

# The COVID-19 Vaccine Coverage Rates Across the Continents and Their Correlation with COVID-19 Cases and Fatalities: An Examination After Ending the Global Emergency

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## ABSTRACT

**Objectives:** The Coronavirus Disease 2019 (COVID-19) vaccine coverage rates for various countries were analyzed to observe how the rates varied across continents as of May 6, 2023. We also aimed to determine their correlation with COVID-19 statistics (cases/fatalities/tests).

**Methods:** The "Our World in Data" website was searched to extract the vaccine coverage rates as of 1 July 2021, 1 January 2022, 1 January 2023, and 6 May 2023 for each country included in the study. Data on COVID-19 were obtained from the "Worldometer" website. Statistics were presented both cumulatively and yearly.

**Results:** This analysis included 180 countries. The analysis of variance test showed a statistically significant difference in the COVID-19 vaccine coverage rates and COVID-19 data, except for the Case-fatality rate (CFR), between continents, with Africa having the lowest. The Independent t-test showed that countries with 50% or higher vaccination coverage had higher rates of cases, deaths, and tests but a lower CFR in 2022, higher median age, and higher Gross Domestic Product. Similarly, in early 2023 (till May 5), there was a notable difference in the rate of cases and deaths. Furthermore, there was a clear positive correlation between vaccine coverage rates and all other data, except for CFRs, which had a negative correlation.

**Conclusions:** Inconsistencies in COVID-19 data, including vaccination coverage, across continents emphasize the importance of establishing uniform standards for identifying and diagnosing cases, ensuring fair vaccine distribution, and equipping all countries with essential diagnostic resources to prepare for future emergencies.

**Keywords:** Case-fatality, Median age, Pandemic, SARS-CoV-2, Tests

## INTRODUCTION

In December 2019, a series of pneumonia cases of unknown etiology emerged in Wuhan, China, with clinical presentations resembling viral pneumonia. The causative pathogen was recognized in January 2020<sup>1</sup>. Deep microbiological investigations indicated a novel coronavirus named severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2), whereas the infectious disease was called coronavirus disease 2019 (COVID-19)<sup>1</sup>. Because of the increased number of cases worldwide, the World Health Organization (WHO) announced COVID-19 as a pandemic on 11 March 2020<sup>2</sup>. Since that, COVID-19 has disrupted everyday life and has fundamentally changed the policies, priorities, and activities of individuals, organizations, and governments<sup>3</sup>. As with most viruses associated with respiratory illnesses, there is no effective antiviral treatment. Therefore, vaccination has been vital in fighting against this emerging virus. Remarkably, in less than a year since the onset of the COVID-19 pandemic, several different types of effective vaccines were successfully tested and made available for public emergency use by the WHO<sup>4</sup>.

The first COVID-19 vaccine outside the clinical trial was delivered in December 2020<sup>5</sup>, nearly a year after the first cases of COVID-19 were discovered. The equitable distribution of the vaccine worldwide has

been crucial in reducing the incidence of COVID-19. However, the process has not been without its challenges<sup>6</sup>. The pace of administering the vaccine has not been as hoped, especially for low-income countries<sup>6,7</sup>. To illustrate, by the end of 2021, only 48.81% of the global population had been fully vaccinated, with a significant disparity between high-income countries (69.35% fully vaccinated) and low-income countries (3.80% fully vaccinated)<sup>7</sup>. One study suggested that income disparity remains a fundamental cause of vaccine inequity, and the tendency toward vaccine nationalism constrains the global vaccine allocation framework<sup>8</sup>.

Recent research has linked COVID-19 vaccine coverage rates to several factors. Studies have found a negative association between the case-fatality rate (CFR) and vaccine coverage rates, as well as a positive correlation with the number of tests, tests per million, and cases per million<sup>9,10</sup>. Another study revealed that a COVID-19 vaccination policy with a coverage rate above 60% could effectively safeguard public health and well-being<sup>11</sup>. However, despite the incredible speed with which COVID-19 vaccines were developed in 2020 and began to be distributed in late 2020, 2021 was the worst year globally in terms of the number of deaths, while in 2022, the largest number of COVID-19 cases (which represented the number of positive tests) were recorded<sup>7,9</sup>.

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COVID-19 vaccination data can be found on the "Our World in Data" website, which is building the International COVID-19 Vaccination Dataset and is an open-source dataset for everyone. Additionally, the website "Worldometer" provides other updated data on COVID-19<sup>12</sup>. These data sets use the latest official numbers from governments and health authorities worldwide<sup>13</sup>. On May 5, 2023, the WHO declared COVID-19 is no longer a global health emergency; however, the WHO stresses that it remains a global health threat<sup>14</sup>. Moreover, understanding how the COVID-19 vaccine coverage rates varied across continents and their effects on the pandemic remains crucial. This could help researchers and decision-makers learn how to respond to public health emergencies more effectively.

Therefore, the purpose of this study was to use COVID-19 vaccine coverage rates for each country to examine the coverage rates across the continents at different dates, namely 1 July 2021, 1 January 2022, 1 July 2022, 1 January 2023, and 6 May 2023. We also aimed to determine their correlation with COVID-19 statistics in 2021, 2022, and early 2023 (up to May 5).

## METHODS

The "Our World in Data" website was searched to extract the COVID-19 vaccine coverage rates (percentage of people with a complete initial protocol: two doses) as of the first of July 2021, the first of January 2022, the first of July 2022, and the first of January 2023 for each country included in the study<sup>7</sup>. Only countries with data on vaccine coverage on the "Our World in Data" website were included. Countries with a population of less than 100,000 were excluded. The total number of vaccine booster doses (doses beyond those prescribed by the original vaccination protocol) administered, divided by the country's total population as of the first of January 2023 and the sixth of May 2023, was also obtained.

Data on COVID-19 were obtained from the "Worldometer" website<sup>12</sup>. Each country's data were obtained at the end of 2020, 2021, and 2022, as well as on May 6, 2023. These data consist of the cumulative incidence of COVID-19 (confirmed cases), the cumulative number of deaths, the total number of tests performed, the total number of cases per million population, the total number of deaths per million population, the total number of tests per population, and the total population. The CFR was calculated by dividing the number of deaths by the number of confirmed cases. Statistics were presented both cumulatively and yearly. In addition, each country's median age for 2021, which represents an average period for the three years 2020-2022, was extracted from the United Nations website<sup>15</sup>. The Gross Domestic Product (GDP) at Purchasing Power Parity per capita for each country (current international \$) was also obtained from the "World Bank" website<sup>16</sup>. To better compare COVID-19 vaccination across the continents, countries were classified by continent. Results were presented as numbers, percentages, rates, and means with standard deviation (SD) as appropriate.

Statistical analysis was done using Statistical Package for Social Sciences (SPSS, version 26). To assess the differences in the COVID-19 vaccine coverage rates and COVID-19 statistics by continent, the analysis of variance (ANOVA) test was utilized. The independent sample t-test was also used to assess the differences in cases per million, CFRs, deaths per million, and tests per population in 2022 and 2023 (up to May 5) between countries with less than 50% vaccine coverage rate and countries with 50% or more. When we look at the Independent Samples t Test results, Levene's Test was used to test the homogeneity of variances assumption. Suppose Levene's test indicates that the variances were not equal across the two groups (i.e.,  $p$ -value < .05),

we needed to rely on the second row of output (Equal variances not assumed). Furthermore, the Spearman correlation coefficient was used to determine the relationship between the vaccine coverage rates and other variables. A  $p$ -value of less than .05 was considered significant. Ethical approval from an Institutional Review Board was not required due to the secondary analysis of publicly available data.

## RESULTS

One hundred and eighty countries were included in this analysis. The ANOVA test showed a statistically significant difference in the COVID-19 vaccine coverage rates between continents (all  $p$ -value were .000), as presented in Table 1. Additionally, median age and GDP varied significantly amongst the continents. Table 2 further indicates a significant difference in the mean of cases per million, deaths per million, and tests per population across continents in 2021, 2022, and early 2023. According to both tables, Africa had the lowest averages (except CFR) among all continents.

Figure 1 illustrates the rates of cases per million, case fatality, deaths per million, and tests per population for each continent in 2020, 2021, and 2022. Except for Africa, the number of COVID-19 cases per million had steadily increased across all continents over the three years. The number of deaths per million was the highest in 2021, except in the continent of Oceania. Likewise, the number of tests per population in 2021 was the highest. The CFR in 2022 was the lowest. On the other hand, Table 3 shows COVID-19 statistics among the six continents from the first of January 2023 till the fifth of May 2023.

In Table 4, a comparison was made between countries with less than 50% vaccine coverage rate and those with 50% or more in terms of COVID-19 data in 2022 and early 2023, median age, and GDP. The results showed that in 2022, there were statistically significant differences in all means, with countries having less than 50% vaccine coverage rate having lower means, except for CFR. In early 2023, there were statistically significant differences in variances, except for CFRs and tests per population.

Table 5 shows a significant correlation between the COVID-19 vaccine coverage rates and all other variables, including COVID-19 data in 2022 and cumulatively as of May 6, 2023. The association was positive, except for CFRs, which showed a negative association.

## DISCUSSION

Approximately more than three years after the declaration of the COVID-19 pandemic by the WHO, precisely on May 5, 2023, an end to the state of emergency associated with the pandemic was announced. According to the Worldometer website, the total count of detected COVID-19 cases was 687,722,214, with 6,870,840 deaths attributed to SARS-CoV-2. Additionally, it was reported that 6,984,736,439 COVID-19 tests had been performed. However, in early 2023 (till May 5), COVID-19 cases represented only 3.36% of all reported cases, deaths accounted for 2.54%, and tests performed amounted to 1.85%. Various pharmaceutical companies had been striving to create a safe and effective vaccine to combat it. As a result, several vaccines became accessible by the end of 2020. However, by the end of 2022, vaccination rates remained low in many countries, with approximately 43% having a rate of less than 50% of their population fully vaccinated and only 26% having a booster vaccination rate of 50% or more. Moreover, the vaccine coverage rate has remained almost the same since the end of 2022. For instance, the percentage of people fully vaccinated worldwide was 63.25%; by May 6, 2023, it increased to around 64.28%<sup>7</sup>. There was also a significant disparity in vaccine coverage

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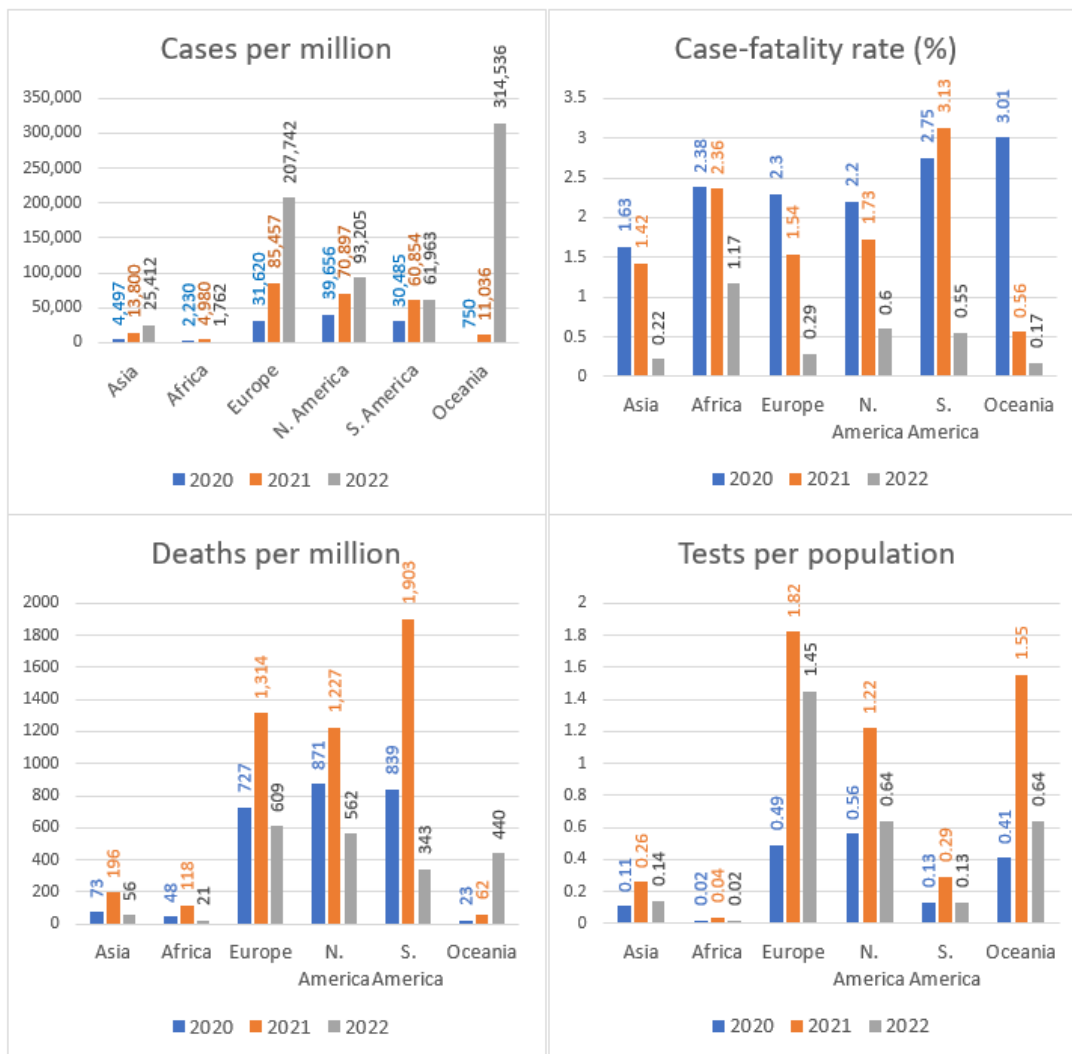


Figure 1: The rates of cases per million, case fatality (%), deaths per million, and tests per population for each continent in 2020, 2021, and 2022

Table 1: The COVID-19 vaccine coverage rates among the six continents

	Asia (N=48)	Africa (N=51)	Europe (N=39)	N. America (N=21)	S. America (N=12)	Oceania (N=9)	Sig.*	All (N=180)
Mean median age ±SD	29.41 ±7.51	19.60 ±4.52	41.32 ±2.55	31.43 ±6.22	29.36 ±3.71	25.00 ±7.00	.000	29.22 ±9.43
Mean booster vac.# as of 6/5/2023 ±SD#	40.07% ±31.78	6.98% ±9.81	46.34% ±28.24	28.77% ±23.94	50.80% ±42.02	30.81% ±26.99	.000	30.99% ±30.51
Mean booster vac. as of 1/1/2023 ±SD	39.67% ±30.57	5.64% ±9.53	46.06% ±28.45	26.44% ±24.15	49.17% ±41.09	28.90% ±27.38	.000	29.83% ±30.32
Mean vac. # as of 1/1/2023 ±SD	64.70% ±24.55	29.45% ±18.08	63.88% ±17.06	56.23% ±22.65	67.55% ±17.80	57.61% ±26.83	.000	53.36% ±25.62
Mean vac. as of 1/7/2022 ±SD	62.51% ±24.55	20.98% ±16.83	63.41% ±17.25	51.65% ±23.07	66.11% ±17.71	54.49% ±27.96	.000	49.43% ±27.48
Mean vac. as of 1/1/2022 ±SD	52.65% ±24.86	13.32% ±15.61	59.28% ±17.39	48.62% ±20.98	56.88% ±17.30	40.59% ±29.68	.000	42.22% ±27.39
Mean vac. as of 1/7/2021 ±SD	12.66% ±17.40	2.57% ±6.97	28.99% ±14.28	19.78% ±21.25	15.63% ±17.63	2.90% ±3.34	.000	14.01% ±17.46
Mean GDP# ±SD	27,742 ±27,107	5,696 ±5,625	45,368 ±24,517	22,471 ±17,221	18,108 ±5,966	15,420 ±20,711	.000	23,379 ±24,270

\*Analysis of variance (ANOVA) test: A p-value of < .05 is considered significant.

#Booster vac: The total number of vaccine booster doses (doses beyond those prescribed by the original vaccination protocol) administered, divided by the country's total population. SD: Standard deviation. Vac: The vaccination coverage rate (the percentage of people who complete the initial protocol). GDM: Gross Domestic Product at Purchasing Power Parity per capita (current international \$).

**Table 2:** COVID-19 data in 2021, 2022, and 2023 (till 6 May) among the six continents

	Asia (N=48)	Africa (N=51)	Europe (N=39)	N. America (N=21)	S. America (N=12)	Oceania (N=9)	Sig.*	All (N=180)
Mean cases/million in 2023 <sup>#</sup> ±SD <sup>‡</sup>	6,845 ±14,921	126 ±248	7,040 ±9,377	2,945 ±3,746	3,344 ±3,662	9,196 ±15,091	.003	4,413 ±9,976
Mean case-fatality rates in 2023 ±SD	3.75 ±18.54	0.94 ±2.60	2.17 ±2.23	0.91 ±0.96	1.18 ±1.21	0.50 ±0.39	.781	1.96 ±9.78
Mean deaths/million in 2023 ±SD	22 ±48	1 ±2.61	81 ±76	27 ±37	23 ±22	41 ±58	.000	30 ±55
Mean tests/pop. in 2023 ±SD	0.028 ±0.080	0.001 ±0.002	0.049 ±0.120	0.222 ±0.332	0.013 ±0.028	0.015 ±0.038	.000	0.046 ±0.150
Mean cases/million in 2022 ±SD	100,181 ±148,187	3,946 ±8,217	220,136 ±143,771	62,899 ±51,205	66,561 ±53,263	131,431 ±168,443	.000	93,876 ±133,902
Mean case-fatality rates in 2022 ±SD	0.66 ±1.48	1.02 ±1.38	0.50 ±0.48	0.66 ±0.46	0.61 ±0.24	0.40 ±0.38	.278	0.71 ±1.11
Mean deaths/million in 2022 ±SD	162 ±266	33 ±65	652 ±278	339 ±279	366 ±305	233 ±241	.000	270 ±325
Mean tests/pop. in 2022 ±SD	0.543 ±1.490	0.035 ±0.078	1.401 ±0.549	0.549 ±0.579	0.246 ±0.309	1.069 ±1.763	.000	0.594 ±1.383
Mean cases/million in 2021 ±SD	39,400 ±42,571	9,762 ±16,869	98,483 ±38,295	52,675 ±36,411	55,910 ±19,303	8,804 ±19,303	.000	44,923 ±46,362
Mean case-fatality rates in 2021 ±SD	1.74 ±2.59	2.23 ±1.50	1.56 ±1.25	2.14 ±1.48	3.51 ±3.20	2.24 ±5.44	.151	2.03 ±2.27
Mean deaths/million in 2021 ±SD	400 ±501	202 ±368	1,380 ±900	904 ±543	1,672 ±1,148	99 ±252	.000	685 ±821
Mean tests/pop. in 2021 ±SD	1.180 ±1.856	0.103 ±0.129	2.140 ±3.229	0.700 ±0.852	0.412 ±0.351	0.860 ±0.805	.001	0.594 ±1.383

\*Analysis of variance (ANOVA) test: A p-value of < .05 is considered significant.

<sup>#</sup>In the period from 1 January 2023 to 5 May 2023.

<sup>‡</sup>SD: Standard deviation.

**Table 3:** COVID-19 statistics among the six continents from the 1<sup>st</sup> of January 2023 to the 5<sup>th</sup> of May 2023

	Asia (N=48)	Africa (N=51)	Europe (N=39)	N. America* (N=21)	S. America (N=12)	Oceania (N=9)	All (N=180)
No. of cases	9,581,039 (41.93%)	70,854 (0.31%)	5,983,401 (26.19%)	4,934,769 (21.60%)	1,706,383 (7.47%)	573,860 (2.51%)	22,850,306
No. of deaths	32,692 (18.82%)	375 (0.21%)	72,688 (41.83%)	51,387 (29.57%)	12,603 (7.25%)	4,019 (2.31%)	173,764
CFR <sup>#</sup>	0.34%	0.53%	1.21%	1.04%	0.73%	0.70%	0.76%
C/M <sup>#</sup>	2,069	51	8,010	8,321	88,222	13,457	2,909
D/M <sup>#</sup>	7	0	97	87	321	94	22
No. of tests	59,073,517 (46.69%)	1,090,457 (0.86%)	22,632,638 (17.89%)	41,624,066 (32.90%)	2,989,578 (2.36%)	3,124,851 (2.47%)	126,515,130
Tests/pop.	0.013	0.001	0.030	0.070	0.007	0.073	0.016

\* North America includes Mexico and Caribbean countries.

<sup>#</sup>CFR: Case-fatality rate, C/M: The number of cases per million, D/M: The number of deaths per million.

rates across continents, with Africa having the lowest. Several studies have shown this to be the case<sup>8-10,17</sup>. Despite the emergency approval of several COVID-19 vaccines by the WHO, vaccine inequity continues to persist worldwide, especially in low-income countries<sup>10,17</sup>. This can be attributed to several factors, including the lack of effective global partnerships, vaccine supply chain logistics, concerns around vaccine safety and efficacy, vaccine apathy by populations, and inadequate government strategies<sup>18</sup>.

The current analysis revealed a significant correlation between the vaccine coverage rates and GDP, with richer countries generally having higher vaccination rates, which is consistent with other studies<sup>9,17</sup>. This could explain the relatively low vaccination rate in Africa, which is the poorest continent. The median age was also positively correlated with the vaccine coverage rates. Poverty is generally associated with a

higher fertility rate and, therefore, a lower median age<sup>19</sup>. Additionally, vaccination coverage was positively related to the number of tests per population, the number of cases per million, and the number of deaths per million both in 2022 and as of May 2023. Countries with more excellent vaccination coverage seem to have active COVID-19 testing programs and, therefore, more cases<sup>9</sup>. A previous study examining 191 countries worldwide showed that vaccination is directly proportional to the number of cases detected and negatively correlated to CFRs<sup>10</sup>. However, it is essential to note that these findings suggest an association rather than a causal relationship.

In 2022, there was a decline in COVID-19 mortality rates on all continents except Oceania. South America and Africa witnessed a significant drop in deaths per million, with 81.98% and 82.20%, respectively, even though Africa had the lowest vaccination rates.

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**Table 4:** Comparison of variance of means of COVID-19 data worldwide based on the vaccine coverage rates

	Booster vac.* coverage rate as of 01/01/2023			Full vac. coverage rate as of 01/01/2023			Full Vac. coverage rate as of 01/01/2022		
	<50%(N=133)	≥50% (N=47)	Sig.#	<50% (N=77)	≥50% (N=103)	Sig.	<50% (N=102)	≥50% (N=76)	Sig.
Mean median age ± SD*	26.85 ± 8.75	36.70 ± 7.03	.000	23.83 ± 8.53	33.26 ± 7.97	.000	24.45 ± 8.12	35.65 ± 6.92	.000
Mean C/M* in 2023 <sup>‡</sup> ± SD	1,509 ± 2,973	12,631 ± 16,386	.000	340 ± 2,240	7,009 ± 12,462	.000	1,039 ± 2,341	9,057 ± 13,866	.000
Mean CFR* in 2023 ± SD	2.17% ± 11.38	1.41% ± 2.15	.656	1.12% ± 2.33	2.56% ± 12.68	.348	1.12% ± 2.15	3.04% ± 14.48	.211
Mean D/M* in 2023 ± SD	14 ± 76	27 ± 82	.000	10 ± 17	46 ± 67	.000	11 ± 22	58 ± 72	.000
Mean T/P* in 2023 ± SD	0.038 ± 0.137	0.069 ± 0.170	.211	0.022 ± 0.087	0.063 ± 0.178	.045	0.027 ± 0.107	1.072 ± 0.186	.060
Mean C/M in 2022 ± SD	44,915 ± 72,924	232,425 ± 167,231	.000	26,824 ± 45,605	144,003 ± 154,669	.000	26,444 ± 43,575	182,865 ± 159,165	.000
Mean CFR in 2022 ± SD	0.86% ± 1.24	0.28% ± 0.31	.000	1.10% ± 1.55	0.42% ± 0.39	.000	0.96% ± 1.38	0.38% ± 0.41	.000
Mean D/M in 2022 ± SD	202 ± 280	460 ± 368	.000	174 ± 267	341 ± 346	.000	169 ± 267	407 ± 349	.000
Mean T/P in 2022 ± SD	0.28 ± 0.60	1.46 ± 2.30	.001	0.18 ± 0.42	0.90 ± 1.73	.000	0.17 ± 0.38	1.14 ± 1.92	.000
Mean GDP* ± SD	14,124 ± 13,187	50,113 ± 28,906	.000	9,302 ± 8,753	33,692 ± 26,739	.000	9,840 ± 8,880	40,270 ± 24,191	.000

\*Booster vac: The total number of vaccine booster doses (doses beyond those prescribed by the original vaccination protocol) administered, divided by the country's total population. SD: Standard deviation. C/M: The number of cases per million. CFR: Case-fatality rate. D/M: The number of deaths per million. The number of tests per population. GDM: Gross Domestic Product at Purchasing Power Parity per capita (current international \$).

#The Independent Samples t-Test: A p-value of < .05 is considered significant.

‡In the period from 1 January 2023 to 5 May 2023.

**Table 5:** Correlation between the COVID-19 vaccine coverage rates and other variables across the world

		Booster Vac.# as	Booster Vac. by	Vac.# by the end of	Vac. as of	Vac. by the end of	Vac. as of
		of 6 May 2023	the end of 2022	2022	1/7/2022	2021	1/7/2021
Median age	Pearson Correlation	.579**	.595**	.570**	.638**	.715**	.565**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000
	N	180	180	180	179	178	177
GDP#	Pearson Correlation	.637**	.657**	.607**	.664**	.728**	.602**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000
	N	175	175	175	174	173	172
C/M# as of 6 May 2023	Pearson Correlation	.566**	.591**	.526**	.571**	.658**	.655**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000
	N	180	180	180	179	178	177
CFRs# as of 6 May 2023	Pearson Correlation	-.293-**	-.299-**	-.371-**	-.380-**	-.362-**	-.261-**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000
	N	180	180	180	179	178	177
D/M# as of 6 May 2023	Pearson Correlation	.237**	.253**	.236**	.300**	.380**	.419**
	Sig. (2-tailed)	.001	.001	.001	.000	.000	.000
	N	180	180	180	179	178	177
T/P# as of 6 May 2023	Pearson Correlation	.380**	.408**	.410**	.433**	.461**	.462**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000
	N	174	174	174	173	172	171
C/M in 2022	Pearson Correlation	.597**	.617**	.506**	.545**	.604**	.527**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000
	N	180	180	180	179	178	177
CFRs in 2022	Pearson Correlation	-.258-**	-.270-**	-.370-**	-.350-**	-.340-**	-.234-**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.002
	N	180	180	180	179	178	177
D/M in 2022	Pearson Correlation	.422**	.438**	.320**	.382**	.443**	.478**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000
	N	180	180	180	179	178	177
T/P in 2022	Pearson Correlation	.315**	.338**	.358**	.375**	.383**	.369**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000
	N	174	174	174	173	172	171

\* Correlation is significant at the 0.05 level (2-tailed).

\*\* Correlation is significant at the 0.01 level (2-tailed).

#Booster vac: The total number of vaccine booster doses (doses beyond those prescribed by the original vaccination protocol) administered, divided by the country's total population. Vac: Vaccination coverage rate (the percentage of people who complete the initial protocol) by the end of the year indicated. GDM: Gross Domestic Product at Purchasing Power Parity per capita (current international \$). C/M: The number of cases per million. CFR: Case-fatality rate. D/M: The number of deaths per million. T/P: The number of tests per population.

Meanwhile, the CFRs decreased on every continent. In contrast, the number of cases increased in 2022 compared to 2021, except for Africa; Europe witnessed the largest increase in case rates, with a staggering 143%. Interestingly, the testing rate decreased despite the high number of cases in 2022. This could be because some countries, like China, had not updated their data<sup>9,20</sup>. Another reason is the high rate of positive results in 2022. The rate of positive COVID-19 tests might significantly change over time. For example, the percentage of positive tests in France in the first six months of 2020 was about 12%, but it declined in 2021 (4.8%); however, the percentage of positive tests in the first half of 2022 rose to 25%<sup>21</sup>.

The current study has also shown that countries with a vaccination coverage rate of 50% or more had a higher rate of COVID-19 cases, deaths, and tests in 2022 and early 2023 but a lower CFR. These countries also had a higher median age and GDP. It is worth noting that all African countries had a booster vaccine coverage rate of less than 50%; seven had a more than 50% vaccine coverage rate by the end of 2022, while only two achieved it by the end of 2021. In contrast, almost half of the European countries had more than a 50% booster vaccine coverage rate as of May 2023. A correlation analysis of 30 European countries showed that vaccines played a significant role in controlling COVID-19<sup>22</sup>.

In 2022, only six countries, namely Hong Kong, Greece, Chile, Croatia, Finland, and Bulgaria, recorded COVID-19 deaths over 1,000 per million. All these countries, except for Bulgaria, had vaccination coverage rates of more than 50%. The United States of America, the country with the most cases, deaths, and tests in the world, achieved a vaccination coverage rate at the end of 2021 of more than 50% (63%); however, in 2022, it recorded 810 deaths per million (among the worst 15 countries according to the number of deaths per million for the year 2022). Surprisingly, among the 71 countries that recorded less than 50 deaths per million in 2022, 43 were African. So, it is believed now that universal vaccination has become inappropriate for Africa<sup>23</sup>.

In the span of three years, from 2020 to 2022, 2021 was the worst year regarding the number of global deaths attributed to COVID-19, while in 2022, the highest number of cases was recorded. It is important to note that studies comparing outcomes before and after vaccination without a control group can be biased as changes may simply reflect natural regression to the mean (any changes in outcomes that might occur naturally in the absence of the intervention)<sup>24</sup>. Additionally, population data may not accurately measure vaccine effects due to ignored confounders like natural immunity and seasonal effects. Some research suggests that natural immunity from prior infection may be superior and longer-lasting than vaccine-induced immunity<sup>25</sup>. Given the high rate of asymptomatic SARS-CoV-2-infected individuals<sup>26</sup>, it is estimated that the rate of previous infection with SARS-CoV-2 exceeds the incidence of reported cases by about tenfold or more<sup>27</sup>. Therefore, at least 2.8 billion infections with SARS-CoV-2 are estimated to have occurred by the end of 2021. This could provide a reasonable explanation as to why the low mortality of COVID-19 occurred in 2022.

Furthermore, SARS-CoV-2, like other viruses, undergoes mutations; however, most of these mutations do not affect viral function. Specific variants have received widespread attention due to their rapid emergence, clinical implications, or possible effect on vaccine effectiveness<sup>28</sup>. Moreover, COVID-19 data vary significantly and over time worldwide, leading to uncertainty regarding the exact figures. There is no agreed-upon international standard for the definition of suspected cases or when to consider the COVID-19 test positive<sup>29</sup>. The challenges related to poor testing and underreporting could further

complicate the situation. The availability of testing is crucial for detecting COVID-19 cases and attributing deaths to SARS-CoV-2, but this varies across countries, with some relying on clinical recording methods<sup>30</sup>. In contrast, others could not do a sufficient number of tests<sup>9</sup>. As a result, analyzing population data to measure the impact of COVID-19 vaccines is not straightforward and may produce different and potentially conflicting results. While several observational studies indicate that the vaccine reduces the burden of COVID-19, caution should be exercised when interpreting the data.

Finally, looking ahead, learning from the COVID-19 pandemic is crucial to prepare for future epidemics. Standardizing criteria for defining and diagnosing cases, ensuring fair vaccine distribution, and fair providing all nations with the necessary diagnostic tools are among the most critical lessons.

This study offers an up-to-date report on global COVID-19 statistics, including the vaccine coverage rates. However, it is essential to note that this study has certain limitations, primarily due to the varying quality of the raw data obtained. Some countries may not have reported COVID-19 data at the same frequency or with the same level of accuracy.

## CONCLUSIONS

**COVID-19 statistics and the vaccine coverage rates across the continents have been inconsistent. By the end of 2022, the average vaccine coverage rate for the 180 countries included in this study was 53.36%; by continent, the rates ranged from 67.55% in South America to 29.45% in Africa. The average booster vaccine coverage globally was 29.83%; the lowest rate was seen in Africa. However, Africa has been the least affected continent by COVID-19. Globally, countries with 50% or more vaccination coverage had higher rates of cases, deaths, and tests but a lower CFR in 2022, a higher median age, and higher GDP. Nevertheless, analyzing vaccine impact based on population data is complex and requires caution to avoid discrepancies.**

**To prepare for future pandemics, it is essential to set standard criteria for defining and diagnosing cases, ensure fair distribution of vaccines, if available, and equip all countries with necessary diagnostic resources.**

**Authorship Contribution:** *All authors share equal effort contribution towards (1) substantial contributions to conception and design, acquisition, analysis and interpretation of data; (2) drafting the article and revising it critically for important intellectual content; and (3) final approval of the manuscript version to be published. Yes.*

**Data and Materials Availability:** The data supporting this study's findings are available from the corresponding author upon reasonable request.

**The Institution at the Time Authors did the Study and to Which the Work is Credited:** The same as mentioned above (Qassim University).

**Previous Presentation of the Paper in Scientific Meetings:** None.

**Funding:** This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

**Potential Conflict of Interest:** None

**Competing Interest:** None.

**Informed Consent:** Not applicable due to the secondary analysis of publicly available data.

**Acceptance Date:** 12 June 2023

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