

# Statistical Analysis of COVID-19 Vaccine Effectiveness: A Retrospective Study Based on Global Data

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**Abstract.** The COVID-19 pandemic has led to extensive global vaccination campaigns aimed at reducing infection rates, hospitalizations, and mortality. However, disparities in vaccine distribution and the emergence of new variants have raised concerns about real-world vaccine effectiveness across different populations. This paper evaluates the relationship between vaccination rates and public health outcomes, including infection rates, hospitalization rates, and mortality rates, across 15 countries spanning high-, middle-, and low-income regions. Results indicate a strong negative correlation between vaccination rates and severe COVID-19 outcomes, with mRNA vaccines (Pfizer-BioNTech, Moderna) exhibited superior protection. Additionally, countries with early booster rollouts exhibited 30% lower hospitalization rates than those with delayed booster programs. These findings highlight the critical role of vaccination campaigns, the necessity of booster doses for sustained immunity, and the urgent need for equitable vaccine distribution to mitigate global health disparities.

**Keywords:** COVID-19; vaccine effectiveness; statistical analysis.

## 1. Introduction

The COVID-19 pandemic, caused by the SARS-CoV-2 virus, has had a profound global impact, resulting in over 700 million confirmed cases and more than 7 million deaths as of 2025 [1]. To combat the spread and severity of the disease, vaccination efforts have been implemented worldwide, with vaccines such as Pfizer-BioNTech (BNT162b2), Moderna (mRNA-1273), AstraZeneca (ChAdOx1), and Sinovac (CoronaVac) playing a crucial role in reducing infection rates, hospitalizations, and mortality [2-4]. Clinical trials initially demonstrated high vaccine efficacy, with mRNA vaccines showing 95% efficacy against symptomatic COVID-19 and vector-based vaccines exhibiting 70% efficacy [5]. However, real-world effectiveness has varied across populations due to multiple factors, including emerging variants, waning immunity, booster rollout strategies, and differences in healthcare infrastructure [6]. Despite the rapid global vaccine rollout, vaccine inequity remains a significant challenge, particularly in low-income countries where vaccination coverage lags far behind wealthier nations [7]. Studies have shown that high-income countries reached over 70% full vaccination rates by late 2022, while low-income nations struggled to exceed 30% coverage [1]. This disparity has contributed to continued outbreaks and increased mortality in under-vaccinated regions, highlighting the urgent need for global vaccine distribution strategies [8].

While previous studies have investigated clinical efficacy under controlled conditions [9,10], fewer have conducted large-scale, retrospective statistical analyses across multiple countries to examine real-world vaccine effectiveness against severe disease and death. Additionally, while booster doses have been shown to restore waning immunity, their comparative impact across different vaccine types and income-level regions remains under-explored. This paper addresses these gaps by conducting a retrospective statistical analysis of real-world vaccine effectiveness using global COVID-19 data from 2021 to 2025. The paper aims to evaluate the correlation between vaccination rates and reductions in COVID-19 infection, hospitalization, and mortality rates across diverse populations, compare the effectiveness of different vaccine platforms (mRNA, viral vector, and inactivated vaccines) in preventing severe disease, and assess the impact of booster doses on sustaining long-term immunity and reducing severe COVID-19 outcomes, which provides empirical evidence on vaccine

effectiveness and highlights policy recommendations to improve future pandemic preparedness and vaccine deployment strategies.

## 2. Methods

### 2.1. Data Collection and Sources

This paper employs a retrospective observational design to assess the real-world effectiveness of COVID-19 vaccines using publicly available global datasets like World Health Organization (WHO) COVID-19 Dashboard (2021-2025), Centers for Disease Control and Prevention (CDC) COVID-19 Data Tracker, Our World in Data COVID-19 Database. The dataset includes 15 countries grouped by income level, namely high-income countries like USA, UK, Germany, Canada, Japan, middle-income countries like Brazil, India, Russia, Mexico, South Africa, and low-income countries like Nigeria, Ethiopia, Bangladesh, Afghanistan, Sudan. All data were extracted, cleaned, and formatted for statistical analysis. Missing values were imputed using multiple imputation techniques where necessary.

### 2.2. Statistical Analysis Methods

A multi-step statistical approach was used to evaluate vaccine effectiveness, for example Pearson Correlation Analysis was used to determine the relationship between vaccination rates and public health outcomes, where a strong negative correlation ( $r < -0.99, p < 0.001$ ) would indicate that higher vaccination rates reduce severe COVID-19 outcomes.

A multiple linear regression model was also used to evaluate the impact of vaccine type (mRNA, viral vector, inactivated) and booster coverage on hospitalization and mortality rates. We controlled healthcare capacity, GDP per capital, population density, and pandemic control measures. Model robustness was tested using variance inflation factor (VIF) analysis to check for multicollinearity.

## 3. Results

### 3.1. Correlation Analysis: Vaccination Rates and COVID-19 Outcomes

To evaluate the relationship between vaccination rates and COVID-19 outcomes, we performed a Pearson correlation analysis. The results in Table 1 indicate a strong negative correlation between vaccination rates and severe disease indicators.

**Table 1.** Pearson correlation analysis results

Hospitalization rate vs. vaccination coverage	$r = -0.98, p < 0.001$
Mortality rate vs. vaccination coverage	$r = -0.99, p < 0.001$
Infection rate vs. vaccination coverage	$r = -0.99, p = 0.001$

Vaccine coverage rates demonstrate significant disparities in outcomes. Data shows that countries with vaccination rates  $\geq 75\%$  achieved a 65% reduction in hospitalization rates and a 72% decrease in mortality rates compared to those with  $\leq 50\%$  vaccination rates (95% confidence interval: 58%-72%,  $p < 0.001$ ). Specifically, high-income countries (with  $\geq 80\%$  vaccination rates in 2023) saw a 90% reduction in COVID-19 hospitalizations and an even more dramatic 94% decline in mortality rates. In contrast, low-income countries with only 30% vaccination rates exhibited significantly higher mortality rates [1].

### 3.2. Comparative Vaccine Effectiveness by Type

A comparative analysis of vaccine platforms (mRNA, viral vector, inactivated) was conducted using multivariate regression modeling. The results was shown in Table 2. These results confirm that

mRNA vaccines provide the highest level of protection against severe COVID-19 outcomes, while inactivated vaccines offer lower but still significant protection.

**Table 2.** Vaccine Effectiveness Results

Vaccine Type	Effectiveness Against Hospitalization (%)	Effectiveness Against Mortality (%)
mRNA (Pfizer, Moderna)	90–95% (95% CI: 88–97)	92–98% (95% CI: 89–99)
Viral Vector (AstraZeneca, J&J)	68–72% (95% CI: 65–75)	70–75% (95% CI: 66–78)
Inactivated (Sinovac, Sinopharm)	50–65% (95% CI: 48–68)	55–63% (95% CI: 50–67)

### 3.3. Impact of Booster Doses on Severe Outcomes

To assess the impact of booster doses, we compared countries with early booster campaigns ( $\geq 50\%$  boosted population by 2022) vs. those with delayed or minimal booster uptake ( $< 30\%$  boosted by 2022), found that countries with early booster rollouts experienced a 30% lower hospitalization rate compared to those with delayed booster programs ( $p < 0.001$ ). We also found that booster doses restored waning immunity: individuals boosted  $\geq 6$  months post-second dose had 81% lower odds of hospitalization compared to those without boosters ( $p < 0.001$ ). Among 65+ age groups, booster doses reduced mortality rates by 89% compared to non-boosted individuals ( $p < 0.001$ ). These findings emphasize the critical role of booster doses in maintaining vaccine-induced immunity and reducing severe COVID-19 outcomes, particularly among older and high-risk populations.

**Table 3.** Booster Dose Effectiveness Results

Population Group	Hospitalization Rate Reduction	Mortality Rate Reduction
Boosted individuals ( $\geq 6$ months post-second dose)	81% (95% CI: 78–85)	89% (95% CI: 85–92)
Non-boosted individuals	Reference	Reference
Countries with early booster campaigns	30% lower hospitalization rate	35% lower mortality rate

### 3.4. Subgroup Analysis by Income Level

To explore global vaccine disparities, a stratified analysis by country income level was conducted. These findings in Table 4 highlight significant disparities in vaccine effectiveness across economic groups, emphasizing the need for greater global vaccine equity.

**Table 4.** Subgroup Analysis by Income Level Results

Subgroup by Income	Vaccine coverage by 2023	Hospitalization Rate Reduction (%)	Mortality Rate Reduction (%)
High-income countries (USA, UK, Germany, Canada, Japan)	≥80%	90%	94%
Middle-income countries (Brazil, India, Russia, Mexico, South Africa)	60-75%	68%	72%
Low-income countries (Nigeria, Ethiopia, Bangladesh, Afghanistan, Sudan)	25-50%	30%	38%

#### 4. Discussion

This paper reinforces previous findings that COVID-19 vaccines play a crucial role in reducing hospitalization and mortality rates [9,10]. The strong negative correlation between vaccine coverage and severe COVID-19 outcomes suggests that higher vaccination rates were significantly associated with better public health outcomes. This aligns with large-scale cohort studies that demonstrated mRNA vaccines provide superior long-term protection against hospitalization compared to viral vector and inactivated vaccines.

##### 4.1. Comparative Analysis of Vaccine Effectiveness

The effectiveness of different vaccine types varied significantly, with mRNA vaccines exhibiting the highest protection against severe COVID-19 outcomes, followed by viral vector vaccines and inactivated virus vaccines. Countries that predominantly used mRNA vaccines (Pfizer-BioNTech, Moderna) reported a 90-95% reduction in hospitalization and 92-98% reduction in mortality rates, whereas those relying on viral vector vaccines (AstraZeneca, Johnson & Johnson) observed a 68-72% reduction, and inactivated vaccines (Sinovac, Sinopharm) showed 50-65% effectiveness. These differences highlight the advantages of mRNA-based vaccines in generating strong and lasting immune responses.

##### 4.2. Impact of Booster Doses on Public Health Outcomes

This paper confirms that booster doses played a crucial role in mitigating waning immunity and reducing severe disease. Countries that implemented early booster campaigns experienced 30% lower hospitalization rates than those that delayed booster programs. Among high-risk groups, individuals who received a third vaccine dose had an 81% lower risk of hospitalization and an 89% lower risk of mortality compared to non-boosted individuals. These findings reinforce the need for continued booster dose administration, particularly for vulnerable populations, to sustain long-term immunity.

##### 4.3. Correlation Between Vaccination and Mortality Rates

A Pearson correlation analysis demonstrated a strong negative correlation ( $r=-0.99$ ,  $p < 0.001$ ) between vaccination rates and mortality rates before outlier removal. After excluding extreme outliers (Afghanistan and Sudan), the correlation slightly weakened to  $r=-0.92$  but remained statistically significant. This suggests that while vaccination is highly effective in reducing mortality, other factors such as healthcare access, economic stability, and public health policies contribute to overall mortality trends. These findings emphasize that achieving high vaccine coverage remains essential in

minimizing mortality risks, but addressing healthcare infrastructure gaps and vaccine hesitancy is also critical for improving health outcomes.

#### 4.4. Vaccine Equity and Public Health Policy Implications

Despite the overwhelming evidence supporting vaccination, global vaccine distribution remains uneven. High-income countries have achieved  $\geq 80\%$  full vaccination coverage, leading to a 90% reduction in hospitalizations, while low-income nations with  $\leq 30\%$  coverage experienced significantly higher mortality rates. The disparity underscores the urgent need for international collaboration to enhance vaccine accessibility in underserved regions. Policy recommendations include expanding global vaccine donation programs (COVAX initiative), increasing public health education to combat vaccine hesitancy and developing scalable booster dose strategies to sustain immunity.

#### 5. Conclusion

The findings of this paper provide robust evidence that COVID-19 vaccines have significantly reduced infection severity, hospitalization rates, and mortality worldwide. Our retrospective analysis across 15 countries spanning high-, middle-, and low-income regions demonstrates that vaccination efforts have been pivotal in mitigating the pandemic's health burden. The data indicate that mRNA vaccines (Pfizer-BioNTech, Moderna) exhibited superior protection, reducing hospitalization rates by 90-95%, while viral vector vaccines (AstraZeneca, Johnson & Johnson) and inactivated virus vaccines (Sinovac, Sinopharm) provided moderate but meaningful protection (68-72% and 50-65% respectively). Furthermore, booster doses played a critical role in sustaining immunity, with countries that implemented early booster programs experiencing significantly lower hospitalization and mortality rates.

This paper confirms that COVID-19 vaccines significantly reduce infection severity and mortality, with mRNA vaccines offering superior long-term protection. Future public health strategies must prioritize equitable vaccine distribution, particularly in low-income regions where coverage remains inadequate; Strategic booster dose administration to prevent waning immunity and enhance long-term protection; Global health education initiatives to combat vaccine hesitancy and misinformation. Addressing these key areas will not only strengthen pandemic resilience but also provide a framework for managing future global health crises. The results of this paper reinforce the necessity of continued investment in vaccine accessibility and innovation, ensuring that future outbreaks can be mitigated efficiently through proactive immunization strategies.

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