing further morbidity and mortality^[7]

Three hypotheses were made, including

1. the IP days on CNCCs in 2021 are improved (i.e., shorter than the year of 2021);
2. the vaccinations are associated with nation GDP and fewer deaths;
3. association is weak between vaccinations and the CNCCs IP based on the argument that vaccinations are limited to protection against milder infection.^[2]

Four tasks would be achieved:

1. determining IP days for each country/region;
2. drawing forest plots^[21] to identify the improvement in 2021;
3. using a pyramid plot^[22] to identify the improvement in US states; and
4. applying the Kano diagram^[23] to verify the three hypotheses mentioned above.

2. Methods

2.1. Data source

The COVID-19 CNCCs and deaths were downloaded from the GitHub website^[24–26] for countries/regions on June 20, 2021 (see Supplemental Digital Content 1, <http://links.lww.com/MD2/A853>). Four variables, including inflection point (IP) days on CNCCs and deaths, gross domestic product (GDP) per capita, and vaccine doses administered per 100 people (VD100) in countries/regions, were collected.

All downloaded data are publicly released on the website.^[24–26] Ethical approval was not necessary for this study because all the data were obtained from the GitHub website.

2.2. Data arrangements and data presentations

2.2.1. IP days on CNCCs and deaths using IRT model. The item response theory (IRT)^[27,28]-based scheme^[16,17] was applied to compute the IP days on CNCCs and deaths in the two phases of 2020 and 2021 until June 20. The shorter the IP days, the more effective containment of COVID-19 will be. The process of IP search is provided in Supplemental Digital Content 1, <http://links.lww.com/MD2/A853>. Choropleth maps^[29] were used to display the distribution of CNCC IP days around the world.

2.2.2. Comparisons of CNCCs IP days among continents.

Forest plots^[22] were used to compare CNCC IP days on continents. First, IP days were compared among continents in 2020 using the means and standard errors in Equation (1).

$$SE = SD/\sqrt{(n-1)}, \quad (1)$$

The standard error (SE) was determined by Equation (1), where SD is the standard deviation and n denotes the number of countries/regions in a continent or sample.

Second, IP days were compared among continents between 2020 and 2021 until June 20 using the means and standard deviations.

2.2.3. Calculations of statistics in a forest plot. The meaningfulness of the study data for the individual effect of the continent (or country, e.g., China or the United States) is denoted by the weight (size) of the box. Data from studies with greater sample sizes and smaller confidence intervals (CIs) are more meaningful data, which contribute to the pooled result (i.e., the overall effect) to a greater degree.^[21] The 95% CIs can be yielded by following Equations (2) to (16) if sample sizes (n1 and n2), mean (M1 and M2), and SD (SD1 and SD2) are known in the 2 years of 2020 and 2021.

$$TVariance = (n1 - 1) \times SD1 \times SD1 + (n2 - 1) \times SD2 \times SD2, \quad (2)$$

$$Variance = TVariance/(n1 + n2 - 2), \quad (3)$$

$$SD = \text{SQRT}(Variance), \quad (4)$$

$$\text{Cohend} = (M1 - M2)/SD, \quad (5)$$

$$\text{Vard} = (n1 + n2)/(n1*n2) + \text{Cohend}*\text{Cohend}/(2*(n1 + n2)), \quad (6)$$

$$Jcorrect = 1 - 3/(4*(n1 + n2 - 2) - 1), \quad (7)$$

$$\text{Hedgesg} = \text{measure} = \text{Cohend}*Jcorrect, \quad (8)$$

$$\text{Varg} = \text{Vard}*Jcorrect*Jcorrect, \quad (9)$$

$$SD = \text{Sqr}(Varg), \quad (10)$$

$$SE = 1/SD \times 1/SD, \quad (11)$$

$$Z = \text{measure}/SD, \quad (12)$$

$$P - \text{value} = (1 - \text{NORMSDIST}(\text{ABS}(Z))) * 2, \tag{13}$$

$$\text{Lower limit} = \text{Measure} - \text{SE} \times 1.96, \tag{14}$$

$$\text{Upper limit} = \text{Measure} + \text{SE} \times 1.96, \tag{15}$$

$$W_i = 1/\text{Varg}, \tag{16}$$

$$Y_i = \text{Mean on the } i\text{th continent}, \tag{17}$$

$$M = \left(\sum_{i=1}^k \text{Mean}_i \right) / k, \tag{18}$$

$$Q = \sum_{i=1}^k W_i (Y_i - M)^2, \tag{19}$$

$$\text{Prob} = \text{Chidist}(Q, \text{df}), \tag{20}$$

$$I^2 = \frac{Q - \text{df}}{Q} \times 100, \tag{21}$$

where Q denotes the summation of squared deviations from the mean, and the P -value can be obtained from Equation (1), and df is the degree of freedom. I^2 is the proportion in Q . We assessed heterogeneity visually by reporting the I^2 statistic.

We decided to present forest plots along with a description of the results. A fixed-effects model was applied in this study. An author-made module was used for statistical analyses to produce forest plots online on Google Maps. The variance in continents was computed by $T(\tau)$ in Equation (22), which is commonly used for calculating the random effect (e.g., the pooled or nonpooled random effect in a subgroup meta-analysis). The Q statistics in Equations (19) and (23) are equal.

$$T^2 = \frac{Q - \text{df}}{C}, \tag{22}$$

$$Q = \sum_{i=1}^k W_i Y_i^2 - \frac{\left(\sum_{i=1}^k W_i Y_i \right)^2}{\sum_{i=1}^k W_i}, \tag{23}$$

$$\text{df} = k - 1, \tag{24}$$

$$C = \sum_{i=1}^k W_i - \frac{\sum_{i=1}^k W_i^2}{\sum_{i=1}^k W_i}, \tag{25}$$

where k is the number of continents. The P -value yielded by the function in MS Excel (i.e., $\text{Chidist}(T^2, \text{df})$) is identical to the approach using analysis of variance (ANOVA).^[21]

2.2.4. Calculations of correlation coefficients between variables. Correlation coefficients (CCs) between variables were

computed to verify the association with vaccine rollout rates. The CC t value was calculated by the formula $\left(\frac{cc}{\sqrt{\frac{1-cc^2}{n-2}}} \right)$. The study process was presented with an MP4 video (see Supplemental Digital Content 1, <http://links.lww.com/MD2/A853>).

2.3. Three tasks to achieve the goals

Three tasks are shown in Figure 1:

1. determining the CNCC IP days for each country/region;
2. drawing forest plots^[21] to identify the improvement in 2021;
3. using a pyramid plot^[22] to identify the improvement in US states; and
4. applying using the Kano diagram^[23] to verify the three hypotheses mentioned above.

2.4. Statistical tools and data analysis

The mean and standard deviation (SD) were extracted to compare the standardized mean difference (SMD) in the forest plot. The professional statistical software MedCalc 9.5.0.0 for Windows (MedCalc Software) was used in this study. A significance level of type I error was set at 0.05.

Visual representations of the forest plot and choropleth map display the comparison of the difference in IP days. The dashboards were plotted online on Google Maps. The data arrangements were carried out in Microsoft Excel (Supplemental Digital Content 1, <http://links.lww.com/MD2/A853>). The study flowchart is shown in Figure 1.

3. Results

3.1. Determining IP days for each country/region

The CNCC IP days for countries/regions are presented using the choropleth maps shown in Figure 2. We can see that the CNCC IP days in China are obviously shorter in 2020 in the top panel of Figure 1. Conversely, the CNCC IP days in the United States are relatively shorter in 2021 in the bottom panel of Figure 1.

Three examples of line charts regarding CNCC IP days are shown in Figure 3 (i.e., 2020 in the left panel and 2021 in the right panel). We can see that Taiwan suffers longer IP days in both years. The United Kingdom and California (US) earn shorter IP days in 2021, indicating that both countries earn effective containment of COVID-19 with vaccinations in the first half of 2021.

3.2. Drawing forest plots to identify the improvement in 2021

In Figure 4, China earns the shortest CNCC IP days (=80.4) in 2020 (shown in the top panel), followed by OCEANIA and South America. The longer CNCC IP days in 2020 are Europe, with a mean = 291.2 days. The Q -statistic (=190,594) implies that a difference in IP days exists among regions ($P < .05$).

The bottom panel in Figure 4 shows that all regions, except China, have made improvements in CNCC IP days in 2021, indicating that the potential effect of vaccination emerged in the half-year of 2021.

Downloaded from <http://journals.lww.com/md-journal> by BhDM5fPHeKAv1ZEUm11QNa4hKJLhE2gjsH04XM0h0CywCX1AMNvYQp/1QIH-D3D00DFRj7TVSF14C3V/C4/OAVPDDa8KKG10Y0my+78= on 12/09/2024

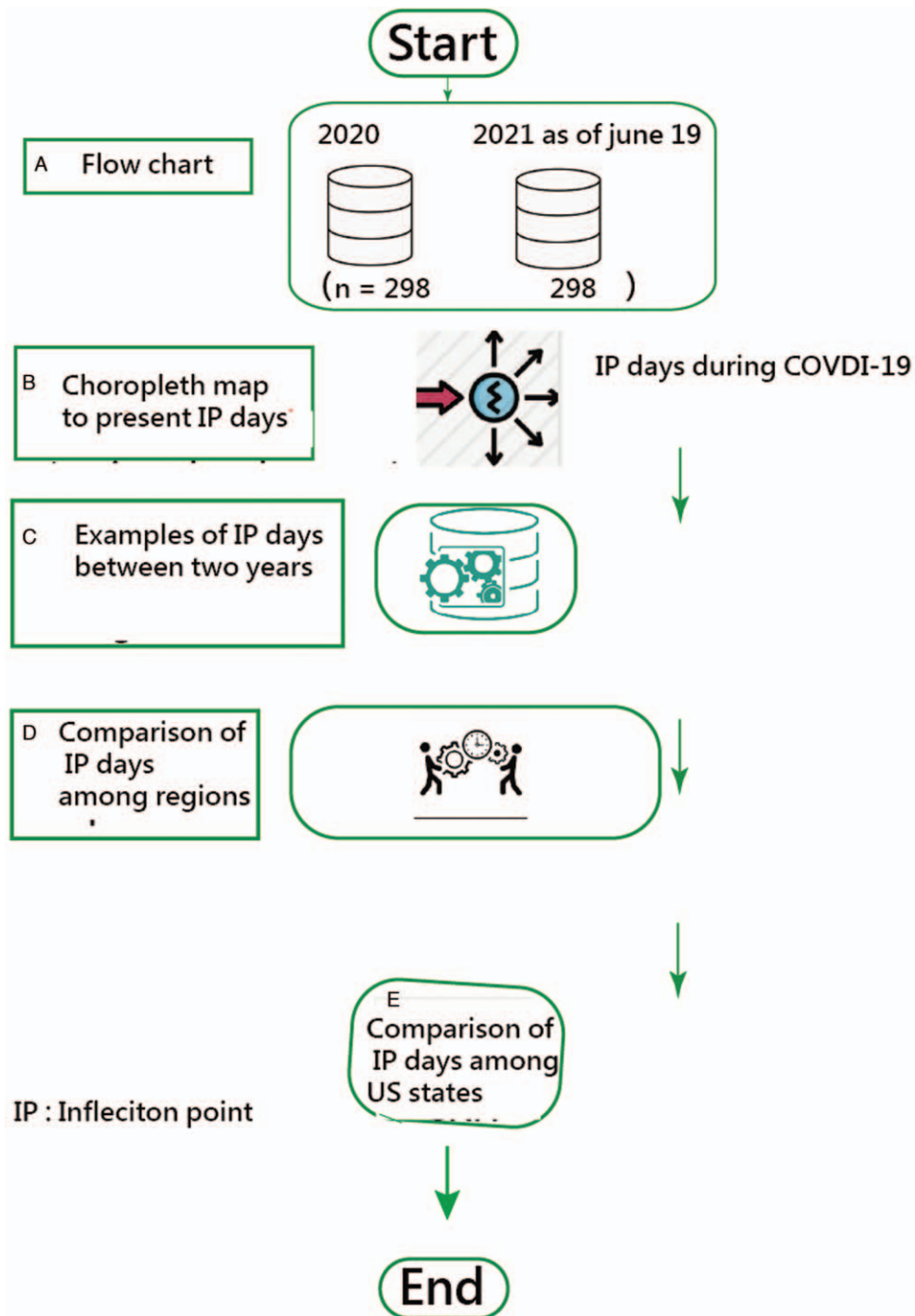


Figure 1. Study flowchart.

3.3. Using the pyramid plot to identify the improvement in US states

When viewing Figure 5, it can be seen that all US states have shorter CNCC IP days in 2021 (with red bars shown in the right panel). The shortest IP day reaches 23 in California. The longest IP days (=162) are in Illinois, Oregon, and the Virgin Islands.

Based on Figures 4 and 5, the first hypothesis was supported: IP days on CNCCs in 2021 are improved among continents and US states.

3.4. Using the kano diagram to verify the three hypotheses

In Table 1, we can see that

1. the CCs are 0.66 ($t = 12.21, P < .01$) and -0.15 ($t = 2.11, P < .01$) when the two paired variables of [VD100, GDP] and [VD100, deaths IP] are compared, respectively;
2. the CC between CNCC IP and deaths IP is 0.73 ($t = 14.84, P < .01$), but a weak association with $CC = -0.01$ exists between CNCC IP and VD100.

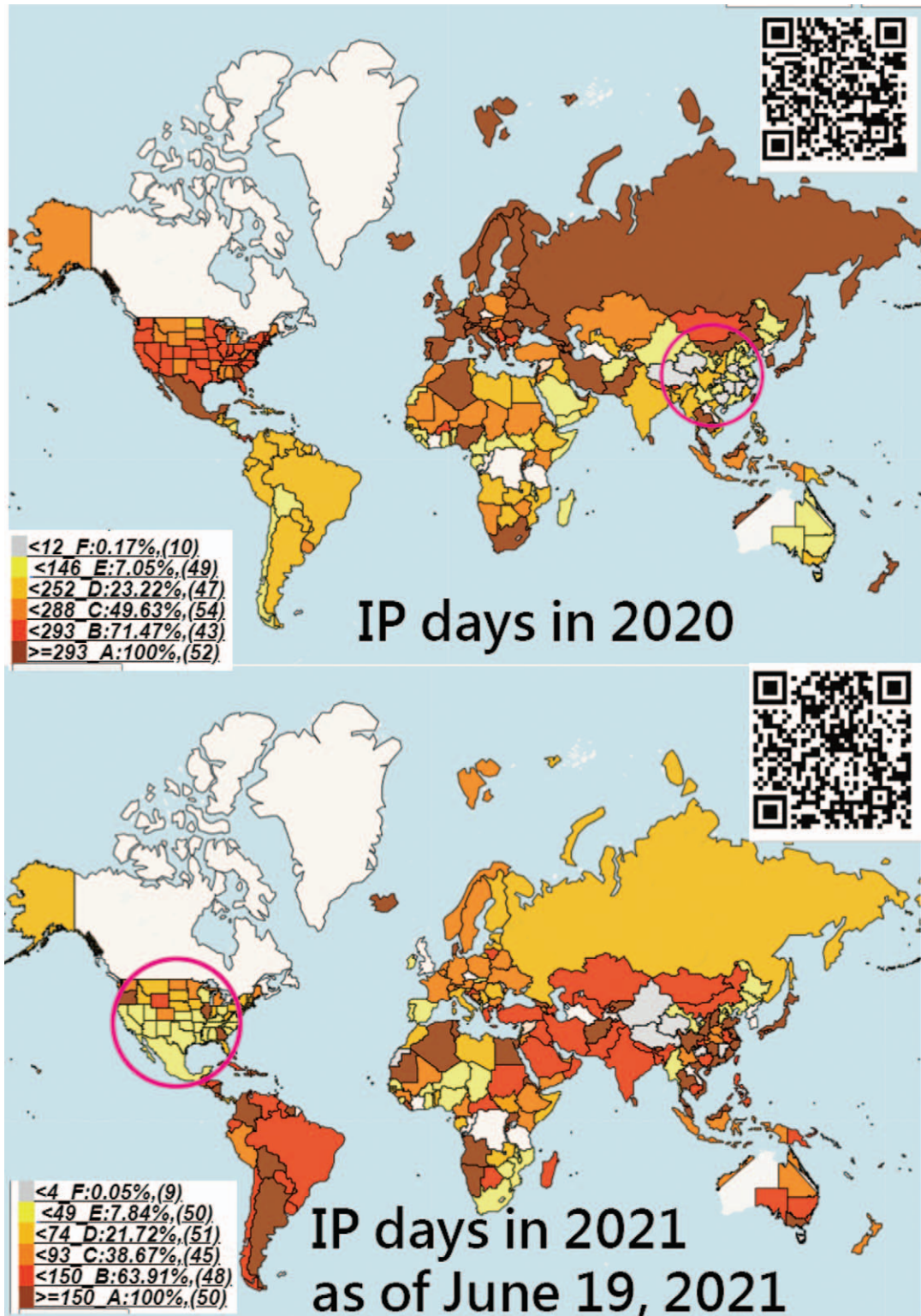


Figure 2. IP days of COVID-19 in regions in 2020 and 2021.

The two hypotheses were thus supported:

1. the vaccinations are associated with national GDP and fewer deaths (see Fig. 6; bubbles dispersed from the bottom-left corner to the top-right side);

2. the association between vaccinations and CNCC IP is weak.

Bubbles are sized by the deaths IP days in Figure 6, indicating that the shorter IP days have smaller bubbles, such as United States, United Kingdom, and China.

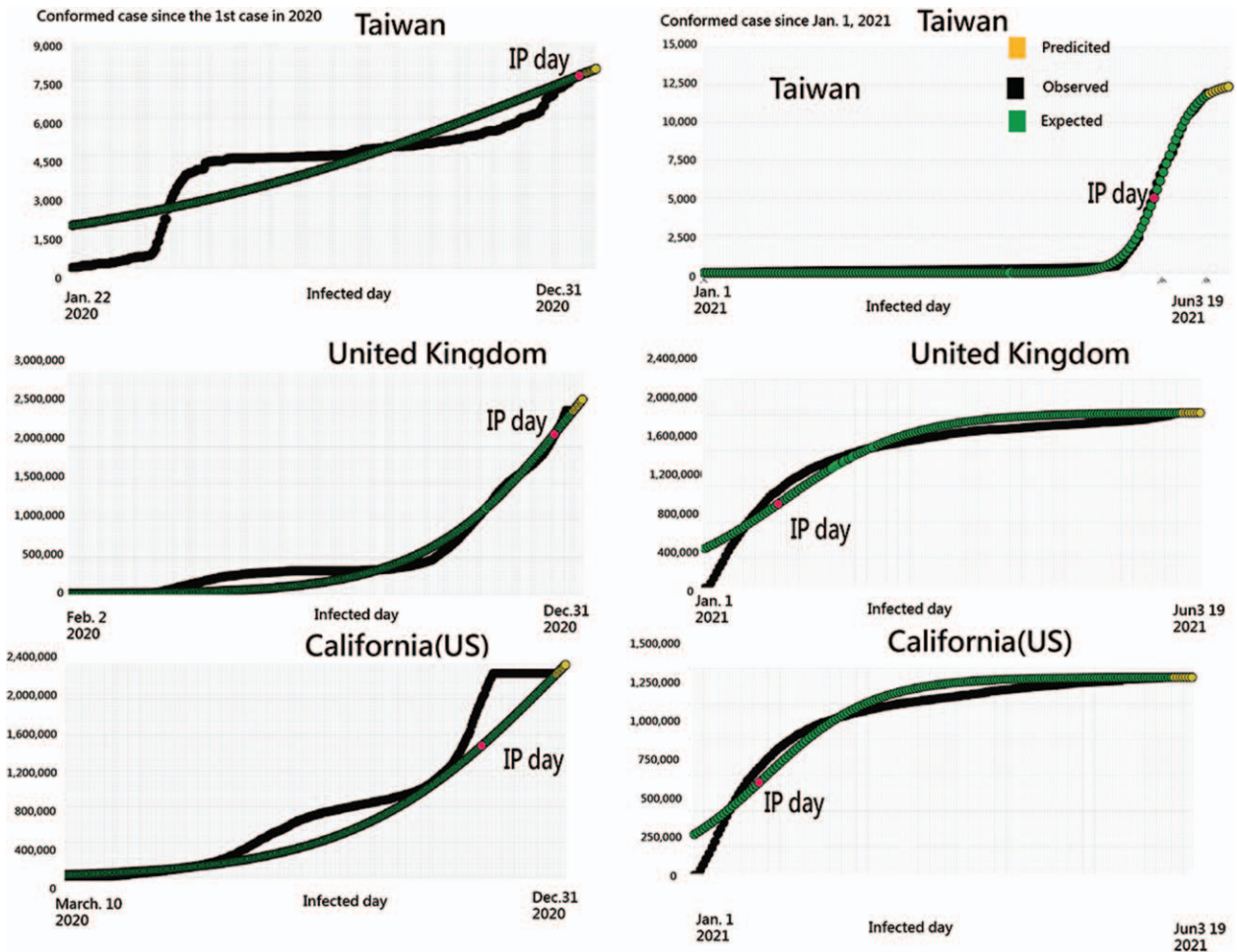


Figure 3. Examples of IP days in comparison between 2 years.

3.5. Online dashboards shown on google maps

All of the QR codes in Figures are linked to the dashboards.^[30–34] Readers are recommended to examine the displayed dashboards on Google Maps.

4. Discussion

4.1. Principal findings

We observed that

1. the IP days on CNCCs in 2021 were shorter than those in 2021 among continents and US states;
2. the CCs were 0.66 ($t=12.21, P<.01$) and -0.15 ($t=2.11, P<.01$) in the paired variables of [VD100, GDP] and [VD100, IP deaths], respectively; and
3. the CC between CNCC IP and IP deaths was 0.73 ($t=14.84, P<.01$), but a weak association with $CC=-0.01$ existed between CNCC IP and VD100.

4.2. Contributions of the study

Vaccination against the COVID-19 virus began in December 2020 in the United Kingdom and into Spring 2021. It has been running at a 5% population/week.^[35] However, the three

phenomena (e.g., vaccine doses administered with inequalities throughout the world,^[20] vaccination with limited protection against infection,^[2] and an efficacious vaccine merely preventing further morbidity and mortality^[17]) were not verified as we did in this study.

As of the end of 2020, a population of 9.3 million in Israel had administered more COVID-19 vaccine doses than all countries aside from China, the United States, and the United Kingdom.^[36] Moreover, Israel had administered almost 118.0 doses per 100 people as of June 21, 2021. Over 55% of Israel's 9.3 million citizens have received two doses of the Pfizer/BioNTech vaccine.^[37] However, Israel quarantines anyone deemed to have been exposed to an especially infectious variant of COVID-19^[38] because the extra contagious delta variant is spreading in Israel.^[39]

Similarly, the National Basketball Association (NBA) player Chris Paul tested positive for COVID-19 even though he received a Pfizer vaccine in February 2021,^[40] which supports our verification of vaccination with limited protection against milder infection,^[2] albeit the vaccine prevents further morbidity and mortality.^[17]

Vaccinations can significantly reduce the number of hospitalizations and deaths,^[35] meeting our CC result ($= -0.15, t=2.11, P<.01$) between VD100 and IP deaths.

The high cost of COVID-19 vaccines equates to low affordability. While three out of four COVID-19 vaccines

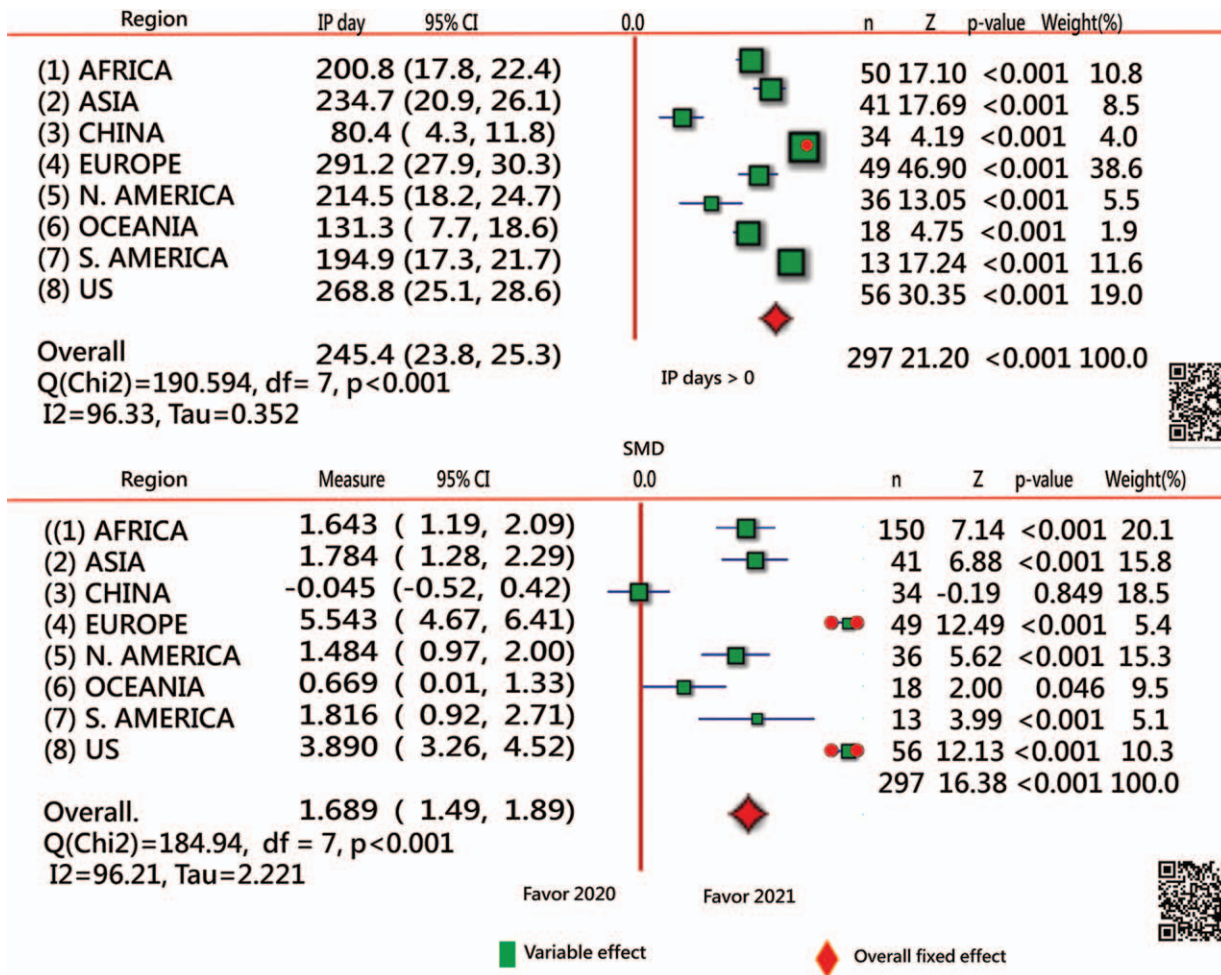


Figure 4. Comparisons of IP days on COVID-19 across regions between 2020 and 2021.

procured by wealthy countries by the end of 2020 were nano vaccines, this amounted to only 1 in 10 for middle-income countries and none for low-income countries,^[14,41] which meets out the finding that the CC is 0.66 ($t=12.21, P<.01$) between VD100 and GDP in countries/regions. As such, high-income countries, representing just one-fifth of the global adult population, have purchased more than half of all vaccine doses, resulting in disparities between adult population share and doses purchased for all other country income groups.^[42]

4.3. Implications and recommendations

Numerous mathematical COVID-19 models^[16,18,43–51] and IP determinations^[52–53] have been proposed in the literature. The IP search scheme was applied to this study because the IP to stand for the effective control of COVID-19 has been used in previous studies.^[16,17,55] Using the CNCC IP and deaths IP is recommended for future studies regarding epidemic pandemics, not just limited to COVID-19.

The forest plot was applied to compare the difference between two entities (e.g., 2020 and 2021) in Figure 4 using Equations (1) to (26). Over 5919 articles were searched by the keywords of RevMan and meta-analysis in PubMed as of June 22, 2021.^[56] It is worth noting that the SMD method using RevMan^[57] would be different in results from our study because of the statistics of

Hedgesg and variance in Equations (9) and (10) are neglected in RevMan. It should be cautious of the matter in the future.

The Kano diagram^[23,58] was applied to compare the association between two variables (e.g., shown in Fig. 5), different from those using the scatter plot in the literature.^[14,59–61] The unidimensional area in the middle part is unique in the Kano diagram that could be easily interpreted when compared to the scatter plot (e.g., the simple one in the study^[14]).

4.4. Strengths of the study

First, the IP of deaths applied as the indicator of effective containment of COVID-19 is modern and unique, different from the CNCC IP used in previous studies.^[16,17]

Second, MP4 videos and modules on how to search for IP days in an IRT-based model have been provided to ordinary readers who are familiar with Microsoft Excel and hope to replicate the study in the future.

Third, using the Microsoft Solver add-in to estimate the model parameters is a common approach that can be easily applied by researchers. Data and model-building videos are provided in Supplemental Digital Content 1, <http://links.lww.com/MD2/A853>.

Fourth, the choropleth and forest plot diagrams used in this study are able to provide comprehensive insights into the evolution of the COVID-19 pandemic in various countries/

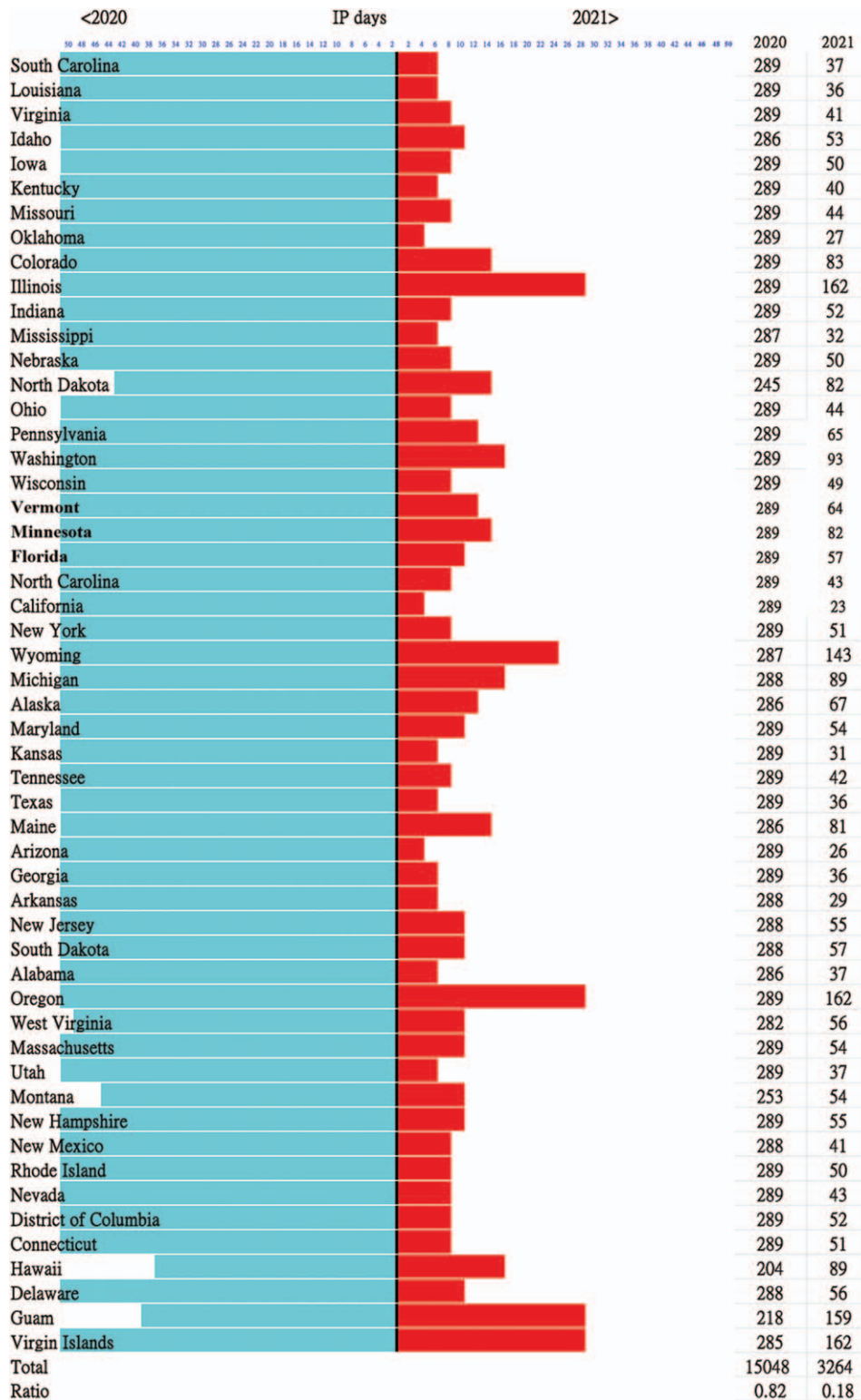


Figure 5. Comparison of IP days in US states between 2 years.

regions, which in turn can be used by policymakers and decision-makers.

Furthermore, a Microsoft Excel module for drawing the forest plot is provided. Readers are recommended to see the abstract video along with the Excel module presented in Supplemental Digital Content 1, <http://links.lww.com/MD2/A853>.

4.5. What this knowledge adds to what we knew

Our study identified the vaccine rollout rates associated with GDP and few deaths. Our findings are consistent with those done in the United States.^[62] As a result, enough people need to have access or be willing to receive the vaccine to achieve herd immunity.^[63] Nonetheless, previous literature has indicated

Table 1
Association between variables.

Variable	CNCCsIP	DeathsIP	VD100	GDP
CNCCsIP	2089.48	1687.85	-20.00	7440.45
DeathIP	0.73*	2621.10	-220.39	-84,099.29
VD100	-0.01	-0.15*	1097.33	424,947.06
GDP	0.01	-0.08	0.66*	378,839,613.07

Covariances in upper triangle, variances in diagonal, and correlation coefficients in bottom triangle.
* $P < .05$; $n = 195$.

disparities in vaccination rates between sociodemographic groups, and such factors play a substantial role in the likelihood of seeking vaccination (e.g., those with lower education and income levels^[64,65] and black individuals^[66] are less likely to get vaccinated). Some studies have used machine learning techniques to build predictive models for vaccination uptake levels for influenza^[67] and childhood immunizations.^[68]

Although the CNCC IP days in the US are pretty shorter in 2021 (shown in the bottom panel of Fig. 1), all other countries/regions, except China, have made improvements in CNCC IP days in 2021 as well. The reason for China's slight improvement in IP days is attributed to her IP days being obviously shorter in 2020 (shown in the top panel of Fig. 1), similar to the findings in previous studies.^[16,17] Readers might have doubts about whether China's strict epidemic prevention policy is more effective than vaccination. This might be true to most countries, including China, where the containment measures initiated by the government play an important role in the fight against COVID-19 pandemics (referred to Supplemental Digital Content

2, <http://links.lww.com/MD2/A854>), such as physical distancing, early detection, self-isolation, and outbreak control, which have been mentioned in previous studies.^[69-71]

The association is weak between vaccinations and CNCC IP based on the argument that vaccinations are limited to protection against milder infection.^[2] The spectrum of COVID-19 ranges from mild to critical.^[62] Although most individuals suffer from a mild form of the disease,^[72] more than half of the patients who died were admitted to the HDU and ICU,^[62] suffering from the critical form of illness. Similar reports of ICU mortality due to COVID-19 have been reported globally.^[73-75] The main cause of mortality in ICU patients suffering from critical forms of COVID-19 has been mainly attributed to diseases, including acute respiratory distress syndrome (ARDS),^[76,77] cardiovascular,^[78-80] thromboembolic,^[81,82] and neurologic complications.^[83] Vaccine-rollout rates to protect against death have been verified in studies.^[84-86]

4.6. What the findings imply and what should be changed?

Based on the findings of the vaccine rollout rates associated with GDP and few deaths and the methodologies used in this study, we shed some light on future relevant studies, such as

1. IP days^[52-54] can be determined using the Newton–Raphson Iteration Method^[87-89] to better the efficiency and effectiveness in searching IP,
2. the forest plot^[21] can make data clearly and easily understood when comparing the standardized mean difference (SMD) between two situations,

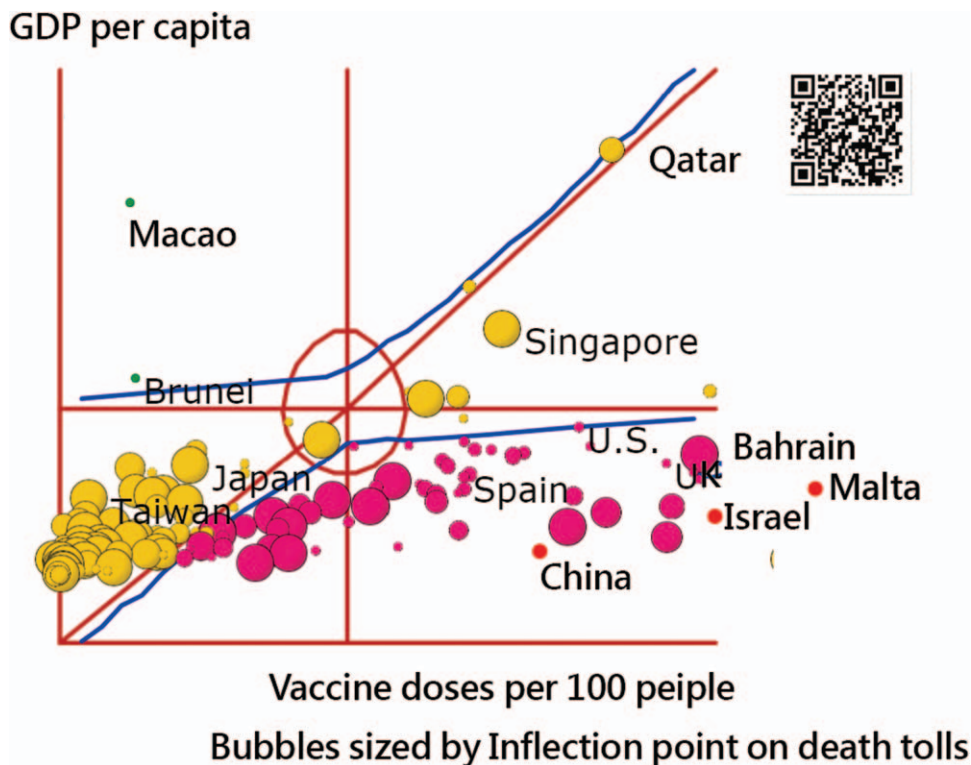


Figure 6. Vaccine doses administered per 100 people associated with income group classifications and inflection points on curves of COVID-19 death tolls in countries and regions.

Downloaded from <http://journals.lww.com/med-journal> by BIRDIMSEPHKAVI ZECUM TICNANAKJLHEZGISHO4XM10HCY WXCX1AWN YQPIIQRHID3I3D00DFR7VSEF14C3VCA4AAVDDA8KKGK10Y0MY+78= on 12/09/2024

3. the Kano diagram^[23,58] can be applied to compare the association between two variables (e.g., shown in Fig. 5, different from the traditional scatter plot,^[14,59–61]
4. the MP4 videos on how to conduct the study (offered in Supplemental Digital Content 1, <http://links.lww.com/MD2/A853>) can help researchers replicate the study on their own,
5. dashboards on Google Maps provide comprehensive insights into the elements of interest for readers.

4.7. Limitations and future studies

Our study has several limitations that should be mentioned. First, only the IP days were taken into account. Confirmed cases should be considered to denote the effective containment of COVID-19, such as the ipcase index used in the studies.^[16,17] Bias would occur in countries with identical IP days but different CNCCs.

Second, visual dashboards on Google Maps are not free of charge, and a paid project key for using the Google cloud platform is required. Thus, one limitation in using the dashboard is that it cannot be easily replicated by other authors or programmers for use in a short period of time.

Third, the case number is changeable and may vary day by day, particularly in countries undergoing second or third waves (peaks) in the ongoing pandemic. Thus, the comparison of IP days in 2020 and 2021 would also vary over time.

Fourth, the Microsoft Solver add-in is not a unique approach in estimating model parameters. Thus, many other methods and mathematical techniques should be used in making estimations and comparisons in the future.

Fifth, the effective containment of COVID-19 is attributable to vaccinations. Other measures of COVID-19, including physical distancing, early detection, self-isolation, and outbreak control, are also important preventive interventions.

Finally, virus variants are rapidly emerging. Only half of the year in 2021 was taken into account. Future studies should involve more months in comparison to IP days between years.

5. Conclusions

Our results indicate that vaccination has a significant effect on mitigating COVID-19 outbreaks, even with limited protection against infection, as the finding of a weak association with $CC = -0.01$ between CNCCs IP and VD100. Continued compliance with nonpharmaceutical interventions (e.g., continue wearing masks, cleaning our hands, ensuring good ventilation indoors, physically distancing, and avoiding crowds) is essential to the fight against COVID-19 in the future.

Acknowledgments

We thank Enago (www.enago.tw) for the English language review of this manuscript. All authors declare no conflicts of interest.

Author contributions

LY developed the study concept and design. TWC, JK, and WC analyzed and interpreted the data. WC monitored the process of this study and helped respond to the reviewers' advice and comments. TWC drafted the manuscript, and all authors provided critical revisions for important intellectual content.

The study was supervised by WC. All authors read and approved the final manuscript.

Conceptualization: Lin-Yen Wang.

Data curation: Lin-Yen Wang, Ju-Kuo Lin.

Investigation: Willy Chou.

Methodology: Tsair-Wei Chien.

References

- [1] Dong E, Du H, Gardner L. An interactive web-based dashboard to track COVID-19 in real-time. *Lancet Infect Dis* 2020;20:533–4. doi: 10.1016/S1473-3099(20)30120-1. Epub 2020 Feb 19. Erratum in: *Lancet Infect Dis*. 2020 Sep;20(9):e215. PMID: 32087114; PMCID: PMC7159018.
- [2] Moghadas SM, Vilches TN, Zhang K, Wells CR, Shoukat A, Singer BH, Meyers LA, Neuzil KM, Langley JM, Fitzpatrick MC, Galvani AP. The impact of vaccination on COVID-19 outbreaks in the United States. *medRxiv* [Preprint]. 2020 Nov 30;2020.11.27.20240051. doi: 10.1101/2020.11.27.20240051. Update in: *Clin Infect Dis*. 2021 Jan 30; PMID: 33269359; PMCID: PMC7709178
- [3] Huang B, Wang HY. [Analysis of the development trend and severity of the COVID-19 pandemic in the global world]. *Beijing Da Xue Xue Bao Yi Xue Ban* 2021;53:536–42. Chinese. PMID: 34145857.
- [4] WIKI. 2020 United States presidential election. 2020/11/8. Available at https://en.wikipedia.org/wiki/2020_United_States_presidential_election
- [5] BBC News. Covid: US President-elect Joe Biden gets vaccine live on TV. 2020/12/20. Available at <https://www.bbc.com/news/world-us-canada-55401706>
- [6] WhiteHouse. FACT SHEET: President Biden to Announce Goal to Administer at Least One Vaccine Shot to 70% of the U.S. Adult Population by July 4th. 2021/5/4. Available at <https://www.whitehouse.gov/briefing-room/statements-releases/2021/05/04/fact-sheet-president-biden-to-announce-goal-to-administer-at-least-one-vaccine-shot-to-70-of-the-u-s-adult-population-by-july-4th/>
- [7] Gavi The Gavi COVAX AMC: an investment opportunity. 2021/5/4. Available at <https://www.gavi.org/covax-facility>
- [8] Hodgson SH, Mansatta K, Mallett G, Harris V, Emary KRW, Pollard AJ. What defines an efficacious COVID-19 vaccine? A review of the challenges assessing the clinical efficacy of vaccines against SARS-CoV-2. *Lancet Infect Dis* 2021;21:e26–35.
- [9] Mahmoodpoor A, Sanaie S, Samadi P, Yousefi M, Nader ND. SARS-CoV-2: unique challenges of the virus and vaccines. *Immunol Invest* 2021;1–8.
- [10] Sheikh AB, Pal S, Javed N, Shekhar R. COVID-19 vaccination in developing nations: challenges and opportunities for innovation. *Infect Dis Rep* 2021;13:429–36.
- [11] Holder J. Where each vaccine is being used. 2021/5/4. Available at <https://www.nytimes.com/interactive/2021/world/covid-vaccinations-tracker.html>
- [12] Harris J. Combatting Covid-19. Or “All Persons Are Equal but Some Persons Are More Equal than Others?”. *Camb Q Health Ethics* 2021;30:406–14.
- [13] Holder J. aTracking Coronavirus Vaccinations Around the World. 2021/5/4. Available at <https://www.nytimes.com/interactive/2021/world/covid-vaccinations-tracker.html>
- [14] Mathieu E, Ritchie H, Ortiz-Ospina E, et al. A global database of COVID-19 vaccinations. *Nat Hum Behav* 2021;doi: 10.1038/s41562-021-01122-8.
- [15] Wiki Definition of an Inflection Point. 2021/6/11. Available at https://en.wikipedia.org/wiki/Inflection_point.
- [16] Wang LY, Chien TW, Chou W. Using the IPcase index with inflection points and the corresponding case numbers to identify the impact hit by COVID-19 in China: an observation study. *Int J Environ Res Public Health* 2021;18:1994.
- [17] Lee KW, Chien TW, Yeh YT, Chou W, Wang HY. An online time-to-event dashboard comparing the effective control of COVID-19 among continents using the inflection point on an ogive curve: observational study. *Medicine (Baltimore)* 2021;100:e24749.
- [18] Yu X, Qi G, Hu J. Analysis of second outbreak of COVID-19 after relaxation of control measures in India. *Nonlinear Dyn* 2020;10:1–19.
- [19] Worldbanklive. COVID-19: Vaccines for Developing Countries. 2021/6/11. Available at <https://live.worldbank.org/covid-19-vaccines-developing-countries>
- [20] Ourworldindata. COVID-19 vaccine doses administered by country income group. 2021/6/11. Available at <https://ourworldindata.org/covid-vaccinations>

- [21] Yan YH, Chien TW. The use of forest plot to identify article similarity and differences in characteristics between journals using medical subject headings terms: a protocol for bibliometric study. *Medicine* (Baltimore) 2021;100:e24610.
- [22] Liu MY, Chou W, Chien TW, Kuo SC, Yeh YT, Chou PH. Evaluating the research domain and achievement for a productive researcher who published 114 sole-author articles: a bibliometric analysis. *Medicine* (Baltimore) 2020;99:e20334.
- [23] Chou PH, Yeh YT, Kan WC, Chien TW, Kuo SC. Using Kano diagrams to display the most cited article types, affiliated countries, authors and MeSH terms on spinal surgery in recent 12 years. *Eur J Med Res* 2021;26:22.
- [24] Google Team 2019 Novel Coronavirus (nCoV) Data Repository. [(Accessed on June 19, 2021)]; Available online: <https://github.com/CSSEGISandData/2019-nCoV>.
- [25] GitHub. Study COVID-19 data. June 19, 2021. Available at <https://github.com/owid/covid-19-data/tree/master/public/data>
- [26] GitHub. Study vaccination data. June 9, 2021. Available at <https://github.com/owid/covid-19-data/tree/master/public/data/vaccinations>
- [27] Lord FM. Practical applications of item characteristic curve theory. *J Educ Meas* 1977;14:117–38.
- [28] Lord FM. Applications of item response theory to practical testing problems. Hillsdale, NJ: Lawrence Erlbaum Associates; 1980.
- [29] Chien TW, Wang HY, Hsu CF, Kuo SC. Choropleth map legend design for visualizing the most influential areas in article citation disparities: a bibliometric study. *Medicine* (Baltimore) 2019;98:e17527.
- [30] Chien TW. Figure 1 in this study. 2021/6/22. Available at <http://www.healthup.org.tw/gps/coviddtipdays2.htm>
- [31] Chien TW. Figure 2 in this study. 2021/6/22. Available at <http://www.healthup.org.tw/gps/coviddtipdays.htm>
- [32] Chien TW. Figure 3(top) in this study. 2021/6/22. Available at <http://www.healthup.org.tw/gps/covid20202021compare.htm>
- [33] Chien TW. Figure 3(bottom) in this study. 2021/6/22. Available at <http://www.healthup.org.tw/gps/covid20202021compare2.htm>
- [34] Chien TW. Figure 5 in this study. 2021/6/22. Available at <http://www.healthup.org.tw/gps/coviddtipvaccine2.htm>
- [35] Miles DK, Heald AH, Stedman M. How fast should social restrictions be eased in England as COVID-19 vaccinations are rolled out? *Int J Clin Pract* 2021;e14191.
- [36] Rosen B, Waitzberg R, Israeli A. Israel's rapid rollout of vaccinations for COVID-19. *Isr J Health Policy Res* 2021;10:6.
- [37] The Telegraph. Israel faces Covid surge as virus circulates even among vaccinated. 2021/6/21. Available at <https://www.telegraph.co.uk/news/2021/06/22/israel-faces-virus-surge-vaccinated-israelis-catch-covid-19/>
- [38] Williams D. Vaccinated Israelis may need to quarantine because of Delta variant. 2021/6/21. Available at <https://www.ctvnews.ca/health/coronavirus/vaccinated-israelis-may-need-to-quarantine-because-of-delta-variant-1.5482198>
- [39] The Times of Israel. Israel pushes vaccines for teens as fast-spreading Delta variant stokes fears. 2021/6/23. Available at <https://www.timesofisrael.com/israel-pushes-vaccine-for-teens-amid-fears-overfast-spreading-delta-variant/>
- [40] Arizonasports.NBA announces 1 positive COVID-19 test after Chris Paul enters protocols. 2021/6/22. Available at <https://arizonasports.com/story/2691397/nba-announces-1-positive-covid-19-test-chris-paul-enters-protocols/>
- [41] Uskoković V. Nanomedicine for the poor: a lost cause or an idea whose time has yet to come? *Nanomedicine* (Lond) 2021;16:1203–18.
- [42] Rouw A, Wexler A, Kates J, Michaud J. Global COVID-19 Vaccine Access: A Snapshot of Inequality. 2021/6/21. Available at <https://www.kff.org/policy-watch/global-covid-19-vaccine-access-snapshot-of-in-equality/>
- [43] Chatham WW. Treating Covid-19 at the inflection point. *J Rheumatol* 2020;47:1–10.
- [44] Gu C, Zhu J, Sun Y, Zhou K, Gu J. The inflection point about COVID-19 may have passed. *Sci Bull* 2020;65:865–7.
- [45] Fan RG, Wang YB, Luo M, Zhang YQ, Zhu CP. SEIR-Based COVID-19 transmission model, and inflection point prediction analysis. *Dianzi Keji Daxue Xuebao/J Univ Electron Sci Technol China* 2020;49doi:10.12178/1001-0548.9_2020029.
- [46] Jeong GH, Lee HJ, Lee J, et al. Effective Control of COVID-19 in South Korea: cross-sectional study of epidemiological data. *J Med Internet Res* 2020;22:e22103.
- [47] Wiki Definition of an Inflection Point. [(Accessed on 22 October 2020)]; Available online: https://en.wikipedia.org/wiki/Inflection_point.
- [48] Perc M, Miksić NG, Slavinec M, Stožer A. Forecasting COVID-19. *Front Phys* 2020;8:127.
- [49] Fang Y, Nie Y, Penny M. Transmission dynamics of the COVID-19 outbreak and effectiveness of government interventions: a data-driven analysis. *J Med Virol* 2020;92:645–59.
- [50] Wu JT, Leung K, Leung GM. Nowcasting and forecasting the potential domestic and international spread of the 2019-nCoV outbreak originating in Wuhan, China: a modeling study. *Lancet* 2020;395:689–97.
- [51] Anastassopoulou C, Russo L, Tsakris A, Siettos C. Data-based analysis, modeling and forecasting of the COVID-19 outbreak. *PLoS ONE* 2020;15:e0230405.
- [52] Chang CS, Yeh YT, Chien TW, Lin JJ, Cheng BW, Kuo SC. The computation of case fatality rate for novel coronavirus (COVID-19) based on Bayes theorem: an observational study. *Medicine* (Baltimore) 2020;99:e19925.
- [53] Lin C-H, Chou P-H, Chou W, Chien T-W. Using the Kano model to display the most cited authors and affiliated countries in schizophrenia research. *Schizophr Res* 2020;216:422–8.
- [54] Buan Q, Wu J, Wu G, Wang YG. Predication of inflection point and outbreak size of COVID-19 in new epicenters. *Nonlinear Dyn* 2020;101:1561–81.
- [55] Jeong GH, Lee HJ, Lee J, et al. Effective control of COVID-19 in South Korea: cross-sectional study of epidemiological data. *J Med Internet Res* 2020;22:e22103.
- [56] Chien TW. RevMan software mentioned in articles in Pubmed. 2021/6/23. Available at <https://pubmed.ncbi.nlm.nih.gov/?term=RevMan+and+meta-analysis+&sort=pubdate>
- [57] Cochrane Informatics and Knowledge Management Department. In: RevMan 5.3. 2014. Available from: <https://community.cochrane.org/help/tools-and-software/revman-5>. Accessed 9 July 2014.
- [58] Kano N, Seraku N, Takahashi F, Tsuji S. Attractive quality and must-be quality. *J Jpn Soc Quality Control* 1984;41:39–48.
- [59] Wang Y, Han F, Zhu L, Deussen O, Chen B. Line graph or scatter plot? Automatic selection of methods for visualizing trends in time series. *IEEE Trans Vis Comput Graph* 2018;24:1141–54.
- [60] Ho KM. Scatter plot and correlation coefficient. *Anaesth Intensive Care* 2012;40:730–1. PMID: 22813517.
- [61] Kamath C. A new approach to detect congestive heart failure using Teager energy nonlinear scatter plot of R-R interval series. *Med Eng Phys* 2012;34:841–8.
- [62] Cheong Q, Au-Yeung M, Quon S, Concepcion K, Kong JD. Predictive modeling of vaccination uptake in US counties: a machine learning-based approach. *J Med Internet Res* 2021;23:e33231.
- [63] Griffith J, Marani H, Monkman H. COVID-19 vaccine hesitancy in Canada: content analysis of tweets using the theoretical domains framework. *J Med Internet Res* 2021;23:e26874.
- [64] Callaghan T, Moghtaderi A, Lueck JA, et al. Correlates and disparities of intention to vaccinate against COVID-19. *Soc Sci Med* 2021;272:113638.
- [65] Fisher KA, Bloomstone SJ, Walder J, Crawford S, Fouayzi H, Mazor KM. Attitudes toward a potential SARS-CoV-2 vaccine: a survey of U.S. adults. *Ann Intern Med* 2020;173:964–73.
- [66] Uscher-Pines L, Maurer J, Harris KM. Racial and ethnic disparities in uptake and location of vaccination for H1N1 and seasonal influenza. *Am J Public Health* 2011;101:1252–5.
- [67] Shaham A, Chodick G, Shalev V, Yamin D. Personal and social patterns predict influenza vaccination decision. *BMC Public Health* 2020;20:222.
- [68] Mannion N. Predictions of changes in child immunization rates using an automated approach: USA. NORMA@NCL Library. 2020 Sep 28. Available at <http://norma.ncirl.ie./4368/1/niallmannion.pdf> [accessed 2021-12-3]
- [69] Chadsuthi S, Modchang C. Modeling the effectiveness of intervention strategies to control COVID-19 outbreaks and estimating healthcare demand in Germany. *Public Health Pract (Oxf)* 2021;2:100121.
- [70] Nakhaeizadeh M, Eybpoosh S, Jahani Y, et al. Impact of Non-pharmaceutical Interventions on the Control of COVID-19 in Iran: A Mathematical Modeling Study [published online ahead of print, 2021 Jun 9]. *Int J Health Policy Manag* 2021;doi:10.34172/ijhpm.2021.48.
- [71] Kucharski AJ, Klepac P, Conlan AJK, et al. Effectiveness of isolation, testing, contact tracing, and physical distancing on reducing transmission of SARS-CoV-2 in different settings: a mathematical modeling study. *Lancet Infect Dis* 2020;20:1151–60.
- [72] Poverty estimates for the U.S., States, and counties, 2019. US Department of Agriculture Economic Research Service. Available at <https://www.ers.usda.gov/data-products/county-level-data-sets/download-data/> [accessed 2021-11-19]

- [73] Bhatraju PK, Ghassemieh BJ, Nichols M, et al. Covid-19 in critically ill patients in the Seattle region—case series. *N Engl J Med* 2020; 382:2012–22.
- [74] Bayrak V, Senturk Durukan N, Demirer Aydemir F, et al. Risk factors associated with mortality in intensive care COVID-19 patients: the importance of chest CT score and intubation timing as risk factors. *Turk J Med Sci* 2021;51:1665–74.
- [75] Armstrong RA, Kane AD, Kursumovic E, Oglesby FC, Cook TM. Mortality in patients admitted to intensive care with COVID-19: an updated systematic review and meta-analysis of observational studies. *Anesthesia* 2021;76:537–48.
- [76] Richardson S, Hirsch JS, Narasimhan M, et al. Presenting characteristics, comorbidities, and outcomes among 5700 patients hospitalized with COVID-19 in the New York City Area. *JAMA* 2020;323:2052–9.
- [77] Onder G, Rezza G, Brusaferro S. Case-fatality rate and characteristics of patients dying in relation to COVID-19 in Italy. *JAMA* 2020;323:1775–6.
- [78] Cao J, Tu WJ, Cheng W, et al. Clinical features and short-term outcomes of 102 patients with coronavirus disease 2019 in Wuhan, China. *Clin Infect Dis* 2020;71:748–55.
- [79] Chen T, Wu D, Chen H, et al. Clinical characteristics of 113 deceased patients with coronavirus disease 2019: retrospective study. *BMJ* 2020;368:m1091.
- [80] Wang D, Hu B, Hu C, et al. Clinical characteristics of 138 hospitalized patients with 2019 novel coronavirus-infected pneumonia in Wuhan, China. *JAMA* 2020;323:1061–9.
- [81] Klok FA, Kruip M, van der Meer NJM, et al. Incidence of thrombotic complications in critically ill ICU patients with COVID-19. *Thromb Res* 2020;191:145–7.
- [82] Helms J, Tacquard C, Severac F, et al. High risk of thrombosis in patients with severe SARS-CoV-2 infection: a multicenter prospective cohort study. *Intensive Care Med* 2020;46:1089–98.
- [83] Liotta EM, Batra A, Clark JR, et al. Frequent neurologic manifestations and encephalopathy-associated morbidity in Covid-19 patients. *Ann Clin Transl Neurol* 2020;7:2221–30.
- [84] Heymann AD, Shapiro Y, Chodick G, et al. Reduced hospitalizations and death associated with influenza vaccination among patients with and without diabetes. *Diabetes Care* 2004;27:2581–4.
- [85] Johnson NB, Hayes LD, Brown K, Hoo EC, Ethier KA. Centers for Disease Control and Prevention (CDC) CDC National Health Report: leading causes of morbidity and mortality and associated behavioral risk and protective factors—United States, 2005–2013. *MMWR Suppl* 2014;63:3–27.
- [86] Roghani A. The influence of COVID-19 vaccination on daily cases, hospitalization, and death rate in Tennessee, United States: Case Study. *JMIRx Med* 2021;2:e29324.
- [87] Shao Y, Chien TW. The determination of inflection point on a given ogive curve using the item response theory (IRT) model. *J Bibliograph Anal Stat* 2021;18:31–3.
- [88] Linacre JM. Rasch estimation: iteration and convergence. *Rasch Measure Trans* 1987;1:7–8.
- [89] Shao Y, Nadkarni S, Niu K, Chien TW. Understanding of the Newton-Raphson Iteration Method in Rasch model. *J Bibliograph Anal Stat* 2021;18:71–6.