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Observational Study

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Estimating Vaccine-Preventable COVID-19 Deaths Among Adults Under Counterfactual Vaccination Scenarios in The United States: A Modeling Study Using Observational Data

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Abstract

Introduction: In early 2021, effective SARS-CoV-2 (COVID-19) vaccines became available in the United States; by mid-April 2021, vaccine availability outstripped demand, daily vaccination rates peaked, and COVID-19 vaccines were found highly effective in adult populations. Accurate estimates of the number of vaccine-preventable deaths had higher vaccination rates been attained could have helped local policymakers and possibly persuaded more to get vaccinated.

Methods: Because existing estimation methodologies are limited, for the period 1/1/21 – 4/30/22, we simulated the number of vaccine-preventable deaths associated with two-dose COVID-19 vaccination that incorporated state-level population, death, and vaccination numbers and three scenarios of vaccination rate achievement.

Results: Nationally, we found that had 100% of the population became fully vaccinated during the period examined, 318,979 deaths, or approximately 50% of reported COVID-19 deaths, might have been prevented; had 85% been so, 28% might have been prevented. Across states, we found substantial variation in the proportion of avoidable COVID-19 deaths that might have been avoided at the state level, from 25% in Massachusetts to 74% in Alaska.

Conclusion: Our findings are sobering when considering the number of deaths and diversion of scarce and expensive healthcare resources that might have been averted had peak vaccination administration efforts been maintained.

Keywords: COVID-19; vaccine-preventable deaths; modeling

Introduction

In early 2021, effective SARS-CoV-2 (COVID-19) vaccines became available in the United States; by mid-April 2021, vaccine availability outstripped demand and daily vaccination rates peaked [1,2]. Early on, COVID-19 vaccines were found highly effective in adult populations: analysis of 50 real-world studies showed full vaccination was associated with ≥82%, ≥81%, and ≥94% reductions in hospitalization, severe disease or ICU admission, and death, respectively [3]. Availability of accurate estimates of the number of vaccine-preventable deaths if higher vaccination rates been attained might have helped local policymakers persuade more to get vaccinated. However, existing estimation methodologies rely on data from a limited

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number of states [4] or use a single vaccine maximization rate scenario [5]. To address these limitations, for the adult US population, we simulated the number of vaccine-preventable deaths associated with two-dose COVID-19 vaccination that incorporated state-level population, death, and vaccination numbers and three scenarios of vaccination rate achievement. We anticipated that models of increasingly higher vaccination uptake would generate estimates of increasing potentially avoidable deaths from COVID-19.

Methods

Data sources

We conducted a modeling study that relied on United States state-level observational data on adult COVID-19 deaths and vaccination rates that were publicly reported between 1/1/21-4/30/22. From the New York Times, [1] we obtained numbers of adult (aged 18+) COVID-19 deaths; from the Centers for Disease Control (CDC), [2] we obtained numbers of adults (aged 18+) who had received at least two COVID-19 vaccination injections.

Statistical methods

We developed a COVID-19 vaccine-preventable death estimation model based on the assumptions that a) once a state reached its peak vaccination administration capacity, it could maintain that level indefinitely, and b) the effective reproductive number of COVID-19 cases did not change. These are both conservative assumptions: as there were no local supply constraints, weekly vaccination administration might have increased; as more of the population becomes vaccinated, the effective reproductive number decreases. These assumptions allowed us to create a model that generates a lower-bound estimate of COVID-19 deaths had different proportions of the adult population been vaccinated following state-specific peak vaccination administration rates, as follows.

For a given state, the week when vaccine administration reached its peak marks the starting point of the counterfactual simulation. Until then, the estimated number equals the reported number of weekly deaths. After that, we assumed the number of vaccines administered remained at the state- and week-specific peak level until 85%, 90% or 100% of the state's adult population was vaccinated. For every week after peak vaccine administration, we applied state-specific death rates of vaccinated and unvaccinated populations to the modeled size of those populations to estimate a counterfactual COVID-19 death count. Vaccine-preventable COVID-19 deaths were obtained by subtracting estimated counterfactual COVID-19 death count estimates from reported ones (**Figure**). We repeated this computation for each state and totaled the results to obtain state and national estimates of avoidable COVID-19 deaths between 1/1/21-4/30/22. We followed STROBE guidelines. No administrative permissions are required to access the data used in this study. Because we used aggregated, publicly available data, the study did not require human subjects approval. The authors did not have access to information that could identify individual participants during or after the study.

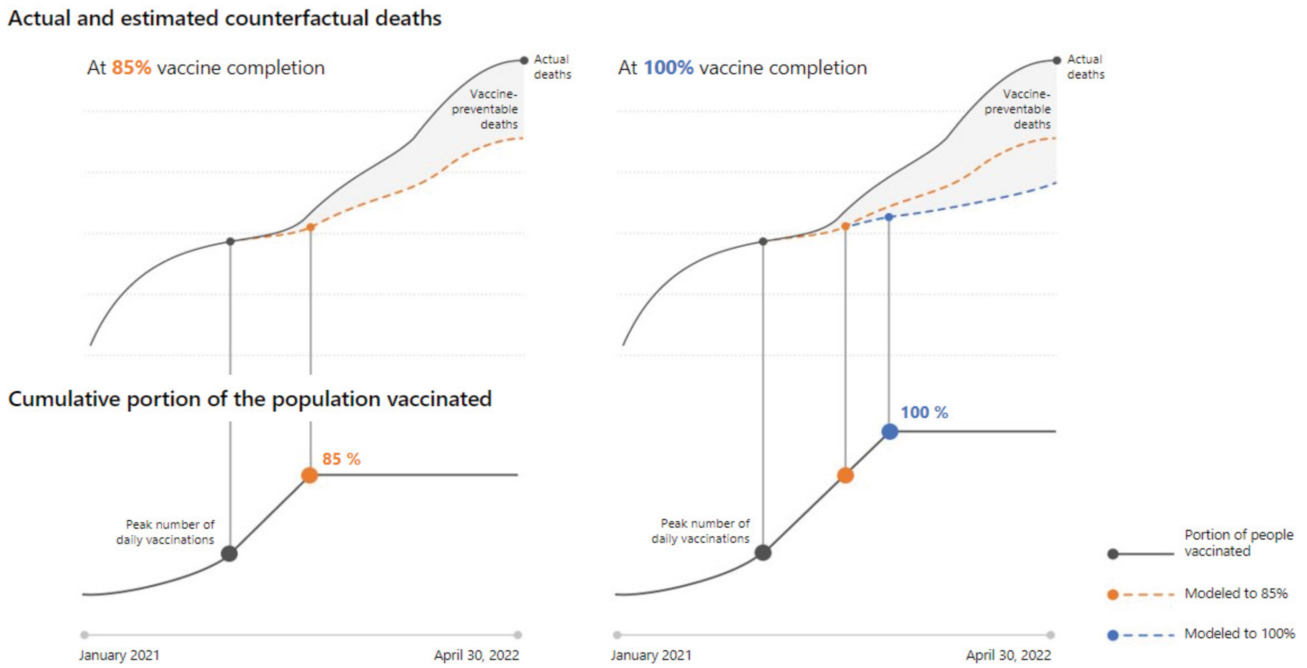

Figure 1: Demonstration of the model, showing the process for estimating vaccine-preventable deaths had 85% (left, orange) or 100% (right, blue) of the adult population been vaccinated. The figure is a representation and does not reflect data for a particular state.

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Results

Nationally, assuming 100% of the population became fully vaccinated during the period examined, we estimated that 318,979 deaths, or approximately 50% reported COVID-19 deaths, might have been prevented (**Table**); had 85% been so, we estimated that 28% might have been prevented. Across states, we found substantial variation in the proportion of avoidable COVID-19 deaths that might have been avoided at the state level, from 25% in Massachusetts to 74% in Alaska.

Discussion

We found that sustaining peak vaccination administration rates might have prevented half of COVID-19 deaths during the period examined. Complemented by recent estimates that 235,000 deaths were avoided because of successful vaccination between 12/1/20-9/31/21, [6] our work helps articulate the public health costs associated with suboptimal vaccination coverage. While our findings likely reflect local decision-making regarding the balance of social, public

Table 1: State-level estimates of the avoidable number and percentage of COVID-19 deaths had 100%, 90%, or 85% of the adult population been vaccinated, at peak state-level vaccination administration rates, between 1/1/21-4/30/22.

State or district	Population aged 18 and older	Reported deaths	Avoidable number and percentage of reported deaths had this proportion of the adult population been vaccinated:					
			100%		90%		85%	
			N	%	N	%	N	%
Alabama	38,11,122	14,695	6,527	44%	5,358	36%	4,671	32%
Alaska	5,51,685	1,005	748	74%	550	55%	451	45%
Arizona	56,36,931	20,890	9,427	45%	6,883	33%	5,579	27%
Arkansas	23,20,067	7,660	4,497	59%	3,562	47%	3,066	40%
California	3,06,18,852	63,877	21,730	34%	13,944	22%	10,034	16%
Colorado	44,97,682	7,390	4,575	62%	2,994	41%	2,199	30%
Connecticut	28,39,879	4,751	1,962	41%	971	20%	476	10%
Delaware	7,70,098	1,977	1,012	51%	686	35%	523	26%
District of Columbia	5,77,314	548	164	30%	107	20%	78	14%
Florida	1,72,34,469	52,059	29,200	56%	20,405	39%	15,918	31%
Georgia	81,07,219	25,737	13,598	53%	10,549	41%	9,021	35%
Hawaii	11,15,979	1,128	734	65%	453	40%	312	28%
Idaho	13,39,965	3,479	2,318	67%	1,793	52%	1,523	44%
Illinois	98,59,679	19,681	10,173	52%	6,973	35%	5,374	27%
Indiana	51,64,353	15,177	7,467	49%	5,792	38%	4,842	32%
Iowa	24,28,640	5,583	2,879	52%	2,050	37%	1,635	29%
Kansas	22,13,106	5,756	2,977	52%	2,187	38%	1,792	31%
Kentucky	34,64,554	12,419	7,154	58%	5,373	43%	4,480	36%
Louisiana	35,60,226	9,760	5,182	53%	4,208	43%	3,641	37%
Maine	10,95,969	1,928	1,092	57%	529	27%	247	13%
Maryland	47,13,082	8,489	3,876	46%	2,331	27%	1,560	18%
Massachusetts	55,39,447	7,761	1,957	25%	1,180	15%	793	10%
Michigan	78,46,375	22,706	12,950	57%	9,566	42%	7,873	35%
Minnesota	43,36,514	7,342	4,258	58%	2,778	38%	2,034	28%
Mississippi	22,78,354	7,604	3,302	43%	2,795	37%	2,509	33%
Missouri	47,66,387	14,289	8,585	60%	6,595	46%	5,571	39%
Montana	8,40,029	2,392	1,464	61%	1,111	46%	934	39%
Nebraska	14,59,044	2,489	1,456	58%	1,030	41%	817	33%

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Nevada	23,85,240	7,617	4,223	55%	3,120	41%	2,556	34%
New Hampshire	11,04,426	1,711	926	54%	607	35%	447	26%
New Jersey	69,43,663	14,246	5,540	39%	3,139	22%	1,938	14%
New Mexico	16,19,953	4,965	2,467	50%	1,493	30%	1,005	20%
New York	1,54,17,677	29,830	11,195	38%	5,983	20%	3,392	11%
North Carolina	81,95,134	16,482	8,604	52%	6,462	39%	5,389	33%
North Dakota	5,81,523	998	650	65%	496	50%	418	42%
Ohio	91,09,592	29,411	15,875	54%	11,956	41%	9,996	34%
Oklahoma	30,06,685	11,744	5,833	50%	4,384	37%	3,654	31%
Oregon	33,52,774	5,999	3,798	63%	2,449	41%	1,773	30%
Pennsylvania	1,01,66,029	28,407	14,146	50%	9,561	34%	7,276	26%
Puerto Rico	26,18,532	2,681	1,232	46%	650	24%	359	13%
Rhode Island	8,54,658	1,763	611	35%	279	16%	113	6%
South Carolina	40,33,799	12,382	6,784	55%	5,187	42%	4,388	35%
South Dakota	6,67,244	1,411	754	53%	543	38%	438	31%
Tennessee	53,19,360	18,987	11,047	58%	8,507	45%	7,192	38%
Texas	2,16,13,563	59,795	29,773	50%	21,741	36%	17,692	30%
Utah	22,75,225	3,453	1,815	53%	1,233	36%	939	27%
Vermont	5,09,761	498	287	58%	137	28%	63	13%
Virginia	66,79,468	15,119	7,123	47%	4,418	29%	3,062	20%
Washington	59,52,622	9,223	5,299	57%	3,207	35%	2,156	23%
West Virginia	14,33,072	5,483	3,350	61%	2,566	47%	2,166	40%
Wisconsin	45,57,330	9,154	5,445	59%	3,809	42%	2,986	33%
Wyoming	4,44,716	1,374	938	68%	744	54%	647	47%
Total	25,78,29,067	6,41,305	3,18,979	50%	2,25,424	35%	1,77,998	28%

health, and economic priorities, such decisions might have differed had studies like ours informed them. Our study was limited because we did not have access to age- or race-specific data, causing us to assume that vaccine effectiveness was the same for all, regardless of age or race. While vaccine effectiveness varies according to age and race, the state-specific unvaccinated- and vaccinated-specific death rates that we used were the reported rates at the time reflecting the experienced death rates of the vaccinated and unvaccinated populations. In addition, we did not have information on variants, waning immunity, or single dose vaccines. Finally, we only had access to reported deaths – it is possible that COVID-19 deaths were underreported during the period examined, possibly making the proportion of deaths potentially saved even higher than what we estimated. Despite these limitations, our findings are sobering when considering the deaths and diversion of scarce and expensive healthcare resources that might have been averted had vaccination administration efforts been maintained at peak levels.

Acknowledgements

All authors have contributed to writing, designing, compiling and editing the final manuscript

Data availability: The datasets analyzed during the current study are publicly available at https://github.com/nytimes/covid-19-data___and https://data.cdc.gov/Public-Health-Surveillance/Rates-of-COVID-19-Casesor-Deaths-by-Age-Group-and/3rge-nu2a

Conflict of Interest: The authors have no conflicts of interest to report. As the study used publicly available data, IRB review was not required.

Disclosures: Views expressed in this manuscript are those of the authors and do not reflect the official views of the US government; the initial draft of this manuscript was prepared prior to the government service of Dr. Tsai and Ms. Friedhoff.

Competing Interests Statement: The authors have no conflicts of interest to report.

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Author Contributions

All authors warrant authorship.

An authorship contribution form is below.

	Criteria 1		Criteria 2		Criteria 3	Criteria 4
Author initials	Contributed to conception or design	Contributed to acquisition, analysis, or interpretation	Drafted the manuscript	Critically revised the manuscript	Gave final approval	Agrees to be accountable for all aspects of work ensuring integrity and accuracy
MZ		X		X	X	X
TG		X	X	X	X	X
MK	X			X	X	X
RJ	X			X	X	X
RD	X			X	X	X
AK		X		X	X	X
DM		X		X	X	X
SS		X		X	X	X
SN	X			X	X	X
TCT	X	X		X	X	X
SF	X			X	X	X
WBW		X	X	X	X	X
JMLF	X	X		X	X	X

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