Impact of Prioritizing Elderly and High-risk Individuals During COVID-19 Vaccine Allocation

Buse Eylul Oruc
Georgia Institute of Technology
Akane Fujimoto
Georgia Institute of Technology
Robert Breiman
Emory University
Pinar Keskinocak (pinar@isye.gatech.edu)
Georgia Institute of Technology

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Abstract

Background

The prioritization of vaccine eligibility for different subpopulations is an important decision to curb spread and severe outcomes of epidemic infectious diseases for which vaccines become available. Using COVID-19 as a prototype, this study evaluates the public health impact of various vaccine prioritization schemes of elderly and high-risk individuals with different vaccination start dates and rollout speeds.

Methods

An agent-based simulation model was adapted and used to project the number of infections, hospitalizations, and deaths under various vaccination start dates, rollout speeds, and prioritization schemes, including (A)no prioritization, (B)two-staged prioritization of elderly population, and (C)multi-staged prioritization of elderly and then high-risk population. The study period was February 18th, 2020 –June 1st, 2021, and the state of Georgia was used as a case study.

Results

The relative effectiveness of the prioritization schemes depends on the outcome considered, as well as the vaccination start date, prioritized subpopulations, and rollout speed. Having no prioritization results in the fewest infections and hospitalizations in most scenarios; however, it yields the highest number of deaths. Prioritizing the elderly and then high-risk individuals results in the fewest overall and high-risk deaths in most scenarios.

Conclusions

Having no vaccine prioritization, i.e., opening vaccination to every adult regardless of age, simplifies vaccine rollout and reduces the infection spread but results in a higher number of deaths, especially among the elderly and high-risk populations. Prioritizing the elderly, then high-risk patients, as opposed to prioritizing only the elderly provides benefit regarding severe outcomes; however, such assumed benefits need to be counterbalanced with challenges in communicating eligibility and criteria and in distributing vaccines effectively and equitably which could result in suboptimal vaccine uptake and coverage, including among people within subpopulations at disproportionate risk of illness, hospitalization and death, of particular concern during periods of high incidence, severe disease, and death.

Background

The COVID-19 vaccine rollout has challenged decision-makers all around the U.S. with the decision when and how to prioritize subpopulations while ensuring vaccines do not go unused [1]. In the U.S., there has been a variety of prioritization guidelines. For example, the Department of Health and Human Services recommended prioritizing first healthcare workers and then prioritizing all people ages 65 and above and those under 65 with high-risk medical conditions while the CDC Advisory Committee on Immunization Practices recommended prioritizing healthcare workers (regardless of age, co-morbidities, or risk of exposure to the virus), long-term care residents, and all people ages 75+ [2, 3]. In addition, the National Academies of Sciences, Engineering, and Medicine put forward a framework for equitable allocation of vaccine allocation to assist policymakers considering individuals, occupations, and populations at higher risk [4]. While some experts advocated for a simple, uniform prioritization scheme based on age because it would be easy to communicate and could improve distribution, states have developed and followed local vaccine prioritization schemes with staggered eligibility requirements [1, 5–7].

Vaccine prioritization schemes under limited supply have been studied in the literature for outbreaks such as H1N1 influenza pandemic [8] and Ebola [9]. However, disease characteristics of COVID-19 make adoption of pre-existing prioritization frameworks suboptimal in mitigating the severe outcomes and the spread of the pandemic. Several studies have discussed and evaluated the health outcomes and equity implications of the COVID-19 vaccine prioritization schemes prioritizing essential workers, elderly, historically marginalized populations [10–15]. The findings suggested that prioritizing elderly had the greatest impact on COVID-19 mortality, whereas prioritizing individuals with high transmission risk had the greatest impact in reducing spread of the disease [11–15]. These studies highlighted the need for evaluating the effectiveness of two-staged and multi-staged prioritization of elderly and high-risk populations in mitigating the spread of the pandemic and adverse outcomes. We set out to evaluate vaccine prioritization schemes, including (A) no prioritization, (B) two-staged prioritization of elderly population, and (C) multi-staged prioritization of elderly and then high-risk population with different vaccination start dates and rollout speeds to understand their effectiveness in mitigating the spread of the pandemic.

In this study, we compared the projected number of infections, hospitalizations, and deaths due to COVID-19 when there is no prioritization in place, elderly are prioritized, and elderly and high-risk individuals are prioritized with different vaccination start dates and rollout speeds.

Methods

Scenario Descriptions

The scenarios modeled study three prioritization schemes:

1. No prioritization: all people of age ≥20 are eligible (i.e., no prioritization);
2. Two-staged prioritization: all people of age ≥65 are eligible, then all people of age ≥20 (only elderly is prioritized);
3. Multi-staged prioritization: all people of age ≥65 are eligible, then high-risk people of age ≥20, then remaining people age ≥20 (i.e., elderly and then high-risk individuals are prioritized).

Being high-risk (for hospitalization and death) was defined as having any of the following conditions: diabetes, heart disease, chronic obstructive pulmonary disease (COPD), obesity, and kidney disease. Although intial emergency authorization of COVID-19 vaccine considered all people of age ≥18 as vaccinable, as the population in the simulation broken down to ages 0-9, 10-19, 20-64, and ≥65, this study considered all people of age ≥20 as vaccinable.

The **base scenario** considers vaccine efficacy of 90% and a vaccination start date of December 16th, 2020, which corresponds to approximately ten months after the first infection was recorded in the simulation, as was the case for the COVID-19 vaccine deployment in the U.S. [16], with a rollout speed of 1 (i.e., each week, 1% of the total population is vaccinated). Additional scenarios with rollouts speeds of 2 and 3 (i.e., each week, 2% or 3%, respectively, of the population, is vaccinated) and a vaccination start on September 16th, 2020, which corresponds to an earlier rollout three months before the actual deployment, are also considered.

For ease of reporting, the scenarios are labeled by their prioritization scheme (no prioritization, two-staged prioritization, or multi-staged prioritization), vaccination start date (Early = September 16th, 2020 and Actual = December 16th, 2020), and rollout speed (1, 2, and 3 = 1%, 2%, and 3% of the population vaccinated each week).

Modeling case projection

An agent-based simulation model with heterogeneous population mixing was adapted and utilized to predict the spread of COVID-19 geographically and over time [17]. The model was populated with the population-related data, including demographic information, high risk conditions, work travel flows, and household statistics in the state of Georgia from publicly available databases (U.S. Census Bureau American Community Survey [https://www.census.gov/newsroom/press-kits/2019/acs-1year.html], U.S. Census Bureau Census Transportation Planning Products [https://ctpp.transportation.org/ctpp-data-set-information/]). The population in the simulation is reflective of the population characteristics of Georgia. The model captured the progression of the disease in an individual with a variant of a Susceptible-Exposed-Infected-Recovered (SEIR) model, and the disease spread with modeling interactions within households, schools, workplaces, and communities. Each individual was assumed to be in one state at a given time, such as susceptible, exposed, transitioning (pre-symptomatic), infected-asymptomatic, infected-symptomatic, hospitalized, recovered, or dead. Diabetes, heart disease, chronic obstructive pulmonary disease (COPD), obesity, and kidney disease were included as risk factors for death, conditional on an individual’s age and county as derived from statewide prevalence data [18, 19]. The model also incorporated non-pharmaceutical interventions such as school closures, shelter-in-place, voluntary quarantine, and universal requirements for the use of face coverings/masks, with different compliance rates over time, in line with what has been observed in the state of Georgia. A more detailed model description can be found in [17], and model parameters and assumptions are provided in Supplementary Section A, Additional File 1. In this study, we also utilized case and vaccination data from publicly available databases (Georgia Department of Public Health COVID-19 Daily Status Report [https://dph.georgia.gov/covid-19-daily-status-report] and Georgia Department of Public Health Covid-19 Vaccine Dashboard [https://experience.arcgis.com/experience/3d8eea39f5c1443db1743a4cb8948a9c]) for calibration of assumptions.

The study period included February 18th, 2020, to June 1st, 2021. The population in the simulation included children, adults, and the elderly stratified by age groups: 0-9, 10-19, 20-64, and 65+ in the state of Georgia. All results presented in this study are the averages of 30 replications (for each scenario) of the agent-based simulation model runs.

Outcome Measures

The outcome measures reported for the time horizon of the study include:

- Cumulative infections: cumulative number of (sub)population infected (including asymptomatic infections).
- Cumulative hospitalizations: cumulative number of (sub)population who hospitalized due to COVID-19.
- Cumulative deaths: cumulative number of (sub)population who died due to COVID-19.

Results

We report the projected number of infections, hospitalizations, and deaths for the outcomes period (from the vaccination start date to the end date of the study period) under the various vaccination prioritization schemes, as displayed in Table 1. Additionally, we report the differences and percentage changes in the outcomes when comparing the prioritization schemes, as seen in Table 2.

Table 1 Outcome measures from the vaccination start date across scenarios.

			Infections			Hospitalizations			Deaths		
Vaccine Start	**Group**	**Rollout Speed**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Dec. 16th, 2020 (Actual)	Overall	1	1381272	1555431	1546644	33584	35546	35346	5994	5583	5601
	High-risk		379888	412649	408295	24426	25409	25269	5206	4855	4886
	Non-high-risk		1001385	1142781	1138348	9158	10137	10078	788	729	715
	Overall	2	1139651	1319601	1298870	27731	29227	28480	5089	4202	4157
	High-risk		308036	335931	319729	20287	20597	19762	4444	3608	3558
	Non-high-risk		831615	983670	979141	7444	8631	8717	645	594	599
	Overall	3	933536	1097199	1074260	23033	24046	22633	4295	3474	3265
	High-risk		249065	271716	245497	16768	16791	15277	3757	2975	2768
	Non-high-risk		684471	825483	828763	6265	7255	7356	538	499	497
Sep. 16th, 2020 (Early)	Overall	1	1031390	1525704	1532060	23349	30066	28965	3960	3645	3488
	High-risk		273167	375341	343275	16786	20712	19200	3429	3107	2957
	Non-high-risk		758223	1150363	1188785	6563	9355	9765	531	538	530
	Overall	2	498106	666753	658103	11551	13438	12171	2052	1772	1669
	High-risk		129421	160745	127426	8334	9227	7647	1799	1521	1393
	Non-high-risk		368684	506008	530678	3218	4211	4524	253	251	276
	Overall	3	358185	434652	441524	8456	9081	8452	1586	1316	1248
	High-risk		90662	103598	82414	6076	6285	5317	1369	1127	1040
	Non-high-risk		267523	331054	359110	2380	2796	3135	217	190	208

Number of infections, hospitalizations, and deaths from the vaccination start date to the end date of the study period under different scenarios.

Table 2: Difference and percentage change in outcome measures across scenarios.

			Δ_{AB}[d] Difference (% change)[e]			Δ_{AC} Difference (% change)			Δ_{BC} Difference (% change)		
Vaccine Start	Group	Rollout Speed	Infections	Hosp.	Deaths	Infections	Hosp.	Deaths	Infections	Hosp.	Deaths
Dec. 16th, 2020 (Actual)	Overall	1	174159 (12.61)	1962 (5.84)	-411 (-6.85)	165372 (11.97)	1762 (5.25)	-393 (-6.55)	-8787 (-0.56)	-200 (-0.56)	18 (0.32)
	High-risk		32761 (8.62)	983 (4.03)	-351 (-6.74)	28407 (7.48)	843 (3.45)	-320 (-6.14)	-4354 (-1.06)	-140 (-0.55)	31 (0.65)
	Non-high-risk		141396 (14.12)	979 (10.69)	-59 (-7.53)	136963 (13.68)	920 (10.04)	-73 (-9.22)	-4433 (-0.39)	-59 (-0.59)	-14 (-1.83)
	Overall	2	179950 (15.79)	1496 (5.4)	-887 (-17.43)	159219 (13.97)	749 (2.7)	-932 (-18.32)	-20731 (-1.57)	-747 (-2.56)	-45 (-1.08)
	High-risk		27895 (9.06)	310 (1.53)	-836 (-18.81)	11693 (3.8)	-525 (-2.59)	-886 (-19.95)	-16202 (-4.82)	-835 (-4.05)	-50 (-1.4)
	Non-high-risk		152055 (18.28)	1187 (15.95)	-51 (-7.91)	147526 (17.74)	1273 (17.11)	-46 (-7.08)	-4529 (-0.46)	86 (1)	5 (0.9)
	Overall	3	163663 (17.53)	1013 (4.4)	-821 (-19.11)	140724 (15.07)	-400 (-1.74)	-1030 (-23.98)	-22939 (-2.09)	-1413 (-5.88)	-209 (-6.02)
	High-risk		22651 (9.09)	23 (0.14)	-782 (-20.82)	-3568 (-1.43)	-1491 (-8.9)	-989 (-26.33)	-26219 (-9.65)	-1514 (-9.02)	-207 (-6.96)
	Non-high-risk		141012 (20.6)	990 (15.81)	-39 (-7.19)	144292 (21.08)	1091 (17.41)	-41 (-7.56)	3280 (0.4)	101 (1.39)	-2 (-0.4)
Sep. 16th, 2020 (Early)	Overall	1	494314 (47.93)	6717 (28.77)	-315 (-7.96)	500670 (48.54)	5616 (24.05)	-472 (-11.93)	6356 (0.42)	-1101 (-3.66)	-157 (-4.31)
	High-risk		102174 (37.4)	3926 (23.39)	-322 (-9.39)	70108 (25.66)	2414 (14.38)	-472 (-13.75)	-32066 (-8.54)	-1512 (-7.3)	-150 (-4.81)
	Non-high-risk		392140 (51.72)	2792 (42.53)	7 (1.25)	430562 (56.79)	3202 (48.78)	-1 (-0.19)	38422 (3.34)	410 (4.39)	-8 (-1.43)
	Overall	2	168647 (33.86)	1887 (16.33)	-280 (-13.65)	159997 (32.12)	620 (5.36)	-383 (-18.68)	-8650 (-1.3)	-1267 (-9.43)	-103 (-5.83)
	High-risk		31324 (24.2)	893 (10.72)	-278 (-15.43)	-1995 (-1.54)	-687 (-8.24)	-406 (-22.57)	-33319 (-20.73)	-1580 (-17.13)	-128 (-8.44)
	Non-high-risk		137,324 (37.25)	993 (30.87)	-2 (-0.92)	161,994 (43.94)	1,306 (40.61)	23 (8.96)	24,670 (4.88)	313 (7.44)	25 (9.97)
	Overall	3	76,467 (21.35)	625 (7.39)	-270 (-17.02)	83,339 (23.27)	-4 (-0.05)	-338 (-21.31)	6,872 (1.58)	-629 (-6.93)	-68 (-5.17)
	High-risk		12936 (14.27)	209 (3.45)	-242 (-17.7)	-8,248 (-9.1)	-759 (-12.49)	-329 (-24.03)	-21,184 (-20.45)	-968 (-15.41)	-87 (-7.69)

Difference and percentage change in the number of cumulative infections, hospitalizations, and deaths between prioritization schemes A, B, and C[1]. The notation Δ_{xy} indicates indicates the difference in the outcomes and percentage change from scheme X to scheme Y, where a positive or negative number means an increase or decrease in the outcome measured from scheme X to scheme Y.

Cumulative infections

Table 1 shows the projected infections during the outcomes period under the three vaccination schemes. No prioritization yielded the fewest number of infections for all scenarios when considering the overall and non-high-risk population. Within the high-risk population, no prioritization performed the best (fewest infections) in all cases, except when the vaccine start was in December with a rollout speed of 3 (3% of the population gets vaccinated weekly) and when the vaccine start was in September with rollout speeds of 2 or 3. In those 3 cases, multi-staged prioritization (prioritization of elderly and then high-risk) performed the best. We observed similar patterns across vaccine prioritization schemes in both vaccine start dates.

Table 2 shows that when comparing no vaccine prioritization to two-staged prioritization of only the elderly and multi-staged prioritization of elderly and high-risk, the prioritization of individuals resulted in a significant increase in infections, ranging up to 500,670 additional infections or up to a 49, 37, and 57% increase in overall, high-risk, and non-high-risk infections, respectively. When comparing two-staged and multi-staged prioritization, multi-staged prioritization performed better in most of the scenarios. The difference in infections for the overall and non-high-risk population was small (less than 9% change). However, multi-staged prioritization significantly decreased infections within the high-risk population when the vaccine start was in December with a rollout speed of 3 (26,219 fewer high-risk infections or a 10% decrease) or when the vaccine start was earlier in September with rollout speeds of 2 or 3 (up to 33,319 fewer high-risk infections or up to a 21% decrease).

Cumulative Hospitalizations

No prioritization yielded the lowest overall hospitalizations in all scenarios when the rollout speed is 1 or 2. Multi-staged prioritization resulted in the lowest overall hospitalizations when the rollout speed is 3. Within the high-risk population, no prioritization was the best at rollout speed of 1, while multi-staged prioritization was the best scheme at rollout speeds 2 and 3 for both vaccination start dates.

Similar to the results observed regarding infections, hospitalizations increased when only the elderly are prioritized by two-staged prioritization versus no prioritization. Multi-staged prioritization of elderly and high-risk populations reduced the hospitalizations for the high-risk group when the rollout speeds are 2, and 3 for both vaccinations start dates compared to no prioritization. Multi-staged prioritization performed better than two-staged prioritization for both the overall and high-risk populations with percentage decreases ranging from 1 to 17% depending on the scenario and up to 1,580 fewer hospitalizations.

Cumulative Deaths

When evaluating cumulative deaths, two-staged and multi-staged prioritization yielded the fewest number of deaths, while no prioritization yielded the highest number of deaths, contrary to the results observed in infections and hospitalizations. The relative ranking between the performance of two-staged and multi-staged prioritization depends on the vaccine start date, subpopulation evaluated, and rollout speed.

When the vaccine start is in December, and we evaluate overall and high-risk populations, two-staged prioritization yielded the fewest number of deaths with the rollout speed of 1, while multi-staged prioritization performed the best with the rollout speed set to 2 and 3. When the vaccine start is in September, multi-staged prioritization yielded the fewest number of deaths for the overall and high-risk population at all rollout speeds.

When vaccine prioritization is put in place (two-staged or multi-staged), there was a substantial proportionate reduction in deaths, up to 1,030 fewer deaths or up to a 26% decrease when compared to no prioritization. The multi-staged prioritization of elderly and high-risk populations results in fewer deaths for the overall and high-risk groups compared to when only the elderly are prioritized (up to 209 fewer deaths or up to 6% and 8% decrease in the overall and high-risk populations, respectively). The percentage reduction in deaths by including the high-risk population as a priority is more significant when the vaccine start is earlier and the rollout speed is faster.

Discussion

Desperate situations often call for desperate measures. In the setting of a rapidly emerging epidemic of a new disease or pandemic, there are usually shortages of critical supplies for prevention or treatment, whether they be non-pharmaceutical (like N-95 masks), novel vaccines, or new therapeutics. In such circumstances, priorities are often set for implementing specific interventions. Informing the approach for setting priorities can be critical for reaching specific outcomes.

Our analyses show the impact on infections, hospitalizations, and deaths when vaccine allocation prioritizes the elderly and/or high-risk populations. No prioritization is the best performing strategy at reducing the number of infections in almost all scenarios (up to 500,670 fewer cases when comparing to two-stage and multi-stage prioritization); however, it results in the largest number of deaths. By contrast, multi-staged prioritization of elderly and high-risk individuals is the best performing scheme to reduce the number of deaths. Our analyses comparing no-prioritization and two-staged prioritization follows the findings in the literature [11–13]; however, different from those, we implemented and evaluated multi-staged prioritizion, prioritizing high-risk individuals after vaccinating elderly and found it provides the greatest benefit in reducing COVID-19 mortality.

When evaluating infections in the high-risk population, multi-stage prioritization results in the fewest number of infections at higher implementation rates. When vaccination starts in December with a rollout speed of 3, there are 3,568 fewer high-risk cases or a 1.4% reduction. When vaccination starts in September with rollout speeds of 2 and 3, there are 1,995 fewer high-risk cases or a 1.5% reduction and 8,248 fewer high-risk cases or a 9% reduction, respectively, when compared to no prioritization. The reduction in hospitalizations as a consequence of the vaccine prioritization schemes is also observed at weekly vaccination rollout speeds of 2 and 3. When looking at hospitalizations within the high-risk population, who is the group that is more likely to get severe complications, the multi-staged prioritization of elderly and high-risk individuals performs the best (up to 687 fewer high-risk hospitalizations or up to an 8% reduction when the rollout speed is 2 and up to 1,491 fewer high-risk hospitalizations or up to a 13%

reduction when the rollout speed is 3, compared to no prioritization). Prioritization of only the elderly does not reduce hospitalizations compared to no prioritization.

The performance of the prioritization policies for deaths does not follow the general pattern we observed for infections and hospitalizations where no prioritization generally performs better. We observe significant reductions in deaths when prioritizing elderly and high-risk individuals since those populations have a higher probability of developing complications and dying, while hospitalizations only depend on age. No prioritization is the worst-performing strategy at reducing overall deaths and deaths among high-risk individuals. When vaccination starts in December and the vaccination rollout speed is 1, two-staged prioritization results in the fewest number of overall deaths and deaths among high-risk individuals (411 fewer overall deaths or a 7% reduction in overall and high-risk deaths compared to no prioritization). When the vaccination rollout speed increases to 2 and 3, multi-staged prioritization is the best at reducing overall deaths and deaths among high-risk individuals (up to 1,030 fewer deaths or up to a 24% and a 26% reduction in overall and high-risk deaths, respectively, compared to no prioritization). For non-high-risk individuals, there are no significant differences in the number of resulting deaths when following two-staged or multi-staged prioritization. When vaccination starts in September, multi-staged prioritization remains the best strategy at reducing overall deaths and deaths among high-risk individuals at all vaccination rates (up to 472 fewer deaths or up to a 21% and a 24% reduction in overall and high-risk deaths, respectively, compared to no prioritization.)

The results show that the ranking of the prioritization schemes depends on the vaccination start date, subpopulation evaluated, rollout speed, and outcome considered. Therefore, policymakers should consider factors related to vaccine deployment when choosing a vaccine prioritization scheme. However, another critical factor to consider is the additional burden that vaccine prioritization can have on the system that might result in delays in getting people immunized. Having no vaccine prioritization, i.e., opening vaccination to every adult regardless of age, reduces the spread of the pandemic by limiting infection but results in a higher number of deaths, especially among the elderly and high-risk population. While the prioritization of the vaccination of the elderly and high-risk individuals can have a significant impact, especially in reducing hospitalizations and deaths in the overall and high-risk populations, it is important to mention that its benefits might be not be realized fully if the rollout of the vaccine slows down due to logistical, access, and communication barriers, among others.

We ran an alternative scenario [see Supplementary Section B, Additional File 1] where the vaccination start date in two-staged and multi-staged prioritization was pushed a week later compared to no prioritization to illustrate potential delays due to following a prioritization schedule. The results showed that when a delay occurs, no prioritization strictly dominates two-staged and multi-staged prioritization for infections and hospitalizations. However, the schemes with prioritization still resulted in lower overall and high-risk deaths than no prioritization for all scenarios. The decrease in deaths due to the prioritization schemes ranges up to 13%, as opposed to 26% when there were no delays. For example, when the vaccine starts in December with a rollout speed of 3, no prioritization results in 4,295 overall deaths and 3,757 high-risk deaths, while multi-stage prioritization results in 3,265 overall deaths and 2,768 high-risk deaths (a 24% decrease in overall deaths and a 26% decrease in high-risk deaths). In the case that vaccines are delayed by one week due to prioritization logistics, multi-stage prioritization results in 4,000 overall deaths and 3,419 high-risk deaths. Even with the week delay, multi-stage prioritization results in 295 fewer overall deaths (a 7% reduction) and 338 fewer high-risk deaths (a 9% reduction).

The findings of this study show that multi-staged prioritization performs better, reducing hospitalization and deaths when compared to two-staged prioritization, especially at a rollout speed of 2 or 3. However, two-staged prioritization only requires the allocation of vaccines prioritizing the elderly as opposed to multi-staged prioritization that also requires allocation by risk group, and therefore implies greater coordination efforts. It is important to ensure that incorporating a staggered vaccination rollout by age and risk factors does not impair the vaccine rollout speed.

African-Americans, Hispanics, and native Americans have been at disproportionate risk for COVID-associated illness, hospitalization, and death since the beginning of the pandemic largely due to greater risks of exposure due to inequitable social determinants of health and access to medical care [20]. It may be useful in future models to consider how equitable vaccine promotion and access would impact hospitalizations and deaths.

The results of the impact of prioritization of elderly and high-risk individuals during vaccination rollout can be applied to vaccine distribution across the US; however, results depend on the prevalence of elderly and high-risk individuals in the population studied.

Conclusion

Opening vaccination to the adult population regardless of age simplifies vaccine rollout and reduces infection spread but results in a higher number of deaths, especially among the elderly and high-risk population. Elderly and high-risk population prioritization during the vaccine rollout results in fewer high-risk hospitalization and overall and high-risk deaths than no vaccine prioritization. Incorporating the prioritization of the elderly and then high-risk population over prioritizing only the elderly provides a benefit in reducing hospitalizations and deaths; however, such benefits might not be realized fully as vaccine eligibility criteria might be harder to communicate, and the vaccine distribution might slow down. The approach taken to evaluate staged approaches could be useful for a variety of other (non-vaccine) interventions in the setting of an acute crisis where key interventions are in short supply.

Declarations

Ethics approval and consent to participate: All methods were carried out in accordance with relevant guidelines and regulations.

Consent for publication: Not applicable.

Availability of data and materials: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request. All data used was publicly available in U.S. Census Bureau American Community Survey (https://www.census.gov/newsroom/press-kits/2019/acs-1year.html), U.S. Census Bureau Census Transportation Planning Products (https://ctpp.transportation.org/ctpp-data-set-information/), Georgia Department of Public Health COVID-19 Daily Status Report (https://dph.georgia.gov/covid-19-daily-status-report) and Georgia Department of Public Health Covid-19 Vaccine Dashboard (https://experience.arcgis.com/experience/3d8eea39f5c1443db1743a4cb8948a9c), and model parameters used are provided in Supplementary Section A, Additional File 1.

Competing interests: The authors declare that they have no competing interests.

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