Assessing the global impact of COVID-19 vaccination

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Abstract

This study aims to statistically assess the effectiveness of vaccination against SARS-CoV-2. It is indispensable to investigate the association between COVID-19 deadliness and vaccination in order to study the impact of vaccine in real-world. The COVID-19 database 'Our World in Data' was analyzed on every three weeks interval. We studied rates of infection and death due to COVID-19 in different countries with respect to their level of vaccination. The estimation of risk of death was investigated using Case Fatality Ratio (CFR). People who received the required dose of vaccination were considered as fully vaccinated in this study. Based on the percentage of fully vaccinated population, countries were categorized into several groups. For the percentage of fully vaccinated population and COVID-19 CFR level, the coefficient of a linear trend line was calculated. During the investigation period, the countries were categorized into various bins of vaccination level and the average CFR of each bin was calculated in order to compare the change of COVID-19 CFR w.r.t vaccination levels.

Background and Methods

In this work, an exploratory data analysis of large-scale epidemiological data is carried out. Modern epidemiology entrusts investigations on massive volumes of complicated, but linkable, data to study diseases in various populations [1]. In the past, such research has yielded insights into disease causes and outcomes, improved therapeutic targets for precision medicine, and improved disease prediction and prevention. For example, the discovery of the association between a province's height and water level [2] and the street water pump [3] with the outbreak of Cholera in England in 1849, which aided in the development of disease prevention techniques to bring the Cholera pandemic under control.

The worldwide health disaster caused by the Novel Coronavirus epidemic in 2020 was the world's greatest challenge in a century. Clinical mitigating measures, including vaccination approval, were put in place. In some nations, a substantial proportion of the population is fully vaccinated, whilst in others, the proportion is lower. The disparities in health outcomes across groups based on vaccination level are required to assess the clinical measure's influence. Various scientists have used statistical modeling, which has resulted in some debates on the impact of vaccination. A survey showed that vaccine hesitation or refusal was associated with the belief that vaccine could be ineffective; the refusal probability increased among the responders with the growth of belief that the vaccine could be ineffective (Coef.: 0.4318) [13]. A study using German federal state's data focusing on age group above 80 years showed that an increase of 5 percentage points in vaccination coverage was associated with a 11% reduction in COVID-19 fatality in the 80 + age group [4]. Another discovery found a full dose of vaccination influences infection rate decrease and significantly reduces disease lethality [5].

'Our World in Data' is an open-source COVID-19 research data maintained by Ritchie H et al. [6] is a national level summary of everyday COVID events. This database has been used by numerous studies particularly to answer whether vaccination has a positive, negative or no impact in the COVID-19 pandemic. One such study focused on infection rates over a seven-day period preceding a certain day in September 2021 and the following seven days, found that the level of vaccination is ineffective in providing defense against the virus [8]. However, the Case Fatality Ratio was not investigated in this study. Another study that used 'Our World in Data' focusing on Asian countries—trained some deterministic machine learning models to fit the monthly averaged data of COVID-19 deaths and cases w.r.t total population who received vaccinations [12]. The best fitted model (Support Vector Regression) in [12] however had a low R-square value (0.2810) for death cases prediction based on vaccination level. In essence, none of the studies showed how the rate of death cases changes among countries as they crossed different level of vaccination. Our study aims to discern the effect of vaccination on the severity (Case Fatality Ratio) of COVID-19 infection across many countries. This population-level study on the vaccine effectiveness is imperative to infer the impact of vaccination as a control measure of the pandemic.

The publicly released database 'Our World in Data' [6] includes the number of COVID-19 confirmed cases, number of deaths, and vaccination doses that are given to people in numerous countries. The database gets updated on a day-to-day basis, albeit there are missing values. The missing values for confirm cases or death cases were filled with zero. On the other hand, if the vaccination level was missing, it was filled using forward filling method (using previous data). As the data of 91 countries were actively being updated during the investigation, we divided the 91 countries into eight bins based on the percentage of the population who received full dose of vaccination on November 1, 2021. Scientists stated that COVID-19 immunity typically develops after 2-3 weeks of getting the complete vaccine dose [9]. As a result, in this investigation, we used a six-week period to observe vaccinations, infections, and mortality caused by the Novel Coronavirus. ***Duration-1*** was the last 21 days of October 2021, while ***Duration-2*** was the first three weeks of November 2021. During the durations 1 and 2, the Delta variant was found to be present in an average of 97.32% to 98.28% of all nations [6]. We also investigated the generalizable association between vaccine level and COVID-19 lethality during the last three weeks of December 2021, ***duration-3***, when the Omicron strain was prevalent. The severity of the disease among different groups of vaccinated people was measured based on the risk of death per confirm case. The standard metric [10] Case Fatality Ratio (CFR) was determined as Eq. 1 based on total confirm deaths (*CD*) and total confirmed cases (*CC*) over a three-week period.

$$CFR = (\sum CD)/(\sum CC) \quad \text{..... (1)}$$

Despite the fact that there should be a delay between death cases and confirmed cases during an ongoing pandemic [10], this study used the most basic type of *CFR* computation.

Findings

Fig. 1 depicts a bar diagram based on whether a country's infection rate increased or decreased over *duration-2* as opposed to *duration-1*. The red bars reflect the number of countries where infection climbed, whereas the blue bars represent countries where infection declined.

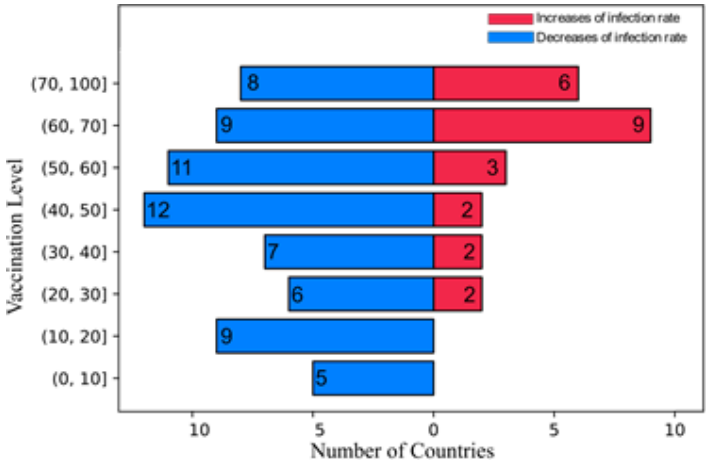

Fig. 1 Increases and decreases of new COVID cases during the observed period in 91 countries grouped by the vaccination level

Certainly, highly vaccinated countries (>60%) had more infection cases than less vaccinated countries (Fig. 1). This pattern suggests that the level of vaccination has little effect on the infection rate. This is also analogous with the finding reported by Subramanian et al. [8], who discovered that lesser vaccinated countries had minimal transmission. However, this conjecture represents just one aspect of vaccination effectiveness studies that could be refuted in a variety of ways. For example, the extent of testing differs across countries, with some having stringent testing procedures while others do not. Partial identification approaches also demonstrate that reported cases may be significantly underestimated in comparison to actual cases [7].

Based on the association between vaccination level and infection rate discussed thus far, we cannot obtain a complete picture of vaccinations' protective benefits against symptomatic infection and negative health outcomes. As a result, we focus on severity in countries classified by vaccination level in our study.

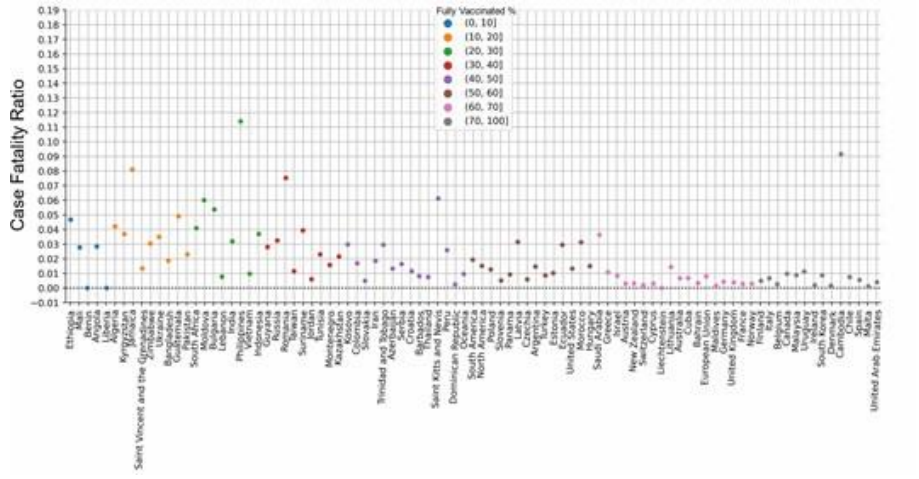

Fig. 2 Case fatality ratios (CFR) of different countries during first three weeks of November (*duration*-2)

CFR for each country in *duration*-2 is shown in Fig. 2. It depicts that CFR is relatively lower in the countries having higher vaccination levels. It means severity of COVID-19 was lower in higher vaccinated countries. The association between vaccination level and CFR is quantified by fitting a linear regression curve [11] in Fig. 3. It has been found that the coefficient of vaccination level on CFR was -0.0007. Furthermore, the regression model depicts that vaccination level has significant impact on CFR with

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an adjusted p-value<0.05. Majority of the countries having vaccination level above 65% were found case fatality ratio under 0.01. Accordingly, it is perceived that lower vaccinated countries experience more severeness of the infection than the higher vaccinated countries.

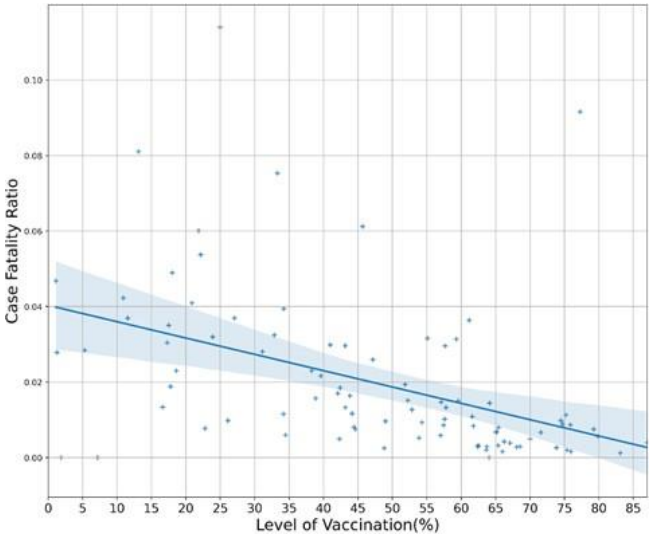

Fig. 3 Regression plot between vaccination level and CFR

To have the exact value of CFR, the death cases should be a subset of confirmed cases tracked over time [10]. However, because to the lack of such data, we used the total number of cases over the same time period to generate an overall estimate as a simplified form of CFR calculation.

To avoid selection bias of duration, we observed CFR throughout the last three weeks of December 2021, *duration-3*, and took the vaccination level on December 10, 2021 into account. The outcome is shown in Fig. 4. The downward trend of the CFR values for higher vaccinated group was observed here too.

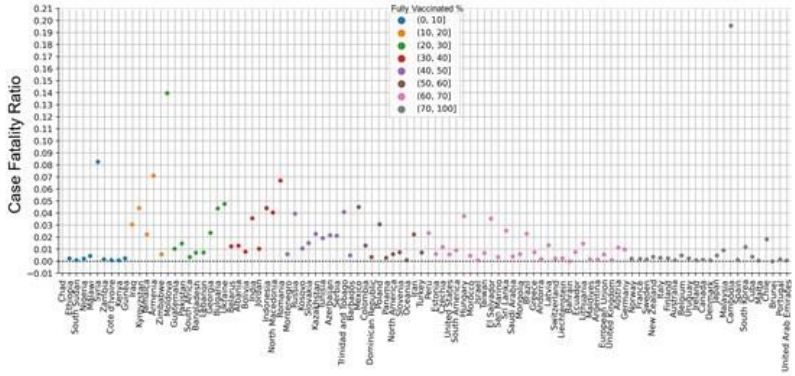

Fig. 4 *CFR*s of different countries at *duration*-3

According to Fig. 4, the United States, Ecuador, Morocco, Argentina, and numerous other countries with vaccination coverage of more than 60% had *CFR*s of less than 0.01 or 1 percent at duration-3, however they were observed with vaccination coverage of less than 60% and CFRs above 0.01 across *duration-2* (Fig-2). In the vaccine group (70-100], Cambodia was an exception. An in-depth case study of Cambodia's COVID-19 severity may explain the phenomenon.

We also applied linear regression on the data of *duration-3*, the outcome of which is presented in Fig. 5. The vaccination level *coefficient* on *CFR* was found -0.0004. This also shows the positive impact of vaccination.

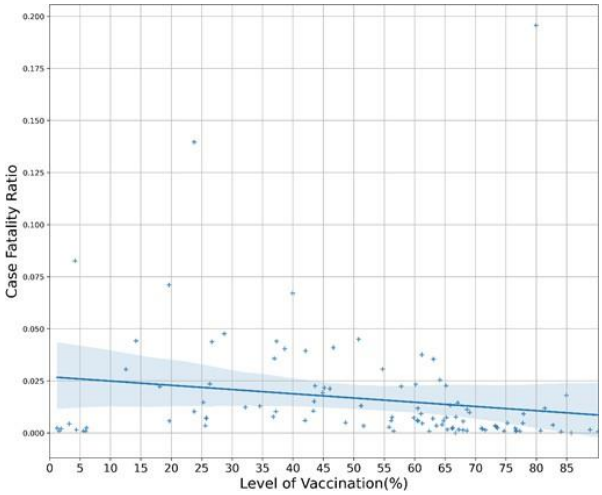

Fig. 5 Regression plot between vaccination level and CFR (*duration-3*)

Fig. 6 illustrates the mean CFR across *duration-2* and *duration-3* for different vaccination groups. For both durations, the observed mean *CFR*s were closely similar. As a whole, *CFR* is found to decrease with the level of vaccination with an exception for the case of the mean *CFR*s for the groups of vaccination level (0-10] and (70-100]. Such behavior of the data may be due to other factors including immunized by previous infection and expiration of the duration of immunization. Further studies may reveal more insights in this regard.

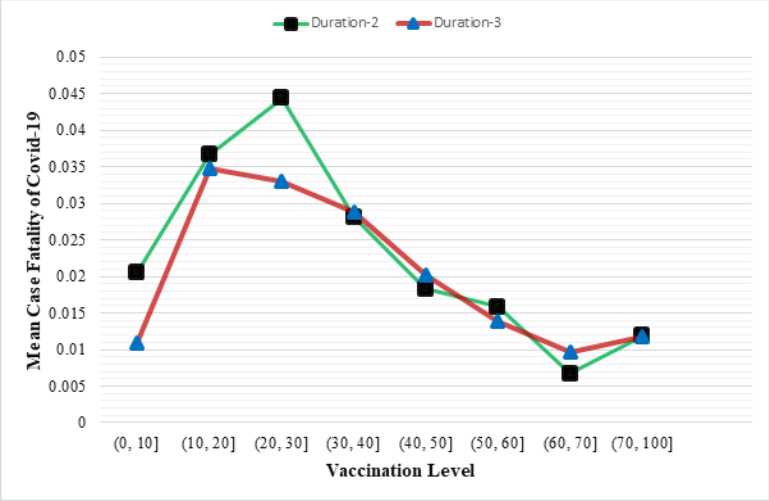

Fig. 6 Mean *CFR*s for two observed durations

Discussions

This study examined the effectiveness of the COVID-19 vaccination by examining worldwide epidemiological time series data. Specifically, we suggest that the effectiveness of the SARS-CoV-2 vaccination is better understandable based on the case fatality ratio (*CFR*). This discovery may help to reduce cynicism about vaccine effectiveness. Moreover, we compared the categorical vaccination level's average COVID-19 CFR level. Using SVM model, Rustagi et al. [12] concluded that death rate falls around 74.89% – 75.31% on getting fully vaccinated. In contrast, this study depicts that the CFR level does not decrease linearly w.r.t vaccination coverage. According to the findings of this study, countries with higher vaccination levels experience less severity of COVID-19 than countries with lower vaccination levels with

exceptions among extreme bins. The quantitative results provide information to formulate public health policies.

We argue that vaccinations may do a little to stop the spread of the SARS-CoV-2 virus since no correlation of the vaccination level of country is found with the rate of infections as found in [8]. However, the impact of vaccinating the population is significant in a country's case fatality ratio (*CFR*). Nonetheless, these results must be interpreted with caution and a number of limitations should be borne in mind. The data set did not offer the information on various kind of vaccines; hence, comparison between the efficiency of different vaccines, such as MRNA vaccines vs. Others, was not undertaken. Additionally, As the database does not contain unique patient data, this study could not perform analysis based on age groups as in [4]. Furthermore, various unobserved confounding factors could be addressed in future research.

Declarations

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- **Competing Interests**

The authors have no relevant financial or non-financial interests to disclose.

- **Conflicts of interests**

All authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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