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Review Article

Impact of SARS-CoV-2 vaccinations on pandemic dynamics: Trends in cases, deaths, and fatality risks

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Abstract

Despite the decrease in COVID-19 testing and reporting new infections, the numbers of new cases and deaths per capita registered in some European countries and USA in September 2024 were higher than endemic limits and exceeded seasonal flu mortality. These facts make the development of new vaccines or the further use of existing ones very urgent. The averaged daily numbers of cases *DCC* and death *DDC* per million, case fatality risks *CFR=DDC/DCC* in 2020-2024 calculated for 34 countries and regions were used to investigate the trends versus vaccination levels. These trends together with the published before results of statistical analysis show that existing vaccines cannot reduce the number of new COVID-19 cases and deaths, i.e. vaccinations reduced severity but not transmission. Therefore, it is still necessary to avoid close contacts and crowded places, trace and isolate infected people, wear masks in transport and medical facilities, wash hands more often, etc. Nevertheless, vaccinations and boosters can be recommended in order to reduce the severity of SARS-CoV-2 disease and probability of dying for infected individuals *(CFR)*. Recent epidemic waves can probably be controlled with the use of the immediate and sufficient increase of the number of tests.

Keywords: COVID-19 pandemic dynamics, Vaccinations, Daily numbers of cases and deaths per capita, Case fatality risk, Statistical methods

Introduction

The gradual loss of interest in SARS-CoV-2 infection (already in August 2023 61% of countries have stopped reporting new cases to WHO,[1]) does not negate the need for further research into the disease, in particular, important questions have to be answered:

1. Is SARS-CoV-2 infection still a significant public health threat?
2. How effective were the strategies employed to combat the pandemic?
3. Should vaccination campaigns against SARS-CoV-2 continue?

Due to further reductions in testing (almost all countries have stopped updating corresponding information already in 2022, [2]), the analysis of disease risks in 2024 is much more complex than in 2023, [3], when the high fatality rates were within the range of estimates for the endemic stage of the disease [4] and in some countries exceeded the mortality of seasonal influenza [3,5]. In 2024 the global average daily numbers of new COVID-19 cases (confirmed and reported to WHO) varied between

4.5K to 40K, [6] and are much lower than the lower endemic limit (300K, [4]). In particular, during 28 days to 29 September 2024, the global number 314,895 of confirmed new COVID-19 cases was reported**,** [6]. Since 301,397 cases (96%) were detected in the WHO European region with population 929 million, [7], we can calculate the average daily numbers of new cases per million *DCC*= 301397/ (28*929)=11.6. This value is much closer to the lower endemic limit DCC^* = 37.2, [3]. In some European countries corresponding *DCC* values (calculated with the use of numbers of cases reported during 28 days to 29 September 2024, [6] and corresponding volumes of populations, [8]) were higher than this limit: Croatia (107.4), Moldova (60.5) and Poland (44.3). Moreover, the figure for Lithuania (*DCC*=200.5) exceeds the upper endemic limit DCC^{**} = 124.1, [3].

In September 2024 the global average daily number of COVID-19 related deaths per million *DDC*=0.021=4862/ (28*8200) (calculated with the use of information available in [6,8]) was also much smaller than the lower endemic limit DDC^* = 0.124 [3,4]. Nevertheless, the figure for Moldova *DDC*=0.31=22/ (28*2.539) exceeded this limit and corresponding values for USA 0.43=4000/ (28*333.3) and Sweden 0.72=210/ (28*10.49) exceed even the upper endemic limit DDC^{**} =0.409, and the maximum flu mortality $DDC^{**}_{(flu)}$ =0.18, [3,5]. High mortality rates make the development of new vaccines or the further use of existing ones very urgent.

Due to rather large numbers of new COVID-19 cases, it is necessary to improve the methods of controlling the spread of infections, [9-26]. In particular, the experience of Zero-COVID countries [27] that in 2020 and 2021 practiced the policy of maximally reducing the number of cases due to lockdowns, closing borders, tracing, high testing levels, etc., requires further research. Increasing the test per case ratio looks quite promising, since many tested and isolated people in the environment of the detected infected person may slow down the further spread of the infection, [16,24,26]. In particular, a simultaneous increase in testing after the start of an increase in daily numbers of COVID-19 cases allowed New Zealand to stop the pandemic waves in 2020 and 2021, [26].

In this study we focus on the impact of vaccination levels (the percentages of fully vaccinated people *VC* and boosters *BC*) on the COVID-19 pandemic dynamics. Some optimistic results about "the effectiveness of the vaccination on reducing the transmission of SARS-CoV-2" in Israel were published in [28] with the use of statistical data from 28 August 2020 to 24 February 2021. The belief that vaccinated people do not spread the infection resulted in the policy of relaxing quarantine restrictions for them and introducing special passports in many European countries. Nevertheless, high level of vaccinations in Israel (VC was around 60%) did not prevent a new pandemic wave in June-August 2021 with huge daily numbers of cases (*DCC*) and deaths (*DDC*), [29]. The same situation occurred in Qatar in March-April 2021 at *VC* values around 50%, [30], in Japan in July-August 2022 (*VC*>82%, *BC*=68% - 87%), [26,31], in New Zealand, which already at the end of 2021 reached the values *VC*=74.4% and *BC*=6.9%; nevertheless, the huge increase in the number of cases occurred (12 thousand in 2021 and 2 million in 2022), and many other countries, [26]. Moreover, the statistical analysis of *DCC* and *DDC* values in 34 countries and regions in 2022 and 2023 demonstrated increasing trends with the increase of vaccination levels *VC* and *BC*, [32]. Even after taking into account differences in population ages no decreasing trends were revealed, [32]. Nevertheless, the case fatality risk *CFR=DDC/DCC* demonstrated the decreasing trends at higher levels of vaccinations, [32].

To support these very important facts we will perform a systematic analysis of *DCC*, *DDC,* and *DDC/DCC* trends in 34 countries and regions in 2020, 2021, 2022, and 2023 versus *VC* and *BC* values.

Materials and Methods

We will use the accumulated numbers of laboratory-confirmed COVID-19 cases CC_i and deaths DC_i per million, accumulated numbers of fully vaccinated people VC_i and boosters BC_i per hundred for 33 countries (shown in **Table 1**) and the world (i =1, 2,.., 34) listed in COVID-19 Data Repository by the Centre for Systems Science and Engineering (CSSE) at Johns Hopkins University (JHU), [2] (version of file updated on September 28, 2023). We have chosen the countries with highest numbers of accumulated cases and death (according to the WHO report [1]), some other countries and regions, [32].

To calculate the average daily numbers of cases *DCC* and deaths *DDC* per million, we will use simple formulas:

$$DCC_i^{(j)} = \frac{CC_i^{(j+1)} - CC_i^{(j)}}{T_i^{(j)}}; \quad i = 1,2,..,34; \quad j = -1,0,1,2\,; \quad (1)$$

$$DDC_i^{(j)} = \frac{DC_i^{(j+1)} - DC_i^{(j)}}{T_i^{(j)}}; \quad i = 1,2,..,34; \quad j = -1,0,1,2\,. \quad (2)$$

Values of the upper index *j*=-1, 0, 1, 2 correspond to 2020, 2021, 2022, and 2023, respectively; $CC_i^{(-1)} = 0;\ DC_i^{(-1)} = 0,$ $i = 1,2,..,34$. For 2021 and 2022 we will use the number of cases and deaths accumulated during these years and the number of days $T_i^{(0)} = T_i^{(1)} = 365, \quad i = 1,2,..,34$; for 2023 - the number of cases and deaths accumulated from 1 January to 10 September and the corresponding number of days $T_i^{(2)} = 252, \quad i = 1,2,..,34$. For 2020 we will use the number of cases and deaths accumulated in this year and different numbers of days $T_i^{(-1)}, \quad i = 1,2,..,34$, according to the appearances of the first COVID-19 cases **(Table 1)**.

The averages values of the case fatality risks corresponding to different years can be calculated with the use of the formula:

$$CFR_i^{(j)} = \frac{DDC_i^{(j)}}{DCC_i^{(j)}}; \quad i = 1,2,..,34; \quad j = -1,0,1,2\,. \quad (3)$$

Values $DCC_i^{(j)};\ DDC_i^{(j)}$ and $CFR_i^{(j)}; i = 1,2,..,34; j = 1,2$ corresponding to 2022 and 2023 were calculated in [32]. We will use them together with the values corresponding to 2020 and 2021 to analyze the trends versus percentages of vaccinations $VC_i^{(j)}$ and $BC_i^{(j)}; i = 1,2,..,34; j = 1,2$ accumulated as of 1 July in a corresponding year. Values $VC_i^{(0)}$ are listed in (**Table 1**), figures $VC_i^{(j)}$ and $BC_i^{(j)}; i = 1,2,..,34; j = 1,2$ are available in [32]. The lack of systematic data for 2024 does not allow us to extend our analysis to this year as well.

Table 1. Accumulated numbers of cases and COVID-19 related deaths and vaccination levels (according to [2]).

No., i	Country, region	Accumulated numbers of cases per million as of 31 December 2020, $CC_i^{(0)}$	Accumulated numbers of deaths per million as of 31 December 2020, $DC_i^{(0)}$	Days in 2020 when the fist COVID-19 were registered	Duration of the epidemic in 2020. days, $T_i^{(-1)}$	Percentages of fully vaccinated people as of 1 July 2021, $VC_i^{(0)}$
1	USA	57872.22	1040.54	Jan 20	347	49.44
2	Taiwan*	33.44	0.293	Jan 22	345	0.18
3	Hong Kong*	1181.221	19.763	Jan 23	344	19.97
4	India	7244.474	104.954	Jan 30	337	4.17
5	France	36181.03	983.093	Jan 26	341	31.96
6	Germany	19913.41	563.861	Jan 04	363	38.16
7	Brazil	35128.09	894.886	Feb 27	309	12.52
8	South Korea	1171.882	17.369	Jan 19	348	9.92
9	Japan	1858.014	27.543	Jan 14	353	15.39
10	Italy	35294.35	1246.734	Jan 31	336	32.69
11	UK	37973.65	1382.291	Feb 01	335	49.24
12	Turkey	25711.74	241.876	March 12	295	17.97
13	Mexico	11733.48	1157.79	Feb 21	315	15.44
14	Peru	29677.19	2733.249	March 06	301	9.85
15	Iran	13763.36	622.187	Feb 21	315	1.85[1]
16	Indonesia	2697.62	80.355	March 02	305	4.95
17	Canada	14705.86	397.198	Jan 26	341	31.76
18	South Africa	17350.04	468.044	March 06	301	2.09[2]
19	Egypt	1231.137	68.258	Feb 16	320	0.7[3]
20	Israel	44413.27	353.053	Feb 13	323	55.08
21	Nigeria	396.154	5.848	Feb 29	307	0.53[4]
22	Australia	1084.179	35.145	Jan 25	342	6.59
23	New Zealand	348.486	4.821	Feb 28	308	8.99
24	Vietnam	14.829	0.356	Jan 25	342	0.21
25	European Union	33290.24	859.54	Jan 04	363	33.77
26	Europe	31188.88	776.686	Jan 04	363	28.15
27	Africa	1925.97	45.595	Feb 16	320	1.1
28	Asia	4342.447	71.142	Jan 04	363	3.45
29	North America	37812.13	892.957	Jan 20	347	33.94
30	South America	29989.63	961.637	Feb 27	309	13.1
31	High income countries	32709.37	711.797	Jan 04	363	33.61
32	Upper middle income countries	9494.427	283.802	Jan 04	363	4.69
33	Lower middle income countries	4953.355	92.966	Jan 23	344	3.25
34	The world	10323.98	242.848	Jan 04	363	8.17

* Data from the JHU file corresponding to 1 January 2023, [2]

Figures corresponding to different days: 1 – 2021-06-29; 2 – 2021-07-08; 3 – 2021-06-28; 4 – 2021-06-28.

Results and Discussion

The results of calculations for values corresponding to 2020 and 2021 with the use of formulas (1)-(3) are listed in **(Table 2)** and used in **(Figures 1-3)** (together with the values corresponding to 2022 and 2023 presented in [32]) to show trends versus vaccination levels *VC* for *DCC, DDC* and *CFR*, respectively. Since the *VC* significantly increased in 2021 and 2022, lines between second and third marker (from left to right) represent the main trends versus vaccination levels. The influence of boosters can be illustrated by figures corresponding to 2022 and 2023. Unfortunately, significant decrease in testing levels led to abrupt decrease in *DCC* and *DDC* values in 2023 (see third and fourth markers in (**Figures 1 and 2)** and [32]). This fact makes our analysis of trends versus *BC* impossible.

Table 2. Calculated values of average daily numbers of cases and deaths, case fatality risks (according to formulae (1)-(3)).

No., i	Country, region	Average daily numbers of cases		Average daily numbers of deaths		Case fatality riscs	
		In 2020 $DCC_i^{(-1)}$	In 2021 $DCC_i^{(0)}$	In 2020 $DDC_i^{(-1)}$	In 2021 $DDC_i^{(0)}$	In 2020 $CFR_i^{(-1)}$	In 2021 $CFR_i^{(-1)}$
1	USA	166.78	275.01	3.00	3.78	0.018	0.014
2	Taiwan	0.097	1.86	0.00085	0.097	0.0088	0.052
3	Hong Kong	3.43	1.39	0.057	0.024	0.017	0.017
4	India	21.50	47.50	0.31	0.64	0.014	0.014
5	France	106.10	270.11	2.88	2.57	0.027	0.0095
6	Germany	54.86	175.94	1.55	2.32	0.028	0.013
7	Brazil	113.68	187.05	2.90	5.42	0.025	0.029
8	South Korea	3.37	30.38	0.050	0.25	0.015	0.0082
9	Japan	5.26	33.23	0.078	0.33	0.015	0.010
10	Italy	105.04	180.88	3.71	2.95	0.035	0.016
11	UK	113.35	441.47	4.12	3.39	0.036	0.0077
12	Turkey	87.16	232.67	0.82	1.97	0.0094	0.0085
13	Mexico	37.25	54.55	3.68	3.36	0.099	0.062
14	Peru	98.60	102.75	9.08	8.81	0.092	0.086
15	Iran	43.69	153.89	1.98	2.37	0.045	0.015
16	Indonesia	8.84	35.00	0.26	1.21	0.030	0.035
17	Canada	43.13	109.50	1.16	1.05	0.027	0.0096
18	South Africa	57.64	110.12	1.55	2.88	0.027	0.026
19	Egypt	3.85	6.12	0.21	0.35	0.055	0.057
20	Israel	137.50	279.01	1.09	1.43	0.0080	0.0051
21	Nigeria	1.29	1.94	0.019	0.022	0.015	0.011
22	Australia	3.17	35.40	0.10	0.16	0.032	0.0045
23	New Zealand	1.13	6.31	0.016	0.014	0.014	0.0022
24	Vietnam	0.043	48.27	0.0010	0.90	0.022	0.019
25	European Union	91.71	235.07	2.37	3.22	0.026	0.0137
26	Europe	85.92	232.45	2.14	3.63	0.025	0.016
27	Africa	6.02	13.64	0.14	0.315	0.024	0.023
28	Asia	11.96	37.22	0.20	0.53	0.016	0.014
29	North America	108.97	188.95	2.57	3.14	0.024	0.017
30	South America	97.05	167.92	3.11	4.85	0.032	0.029
31	High income countries	90.11	204.25	1.96	2.52	0.024	0.012
32	Upper middle income countries	26.16	64.68	0.78	1.61	0.030	0.025
33	Lower middle income countries	14.40	38.80	0.27	0.69	0.019	0.018
34	The world	28.44	69.78	0.67	1.22	0.024	0.017

Dashed horizontal magenta lines represent global endemic limits DCC^{*} = 37.2, DCC^{**} = 124.1, DDC^{*} = 0.124, DDC^{**} =0.409 and CFR^{*}=0.0033 estimated with the use of COVID-19 pandemic dynamics in 2022, [3]. Dotted horizontal magenta lines represent global flu mortality limits $DDC^{*}_{(flu)}$ =0.1 and $DDC^{**}_{(flu)}$ =0.18, [3,5].

Shown in **Figure 1** lines between second and third marker (from left to right) illustrate that the numbers of cases *DCC* mostly increased with the increase of the vaccination levels *VC* (the same is the global trend represented by magenta markers). Opposite trends demonstrate less vaccinated Africa, Lower middle income countries, India, Indonesia, Iran, South Africa, Nigeria, and Egypt. Slightly lower values of *DCC* in 2022 (in comparison with 2021) have also been observed in Brazil and the UK. Therefore, it is not surprising that the statistical analysis carried out in [32] showed an increase in the numbers of cases with an increase in the percentage of fully vaccinated persons *VC*. A similar trend was also detected versus *BC* values, and no decrease in the number of cases *DCC* with increasing levels of vaccinations was detected even after corrections taking into account the median age of the populations, [32]. Thus, to reduce the

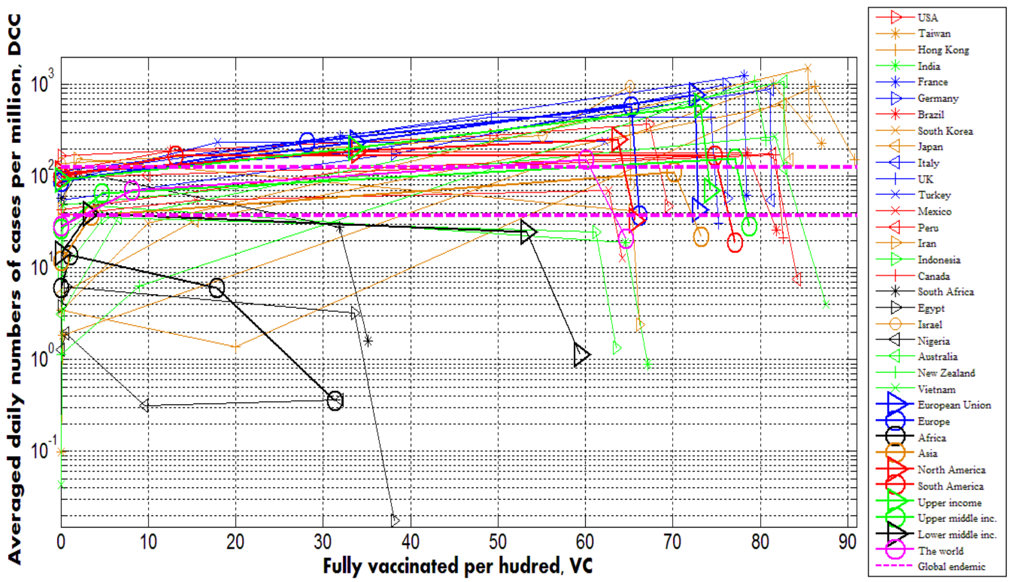

Figure 1. Averaged daily numbers of COVID-19 cases *DCC* per million from 2020-2023 for different countries and regions versus percentages of fully vaccinated people *VC*. Dashed horizontal magenta lines represent global endemic limits DCC^{*} = 37.2, DCC^{**} = 124.1, [3].

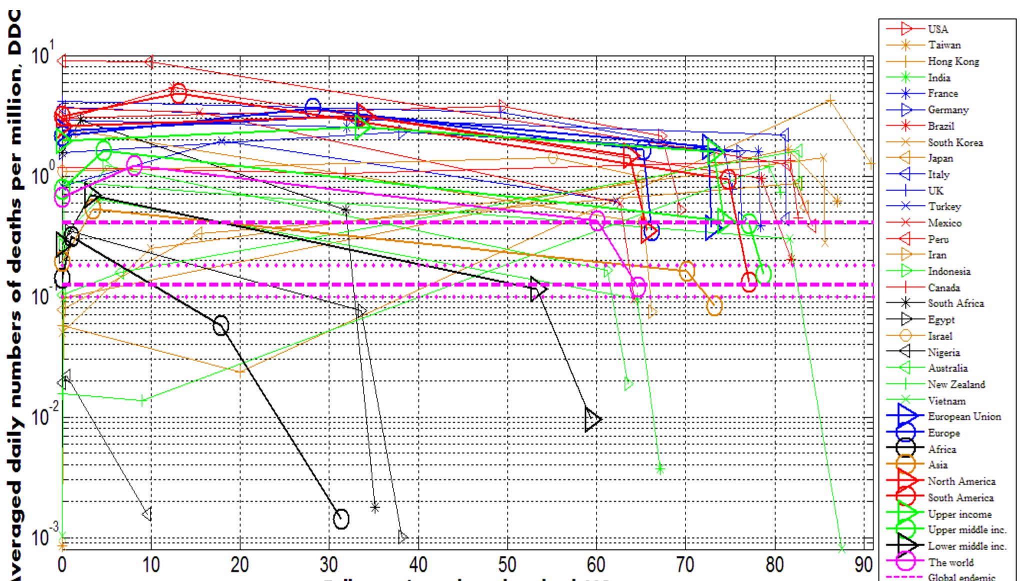

Figure 2. Average daily numbers of COVID-19 related deaths *DDC* per million from 2020-2023 for different countries and regions versus percentages of fully vaccinated people *VC*. Dashed horizontal magenta lines represent global endemic limits DDC^{*} = 0.124, DDC^{**} =0.409, [3]. Dotted horizontal magenta lines represent global flu mortality limits $DDC^{*}_{(flu)}$ =0.1 and $DDC^{**}_{(flu)}$ =0.18, [3,5].

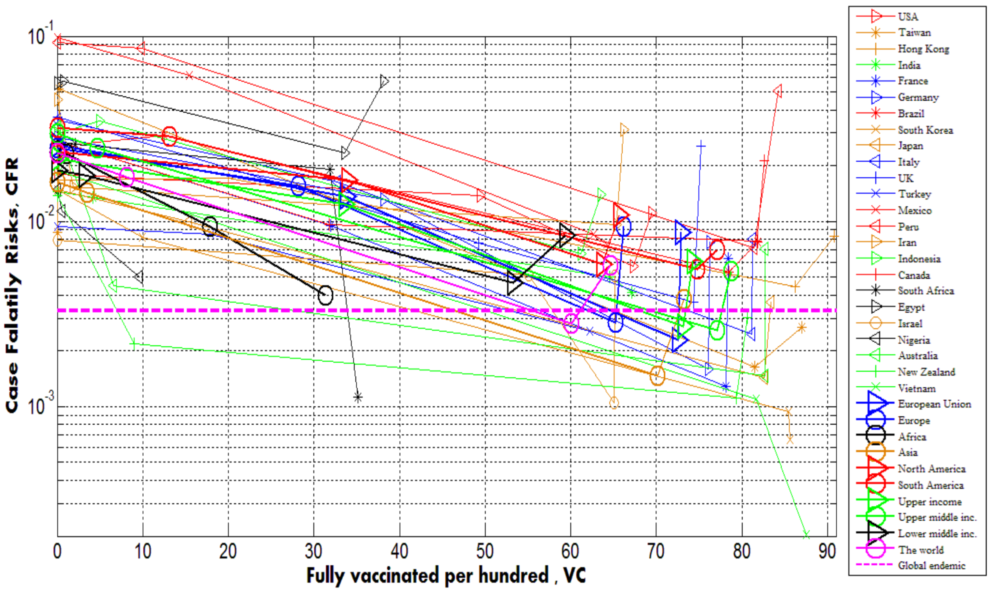

Figure 3. Average case fatality risks *CFR* from 2020-2023 for different countries and regions versus percentages of fully vaccinated people. The dashed horizontal magenta line represents the global endemic value CFR^*=0.0033, [3].

number of new COVID-19 cases, further use of existing vaccines is impractical.

Figure 2 illustrates the trends for the average daily numbers of COVID-19 related deaths per million *DDC*. Lines between second and third marker (from left to right) show that *DDC* mostly decrease with the increase of the vaccination levels *VC* (the same is the global trend shown by magenta markers). Nevertheless, in some highly vaccinated countries and regions (Taiwan, Hong Kong, Japan, South Korea, Canada, Australia, and New Zealand) *DDC* values increased in 2022 in comparison with 2021 (when the levels of vaccinations were much lower). The statistical analysis carried out in [32] showed an increase in the numbers of deaths with an increase in the percentage of fully vaccinated persons *VC*. A similar trend was also detected versus *BC* values, and trends to decrease the number of deaths *DDC* with increasing levels of vaccinations were not detected even after corrections taking into account the median age of the populations, [32]. Thus, further use of existing vaccines cannot reduce the number of COVID-19 related deaths per capita as well. In most countries it remains higher than seasonal flu mortality (see horizontal magenta dotted lines in **(Figure 2)**, [3,5]).

Figure 3 illustrates the trends for the average case mortality risks *CFR=DDC/DCC*. Lines between second and third marker (from left to right) show that *CFR* significantly decreased in 2022 in comparison with 2021 (when vaccination levels *VC* much lower). The *CFR* decreasing trends in 2022 and 2023 with the increase of *VC* and *BC* values were also revealed in [32] without and with taking into account the age of populations. It looks that vaccinations really reduced the probability of dying for persons tested positive (i.e., *CFR*), despite the sharp *CFR* increase in 2023 in many countries and worldwide (exceptions are India, South Korea, South Africa, Mexico, Nigeria, Vietnam, and Africa, see lines between third and fourth markers in **Figure 3**). This increase can be attributed to a decline in vaccination rates (see high slopes between third and fourth markers in **Figure 3**), but the most likely reason may be a significant reduce in testing levels after mid-2022, resulting in a disproportionate decrease in the numerator and denominator in the formula (3), [32]. It must be noted that according to the number of cases and deaths reported to WHO, [6], during 28 days to 29 September 2024, the global *CFR* figure 0.0154= 4862/314895 is much higher than the endemic level CFR^*=0.0033, [3] shown in **(Figure 3)** by the dashed magenta line. The corresponding value for Europe *CFR*=0.0025=758/301397 is close to the endemic level.

Thus, vaccinations and boosters can be recommended in order to reduce the severity of SARS-CoV-2 disease and probability of dying for infected individuals *(CFR)*. Unfortunately, due to the high number of infections (which is proportional to the *DCC* values and cannot be reduced by existing vaccines), the probably of dying in a population (proportional to the *DDC* values) will remain high without additional means of controlling the spread of infection. Therefore, it is still necessary to avoid close contacts and crowded places, trace and isolate infected people, wear masks in transport and medical facilities, wash hands more often, correct nutritional diet [33], etc.

Here, the experience of Zero-COVID countries [27], where the number of deaths per capita accumulated as of 10 September 2023 is approximately half as much as in other countries [34], is very indicative. During some periods of the pandemic, these countries managed to maintain very high test-to-case ratios *TC* which probably allowed completely controlling the spread of infection with very small values of *DCC* and *DDC*, [26]. For example, before 2022 the average *TC* values varied from 71 to 2,733 in Taiwan, Hong Kong, South Korea, Australia, and New Zealand (these figures were calculated with the use of numbers of test per thousand and cases per million accumulated as of 31 December 2021, [2,32] and are much higher than in the US (13.6) and the UK (23.3)). Due to the fact that the number of tests could not be increased accordingly with the increase in the daily number of cases during the new pandemic waves, the number of cases and deaths increased sharply in these countries in 2022 despite a very high level of vaccinations (see **Figures 1, 2** and [26]). To control recent waves of SARS-CoV-2 disease, the immediate and sufficient increase of the number of tests can be recommended. If many people having contact with an infected person will be tested and isolated (e.g., *TC* value have to exceed 200), the spread of infection can be controlled, [26].

Many other factors (e.g., new variants, public health measures) also influence the trends studied, so they should be taken into account in the future, as well as the data incompleteness due to a sharp decrease in the level of testing. The presented analysis is based on the country-level data which may not reflect individual-level effects.

Conclusions

The average daily numbers of cases *DCC* and death *DDC* per million, case fatality risks *CFR=DDC/DCC* in 2020-2024 calculated for 34 countries and regions were used to investigate the trends versus vaccination and booster levels. These trends together with the published before results of statistical analysis show that existing vaccines cannot reduce the number of new COVID-19 cases and deaths. Therefore, it is still necessary to apply non-pharmaceutical measures such as: avoiding close contacts and crowded places, tracing and isolating infected people, wearing masks in transport and medical facilities, hands washing, etc.

Vaccinations and boosters can be recommended in order to reduce the severity of SARS-CoV-2 disease and probability of dying for infected individuals *(CFR)*. Unfortunately, due to the high number of infections (which is proportional to the *DCC* values and cannot be reduced by existing vaccines), the probably of dying in a population (proportional to the *DDC* values) will remain high without additional means of controlling the spread of infection. Recent epidemic waves can probably be controlled with the use of the immediate and sufficient increase of the number of tests. Since vaccinations reduce the severity of SARS-CoV-2 disease and probability of dying for infected individuals, they should be recommended for the elderly and those with weakened immune systems.

Competing Interests

The author declares no competing interests.

Clarification Point

No humans or human data was used during this study. No human participants are involved in this study.

Data Availability

The study uses only open statistical data available on the Internet. All data generated or analyzed during this study are included in this text.

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