The Ethics of COVID-19 Vaccine Allocation: Don't Forget the Trade-Offs!

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The issue of COVID-19 vaccine allocation is still highly controversial on the international as well as on the national level (particularly in many low- and middle-income countries), and policy-makers worldwide struggle in striking a fair balance between different ethical principles of vaccine allocation, in particular maximum benefit, reciprocity, social justice and equal respect. Any political decision that implements these principles comes at a cost in terms of loss of lives and of loss of life years that could potentially have been prevented by a different vaccination strategy. This article illustrates these trade-offs using quantitative analysis and shows how this approach can contribute to providing a rational and transparent grounding of political decisions on COVID-19 vaccine allocation.

Introduction

There is no doubt that vaccination is by far the most effective measure to prevent hospitalizations and premature deaths from COVID-19. In addition, vaccination campaigns are likely the only strategy capable of allowing societies to overcome the pandemic and to return to normal functioning in the long run.

It is thus hardly surprising that global demand for COVID-19 vaccines still greatly exceeds supply (as of November 2021), and there is little hope that this situation will change in the short term. Instead, the spread of novel virus variants, against which existing vaccines are less effective, entails new allocation problems with regard to both established vaccines (e.g. the problem of prioritization of 'booster' vaccinations) and new vaccines, which will be developed in the future.

Consequently, ferocious competition for COVID-19 vaccine supplies plays out on the international level, with national governments trying to secure a maximum of vaccines for their respective country. Similarly, the allocation of vaccines to different subgroups of the population is also highly disputed and controversial on the national level in many countries.[1]

National vaccination strategies in most States have generally assigned persons at the highest risk of death or serious illness from COVID-19 and frontline healthcare workers to the highest vaccination priority groups (see European Centre for Disease Prevention and Control, 2020). Regarding the prioritization of other population subgroups, however, there has been a lack of consensus, causing heated public and political controversy about the principles that should govern COVID-19 vaccine allocation: Should age- and

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morbidity-specific lethality be the sole (or at least the predominant) criterion for COVID-19 vaccine allocation? Should the criterion of age-specific lethality be set aside to prioritize the vaccination of persons at an increased professional risk of infection with SARS-CoV-2, even in population subgroups in which the age-specific lethality of COVID-19 is relatively low (e.g. in the case of teachers or transport workers)? Should the 'social utility' of a person's profession be taken into account, e.g. by prioritizing employees that ensure critical infrastructure?[2] Should high-income countries offer vaccination to groups at low risk of death from COVID-19 (e.g. children and adolescents; 'booster' vaccinations), whilst high-risk groups in many low- and middle-income countries have not yet been able to access COVID-19 vaccination (see Jecker and Lederman, 2021)?[3]

Public health ethics provides decision-makers with several principles that offer guidance in answering these questions. Chief amongst these principles arguably are the principles of minimization of loss of lives and of loss of life years. Indeed, it appears intuitively sensible to evaluate vaccination strategies against a disease, which has cost more than 5.2 million lives worldwide (by 3 December 2021, according to data from the Johns Hopkins University), by assessing their capacity to reduce the number of deaths and the number of life years lost. Furthermore, strategies that follow the principle of minimization of loss of lives and of loss of life years give everyone a fair chance of access to vaccination, irrespective of comorbidity and profession, and are susceptible to reducing politization of the issue of COVID-19 vaccine allocation. In this regard, it is, however, important to realize that minimizing loss of lives may not minimize the loss of life years and vice versa.

There are also other ethical principles that are relevant to COVID-19 vaccine allocation, most importantly the principles of reciprocity (see, e.g. Liu *et al.*, 2020; World Health Organization, 2020; Symons *et al.*, 2021), of social justice and equitable distribution (see, e.g. Bollyky *et al.*, 2020; Feiring *et al.*, 2020; Schmidt, 2020; Schmidt *et al.*, 2020; Brown, 2021; Farina and Lavazza, 2021; Gayle and Childress, 2021; Jecker *et al.*, 2021; Rhodes, 2021), and of equal treatment (see, e.g. Emanuel *et al.*, 2020; Feiring *et al.*, 2020; Gayle *et al.*, 2020; World Health Organization, 2020; Paloyo *et al.*, 2021).

This article does not contest that political decision-makers can be well-founded in setting aside the principles of minimization of loss of lives and of loss of life years to give greater consideration to another ethical principle of vaccine allocation. They should, however, be aware of the fact that this means a trade-off in terms of loss of lives and/or of loss of life years.

To illustrate the trade-offs inherent to vaccine allocation decisions, the present study uses a quantitative analysis that evaluates these opportunity costs in terms of loss of lives and loss of life years incurred by six (idealized) real-world vaccination strategies.

In this sense, the quantitative analysis developed in this paper is not intended to inform policymaking on COVID-19 vaccine allocation by itself. Rather, the aim is to explicate essential trade-offs that many policymakers may not have considered explicitly and to illustrate the potential merits of easy-to-conduct quantitative analysis as a source of information for policymaking on COVID-19 vaccine allocation.

Methodology

Quantitative Analysis

To estimate the opportunity cost of different ethical principles, lost lives and lost life years attributable to COVID-19 mortality have been calculated for various theoretical scenarios of vaccine allocation strategies. The analysis simulates 1 year of time starting on 5 January 2021 for the German population, based on evidence and information that was available to decision-makers on that date. A schematic representation of the logic of the analysis is visualized in Figure 1. The population at risk consists of individuals not yet diagnosed with COVID-19 and not yet vaccinated. COVID-19 deaths are additive to the observed background mortality. The expected excess mortality of COVID-19 comprises the predicted case numbers (i.e. infection rate), case–fatality ratios and previously acquired immunity in the population (i.e. those already diagnosed with COVID-19 and therefore immune). To predict the case numbers for the 1-year time horizon of the analysis, a simple SEIR (Susceptible—Exposed—Infectious—Recovered) model has been built using actual daily basic reproductive numbers (R) reported by the Robert Koch Institute (RKI) (2021) and two selected values for the time without available data. The basic reproductive number $R = 0.9$ has been used to set up a scenario with no new waves of infections and $R = 1.04$ to simulate another wave. The relative risk of infection amongst healthcare professionals compared to the general population has been set to 2 and assumed to be constant across age groups.

Input Data

Ten-year wide age groups of the general population and of healthcare professionals have been defined to estimate

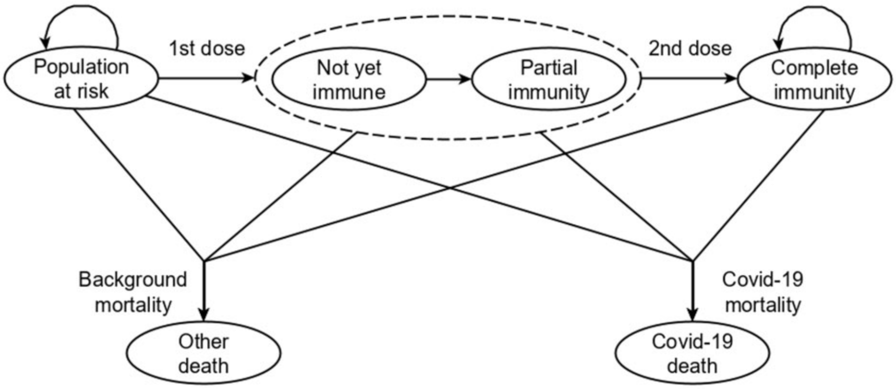

Figure 1. Schematic representation of the quantitative analysis.

the impact of various vaccine allocation strategies. The age structure of the general population and of the healthcare workforce and the background mortality and remaining life expectancy have been obtained from data tables published by the Federal Statistical Office of Germany (*Statistisches Bundesamt*) [Federal Statistical Office of Germany (Destatis), 2021]. To calculate the size of age groups 80–89 years and 90+ years, a highest age limit of 100 years and exponential distribution of the population alive have been assumed. In case of healthcare professionals, the lowest and highest age limits have been defined as 20 and 69 years. Linear distribution until age 79 years and exponential distribution from age 80 years have been used to calculate average remaining life expectancy. Case–fatality ratios by age group have been calculated as the total number of COVID-19 deaths divided by the total number of COVID-19 cases reported by the RKI by the time of the analysis [Robert Koch Institute (RKI), 2021]. No difference in case–fatality ratios between healthcare professionals and individuals in the general population has been assumed. The input parameters by age group and sex are presented in Table 1.

The vaccination process has been described in accordance with public information on the timeline and efficacy of COVID-19 vaccines. Partial immunity with 50 per cent efficacy has been assumed at average 7 days after administering the first dose. Complete immunity (95 per cent) is reached after the second vaccine dose, which is administered on average 21 days after the first dose. We assumed that the efficacy is independent of the recipient (e.g. age), acquired immunity from vaccination persists on the 1-year time horizon of the qualitative analysis and a full adherence to the vaccination process meaning that each individual receives both doses (Figure 2).[4]

Vaccine Allocation Strategies

Six different vaccine allocation strategies have been evaluated (Table 2). For all scenarios, vaccine scarcity has been implemented by restricting the total available vaccine doses to approximately 21.17 million and assuming a daily number of 100,000 vaccine administrations. These values reflect the necessary number of doses to vaccinate everyone above 70 years, who are willing to be vaccinated (i.e. uptake rate), and the real-world vaccine administration numbers in Germany at the time of the analysis. A constant vaccination capacity throughout the entire year has been assumed, which is a composite of various factors affecting the speed of vaccination, including the distribution of available vaccine doses in time, capacity of the healthcare workforce or organizational and administrative issues. We have also assumed that the distribution of vaccine doses amongst age groups is proportional to their size.

In scenarios 1a and 1b, persons above 69 years of age are eligible for COVID-19 vaccine, including the healthcare professionals as a group in scenario 1b. Scenarios 2a and 2b describe a prioritization sequence amongst the aforementioned age groups: the vaccination programme starts with persons older than 89 years, followed by the age groups of 80–89 years and then 70–79 years, with or without healthcare professionals, respectively. In scenario 2c, the healthcare workforce is prioritized over the elderly. Scenario 3 defines a vaccination programme targeting the working age groups and allocating the available vaccine doses to persons between 30 and 69 years of age.

All scenarios have been evaluated under the conditions of facing a new wave of infections during the year or not.

Table 1. Input data

Age	Input parameters by age group, women					Input parameters by age group, men				
	Total population	Healthcare professionals	CFR	*q*(*x*)	*e*(*x*)	Total population	Healthcare professionals	CFR	*q*(*x*)	*e*(*x*)
0–9	3,741,794	0	0.0002	0.0038	79.02	3,946,552	0	0.0001	0.0045	74.30
10–19	3,698,159	0	0.0000	0.0011	69.21	3,943,997	0	0.0000	0.0019	64.53
20–29	4,630,423	565,000	0.0002	0.0019	59.30	5,052,479	150,000	0.0001	0.0044	54.71
30–39	5,271,544	764,000	0.0006	0.0043	49.46	5,513,386	204,000	0.0003	0.0079	44.99
40–49	5,062,510	807,000	0.0020	0.0108	39.75	5,119,874	192,000	0.0013	0.0190	35.47
50–59	6,693,379	1,045,000	0.0051	0.0305	30.38	6,754,161	239,000	0.0048	0.0550	26.46
60–69	5,414,823	406,000	0.0301	0.0763	21.61	5,091,980	150,000	0.0235	0.1395	18.43
70–79	4,099,205	0	0.1537	0.1824	13.64	3,451,310	0	0.0920	0.2917	11.53
80–89	2,901,389	0	0.0984	0.5424	6.74	1,924,100	0	0.2126	0.6606	5.73
90+	615,872	0	0.1259	0.9397	2.90	239,774	0	0.2721	0.9640	2.56

Source: calculated based on Federal Statistical Office of Germany (Destatis) (2021) and Robert Koch Institute (RKI) (2021).
CFR, case-fatality ratio; $q(x)$, probability of death between ages x and $x+1$; $e(x)$, average life expectancy at exact age x (in years).

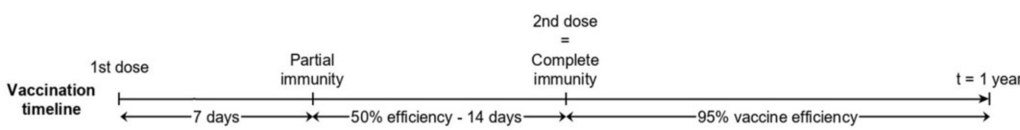

Figure 2. Simplified vaccination timeline used for the quantitative analysis.

Table 2. Summary of the theoretical vaccine allocation scenarios

	Scenario 1a	Scenario 1b	Scenario 2a	Scenario 2b	Scenario 2c	Scenario 3
Age groups vaccinated	70+	70+	70+	70+	70+	30–69
Healthcare professionals vaccinated	No	Yes	No	Yes	Yes	Yes, included in the age groups
Prioritization amongst the selected groups	Vaccine doses administered parallelly	Vaccine doses administered parallelly	Starting from 90+, to 80+ and 70+	Starting from 90+, to 80+ and 70+; HC parallelly	Starting with HC, then 90+, 80+ and 70+	Vaccine doses administered parallelly
Uptake rate	80%	80%	80%	80%	80%	30–59: 50% 60–69: 70%
Vaccine doses available	∼21.17 million					
Capacity (doses per day)	100,000					

HC, healthcare professionals.

Results

The simulated COVID-19 scenarios regarding case numbers are presented in Figure 3A and B assuming no new waves of infections in the first case and another wave of infections having a peak around July 2021 in the second.

Our results show (i) that vaccination has a significant impact on the number of deaths and lost life years attributable to the COVID-19 pandemic, (ii) that this impact differs between different vaccination strategies and (iii) that assuming a second wave of infections magnifies this impact significantly. The estimated total number of lost lives and the estimated total number of lost life years in case of no new wave of infections and another wave of infections are presented in Tables 3 and 4.

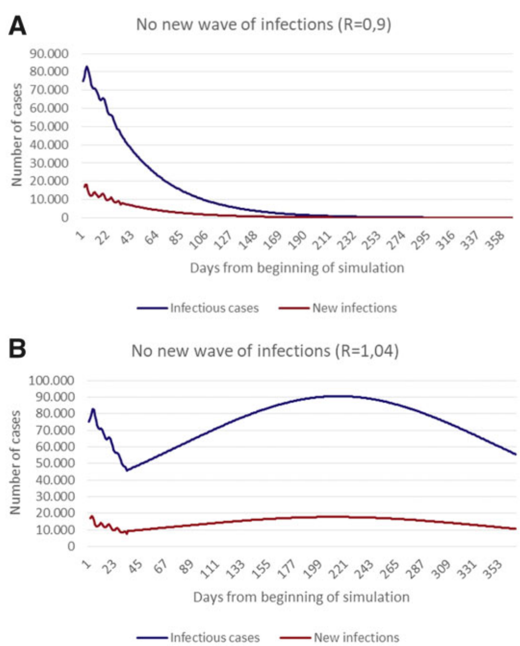

Figure 3. (A) Estimated case numbers in case of no new wave of infections. (B) Estimated case numbers in case of another wave of infections.

Any scenario of vaccinating healthcare professionals results in a higher number of deaths and lost life years compared to the related scenario without the healthcare workforce being eligible for vaccination. Comparing scenario 1a to scenario 2a (similarly, scenario 1b to scenario 2b) the number of lost lives is higher in the first, whilst the number of lost life years is higher in the second scenario. This deviation of the observed outcomes is due to the prioritization sequence allocating vaccine doses to the oldest age groups first in scenario 2. Figure 4 shows the predicted numbers of lost lives and lost life years by age group without vaccination in case of no new wave of infections. The difference between lost lives and lost life years is the highest in the age group 70–79 years (amongst the three oldest age groups), whilst it is less than 3-fold for the age group older than 89 years.

Limitations

We are aware of the following limitations of the quantitative analysis that need to be addressed. There are several models published with sophisticated methodologies that aim to estimate the impact of the COVID-19 pandemic and/or vaccination strategies in various countries (e.g. Bartsch *et al.*, 2021; Bubar *et al.*, 2021; Foy *et al.*, 2021; Hogan *et al.*, 2021; Islam *et al.*, 2021; Joshi *et al.*, 2021; Matrajt *et al.*, 2021; Nguyen *et al.*, 2021; Šušteršič *et al.*, 2021; Tran Kiem *et al.*, 2021). Our analysis does not claim to predict the future course of the COVID-19 pandemic but to provide a structured way to consider various ethical principles around the vaccine allocation strategies and to evaluate the potential outcomes quantitatively. Therefore, the underlying SEIR model has undertaken significant simplifications.

We have assumed a constant COVID-19 infection rate across age groups and approximated the individual risk of

Table 3. Estimated number of lost lives and lost life years in case of no new wave of infections

	COVID-19 deaths	Lost life years due to COVID-19	Difference to no vaccination (deaths)	Difference to no vaccination (life years)
No vaccination	19,340	230,321		
Scenario 1a	16,653	204,762	2687	25,559
Scenario 1b	17,302	210,151	2038	20,170
Scenario 2a	16,470	212,410	2870	17,911
Scenario 2b	17,164	217,379	2176	12,942
Scenario 2c	18,597	224,630	743	5691
Scenario 3	19,141	225,896	199	4425

Table 4. Estimated number of lost lives and lost life years in case of another wave of infections

	Covid-19 deaths	Lost life years due to Covid-19	Difference to no vaccination (deaths)	Difference to no vaccination (life years)
No vaccination	132,003	1,589,965		
Scenario 1a	68,978	986,530	63,025	603,435
Scenario 1b	84,544	1,126,373	47,459	463,592
Scenario 2a	68,706	1,021,373	63,297	568,592
Scenario 2b	83,666	1,199,102	48,337	390,863
Scenario 2c	92,841	1,284,901	39,162	305,064
Scenario 3	127,256	1,484,129	4747	105,836

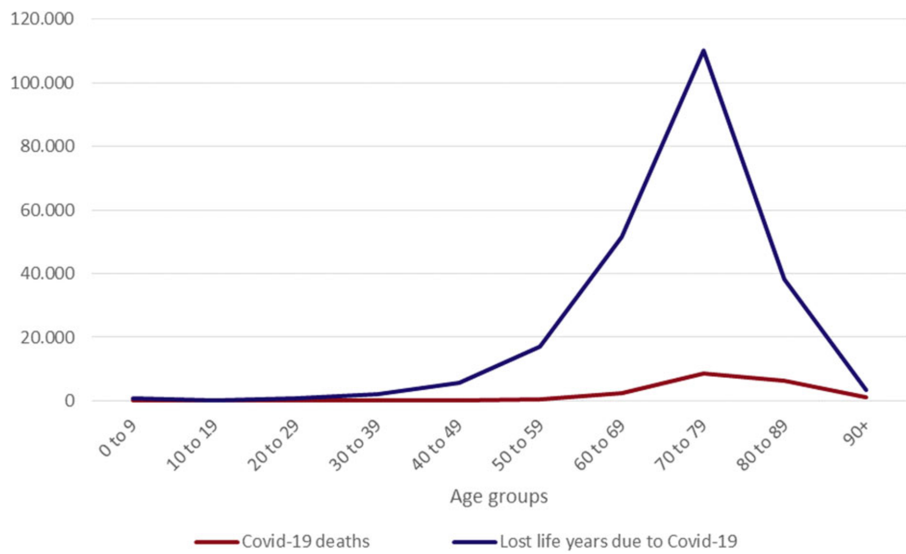

Figure 4. Estimated number of lost lives and lost life years with no vaccination and assuming no new wave of infections.

COVID-19 mortality only by age rather than chronic conditions or other health problems posing a high risk of death.

The quantitative analysis has been based on the assumption that vaccination provides only individual protection, meaning that vaccinated persons can still spread the virus. Therefore, the impact of the vaccination programme in terms of absolute numbers of lives saved and life years saved is most probably underestimated. It may affect the relative impacts as well and provide scope for considerations on prioritizing younger age groups, who are more likely to infect others.

Potential delays in reporting COVID-19 cases or deaths might influence the calculated case–fatality ratios. However, we evaluated this issue as rather negligible and having an insignificant effect on the outcomes of the quantitative analysis.

Since there is currently no testing applied prior to vaccine administration, previously infected patients are still eligible for vaccination. This assumption, however, reflects real-world vaccination policies. Further analyses may address the potential of testing before vaccinating under the current state of vaccine scarcity in many countries.

Discussion

In the preceding, we have presented a quantitative analysis that outlines the trade-offs in terms of loss of lives and of loss of life years incurred by opting for different COVID-19 vaccine allocation strategies.

In calculating the number of life years lost, we have solely referred to the (statistical) life expectancies at the age of death of persons dying from COVID-19 and we have disregarded the effects that pre-existing comorbidities might have on their (statistical) remaining life years. This approach, which is outlined by Emanuel *et al.* (2020), is justified by the imperative of nondiscrimination of persons with disabilities and by the imperative not to put people, who are at higher risk of death or serious illness from COVID-19 due to their pre-existing comorbidities, in double jeopardy by disadvantaging them in the process of COVID-19 vaccine allocation because of the negative impact of their pre-existing comorbidities on their (statistical) life expectancy. It also reflects the logistical challenge of rolling out a population level vaccination programme where the groups sequentially invited for vaccination have to be easily identifiable from public records, which makes very fine-grained risk distinctions based on multiple risk factors difficult to implement in practice.

On this basis, we have presented strategies that are most apt at preventing loss of lives and loss of life years in scenarios 1a and 2a. Scenario 1a describes a strategy which gives highest priority to all persons above the age of 70 without further differentiation, whereas scenario 2a further differentiates between three age subgroups (90+, 80–89 and 70–79). As our results show, the difference between both scenarios in terms of lives saved is relatively small (with a difference of 183 in case of no new wave of infections and of 272 in case of another wave of infections), but the results suggest that strategy 1a is much more apt at preventing loss of life years (with a difference to strategy 2a of 6748 in case of no new wave of infections and of 34,843 in case of another wave of infections). This information is interesting for political decision-making on vaccine prioritization, given the fact that strategy 1a is likely easier to implement than strategy 2a: Whilst the assignment only of persons above the age of 90 to the highest priority group likely requires the immediate establishment of at home vaccination programmes and of vaccination facilities in nursing homes, this could potentially be delayed in the case of a blanket prioritization of persons above the age of 70, since many persons in this age group are fit for vaccination in vaccination centres or in medical practices.

Minimization of deaths and loss of life years from COVID-19 is, however, not the sole possible principle for COVID-19 vaccine allocation. Scenarios 1b, 2b and 2c reflect strategies of prioritization of healthcare staff. There are numerous ethical rationales for prioritizing healthcare staff: most importantly, healthcare professionals make the most significant contribution to the management of the COVID-19 pandemic and, especially in cases of shrinking ICU capacity, they might be difficult or impossible to substitute in case of illness from COVID-19. Furthermore, as the Strategic Advisory Group of Experts on Immunization of the World Health Organization puts it, societies should 'honor obligations of reciprocity to those individuals and groups within countries who bear substantial additional risks and burdens of COVID-19 response for the benefit of society' (World Health Organization, 2020: 2).

Nevertheless, the trade-offs in terms of loss of lives and loss of life years should not be completely lost out of sight. Our results suggest that the prioritization of healthcare professionals could, in comparison to vaccination strategy 1a, entail a substantial amount of additional loss of lives as well as loss of life years.

These results do not mean that decision-makers should rule out prioritization of healthcare professionals. However, they suggest that decision-makers should be cautious in departing from the principle of minimization of loss of lives and of loss of life years when prioritizing younger persons with a higher risk of infection with COVID-19 on professional grounds. Given their contribution to the management of the pandemic, it appears very sensible to give highest priority to the vaccination of nurses and physicians treating COVID-19 patients, but our results suggest that this should be treated as an exception from the principle of minimization of loss of lives and of loss of life years, and that this exception should be construed narrowly and should not be extended to other professional groups (e.g. physicians and nurses not treating COVID-19 patients, teachers, and transport workers).

Finally, we have examined a strategy that prioritizes the vaccination of the economically active, which has been pursued notably by China and Indonesia, in scenario 3. Although economic considerations should not be excluded from the decision-making process on COVID-19 vaccine allocation, the trade-offs in terms of loss of life and of loss of life years provide strong arguments against this vaccination strategy of prioritization on the basis of economic activity (instead of age- and morbidity-specific lethality): our results show that strategy 3 as compared to scenario 1a leads to the loss of an additional 2488 lives and 21,134 life years in case of no new wave of infections and of 58,278 lives and of 497,599 life years in case of a new wave of infections.

Conclusions

Developing COVID-19 vaccination prioritization schemes is a highly complex task, with decision-makers having to strike a fair balance between different ethical principles of COVID-19 vaccine allocation and between different groups in society. In this process, the principles of minimization of loss of lives and of loss of life years should not be the sole basis of decision-making, but they should be taken into account in vaccine allocation decisions. For this reason, decision-makers should be aware of the (self-evident) fact that any vaccination strategy that privileges other ethical principles over the principle of minimization of loss of lives and of loss of life years comes at a cost in terms of lives lost and of life years lost. Quantitative analysis, as we have presented in the present study, can help illustrate these trade-offs and inform political decisions on COVID-19 vaccine allocation. The analysis is not particularly complex and could quickly be performed prior to decisions being made about vaccination strategies to illustrate the trade-offs between different strategies. Even though quantitative analysis cannot deliver conclusive answers to the issue of vaccine allocation (which, after all, remains a task for policymakers), it can contribute to providing a rational and transparent basis for decision-making on vaccine allocation.

Conflict of Interest

None declared.

Notes

1. As of November 2021, vaccine supply problems have been solved in most high-income countries but still persist in many low- and middle-income countries. In many African States (e.g. Burundi, Chad and Guinea-Bissau), less than 2 per cent of the populations have received a (first) vaccine dose as of 3 December 2021 (according to data from the Johns Hopkins University). We contend that the findings of our paper, which shows the merits of easy-to-conduct quantitative analysis in vaccine allocation debates, could also be helpful in developing vaccine allocation policies in these countries.
2. Whilst these issues are by and large obsolete in many high-income countries as of November 2021, they continue to be of great relevance in many low- and middle-income countries, which still suffer problems of COVID-19 vaccine supply.
3. 'Vaccine nationalism', which means the policy of many high-income countries to purchase disproportionate supplies of COVID-19 vaccines (in relation to their population size) to the detriment of low- and middle-income countries, is a much debated issue in public health ethics (see, e.g. Emanuel *et al.*, 2021; Ferguson and Caplan, 2021; Gollier, 2021; Hassoun, 2021; Herlitz *et al.*, 2021; Jecker *et al.*, 2021; Katz *et al.*, 2021; Obinna, 2022). We contend that quantitative analysis like the one developed in this article can contribute to this debate by illustrating potential trade-offs of 'vaccine nationalism', without claiming that this approach provides a conclusive or exclusive solution to the debate whether 'vaccine nationalism' is ethically justifiable.
4. The quantitative analysis is based on data and reports on Comirnaty (Pfizer-BioNTech), which had been published by January 2021.

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