



Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.



## Original Research

# Increasing COVID-19 vaccination in the United States: projected impact on cases, hospitalizations, and deaths by age and racial group



N. Kirson <sup>a</sup>, E. Swallow <sup>a,\*</sup>, J. Lu <sup>b</sup>, C. Foroughi <sup>a</sup>, B. Bookhart <sup>c</sup>, J.K. DeMartino <sup>c</sup>, J. Maynard <sup>a</sup>, Y. Shivdasani <sup>a</sup>, D. Eid <sup>a</sup>, P. Lefebvre <sup>d</sup>

<sup>a</sup> Analysis Group, Inc., Boston, MA, USA

<sup>b</sup> Analysis Group, Inc., Menlo Park, CA, USA

<sup>c</sup> Janssen Scientific Affairs, Titusville, NJ, USA

<sup>d</sup> Analysis Group, Inc., Montreal, Quebec, Canada

## ARTICLE INFO

## Article history:

Received 17 February 2022

Received in revised form

1 June 2022

Accepted 15 June 2022

Available online 23 June 2022

## Keywords:

COVID-19

Vaccine

Cases avoided

Hospitalizations avoided

Deaths avoided

Equity

## ABSTRACT

**Objectives:** Minority populations in the United States face a disproportionate burden of illness from COVID-19 infection and have lower vaccination rates compared with other groups. This study estimated the equity implications of increased COVID-19 vaccination in the United States, with a focus on the number of cases, hospitalizations, and deaths avoided.

**Study design:** This was an observational real-world modeling study.

**Methods:** Data from the Centers for Disease Control and Prevention (CDC) were used to identify the remaining unvaccinated US population by county, age, and race as of October 22, 2021. The number of COVID-19 cases, hospitalizations, and deaths avoided were calculated based on case incidence and death data from the CDC, along with data on race- and age-specific hospitalization multipliers, under a scenario in which half of the remaining unvaccinated population per county, race, and age group obtained a full vaccine regimen.

**Results:** Vaccinating half of the remaining unvaccinated population in each age and race subgroup within counties would result in an estimated 22.09 million COVID-19 cases avoided, 1.38 million hospitalizations avoided, and 150,000 deaths avoided over 12 months. Some minority groups, particularly Black and Hispanic/Latino populations, were projected to experience substantial benefits from increased vaccination rates as they face both lower vaccination rates and worse outcomes if infected with COVID-19.

**Conclusions:** Increasing COVID-19 vaccination in the United States not only benefits the population as a whole but also serves as a potentially useful lever to reduce the disproportionate burden of COVID-19 illness among minority populations.

© 2022 The Authors. Published by Elsevier Ltd on behalf of The Royal Society for Public Health. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

## Introduction

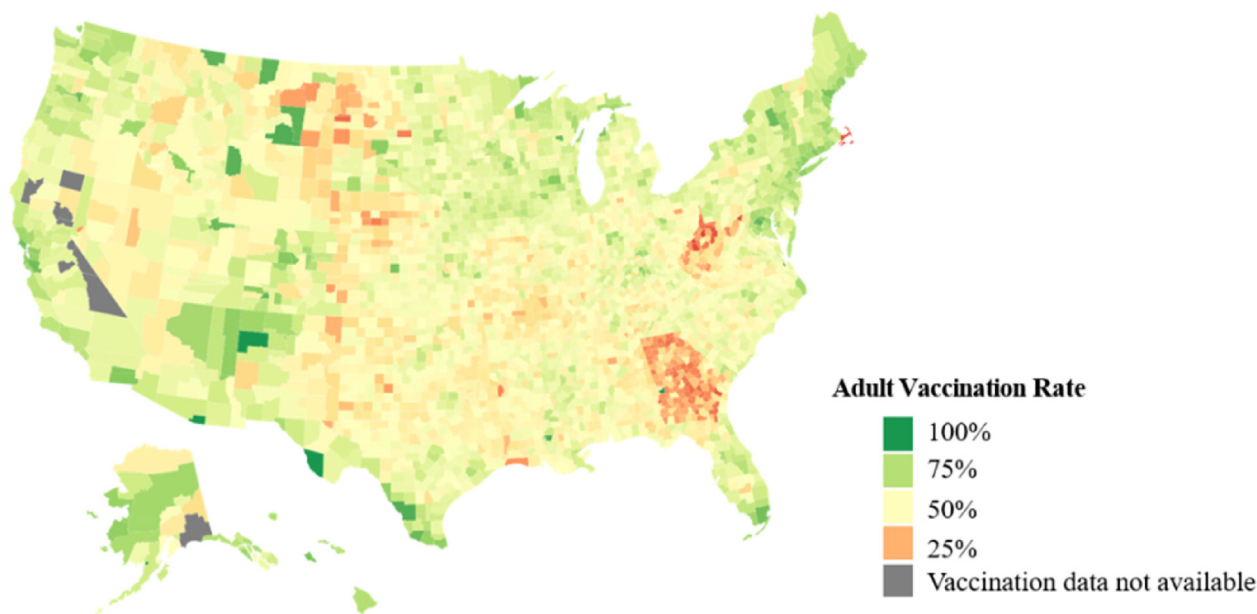
As of May 2022, more than 83.9 million cases of COVID-19 have been recorded in the United States, claiming the lives of more than 1 million people.<sup>1</sup> The approval of COVID-19 vaccines beginning in December 2020 has provided an important tool to combat the pandemic and prevent many hospitalizations and deaths associated with COVID-19. As of May 2022, approximately 221.3 million Americans have been fully vaccinated, and an additional 37.3 million Americans have received one dose of a two-dose regimen vaccine.<sup>2</sup> In addition, approximately 103.4 million fully vaccinated

Americans have received a booster dose.<sup>2</sup> However, vaccine uptake has varied widely across race, age, geography, and other socio-economic factors, contributing to inequities in COVID-19 hospitalizations and mortality in the United States. For example, the adult vaccination rate by US county ranges from 2% to 100% as of October 22, 2021 (Fig. 1).

Lower rates of COVID-19 vaccination have also been observed among vulnerable populations.<sup>3–5</sup> Using the Centers for Disease Control and Prevention (CDC)'s Social Vulnerability Index (SVI), which accounts for 15 social factors (e.g., poverty, lack of vehicle access, and crowded housing),<sup>6</sup> we plotted the county-level adult vaccination rates against SVI at two points in time: June 2021 (Fig. 2a) and October 2021 (Fig. 2b). At both time points, higher SVI was associated with lower vaccination rates. Interestingly, an additional 50.4 million US adults were vaccinated between June and

\* Corresponding author. Analysis Group, Inc., 111 Huntington Avenue, 14th floor, Boston, MA 02199, USA. Tel.: +1 617-425-8483

E-mail address: [elyse.swallow@analysisgroup.com](mailto:elyse.swallow@analysisgroup.com) (E. Swallow).



**Fig. 1.** COVID-19 vaccination rate by US county as of October 22, 2021. CDC, Centers for Disease Control and Prevention; US, United States. Data sources: (1) CDC (2021). COVID-19 vaccinations in the US, county. <https://data.cdc.gov/vaccinations/COVID-19-Vaccinations-in-the-United-States-County/8xkx-amqh>. Accessed October 22, 2021. (2) Texas Department of State (2021). Accessible Vaccine Dashboard Data. <https://dshs.texas.gov/coronavirus/AdditionalData.aspx>. Accessed October 22, 2021. (3) State of Hawai'i – Department of Health, Disease Outbreak Control Division (2021). Hawaii COVID-19 Vaccine Summary. <https://health.hawaii.gov/coronavirusdisease2019/current-situation-in-hawaii/>. Accessed October 22, 2021. (4) CDC (2021). Bridged-Race Population Estimates – Data Files and Documentation. [https://www.cdc.gov/nchs/nvss/bridged\\_race/data\\_documentation.htm](https://www.cdc.gov/nchs/nvss/bridged_race/data_documentation.htm). Accessed January 18, 2022.

October 2021,<sup>7</sup> while the Delta variant was circulating in the United States, and this increase appears to have weakened the strength of the negative relationship between vaccination rates and social vulnerability, as can be observed from the slopes of the two lines.

Motivated by these data, we sought to estimate how further increasing vaccination rates could impact COVID-19 cases, hospitalizations, and deaths among adults in the United States, stratified by age and race.

**Methods**

*Model overview*

A model was constructed in Excel to estimate the effect of increased COVID-19 vaccination among US adults, stratified by race and age, in terms of avoiding COVID-19 cases, hospitalizations, and deaths. The population of focus was unvaccinated US adults. Race categories included White, non-Hispanic; Hispanic/Latino; Black, non-Hispanic; Asian and Native Hawaiian/Pacific Islander, non-Hispanic; and American Indian/Alaskan Native, non-Hispanic. Age categories included 18–29 years, 30–39 years, 40–49 years, 50–64 years, 65–74 years, 75–84 years, and 85+ years. The time projection of the model was 12 months. We relied on several assumptions and findings from prior analyses and conducted a targeted review of existing CDC data, published literature, news articles, and public reports to identify the most relevant and up-to-date inputs for the model. The detailed model inputs, sources, and embedded assumptions used in the model are described in [Supplemental Tables 1 and 2](#).

*Estimating the currently unvaccinated US population*

The remaining unvaccinated population was quantified at the county level to identify the target population of expanded vaccination efforts. Vaccination data by county and age group reported by the CDC as of October 22, 2021 were used to inform the number of fully vaccinated adults in the United States. For 96% of US

counties, the October 22, 2021 vaccination counts were directly used as the steady state because vaccination uptake was plateauing in these counties. After fitting logistic curves to the CDC vaccination uptake data, a slightly higher steady-state vaccination rate was predicted for the remaining 4% of counties because they continued to exhibit an upward logistic trend in vaccination.

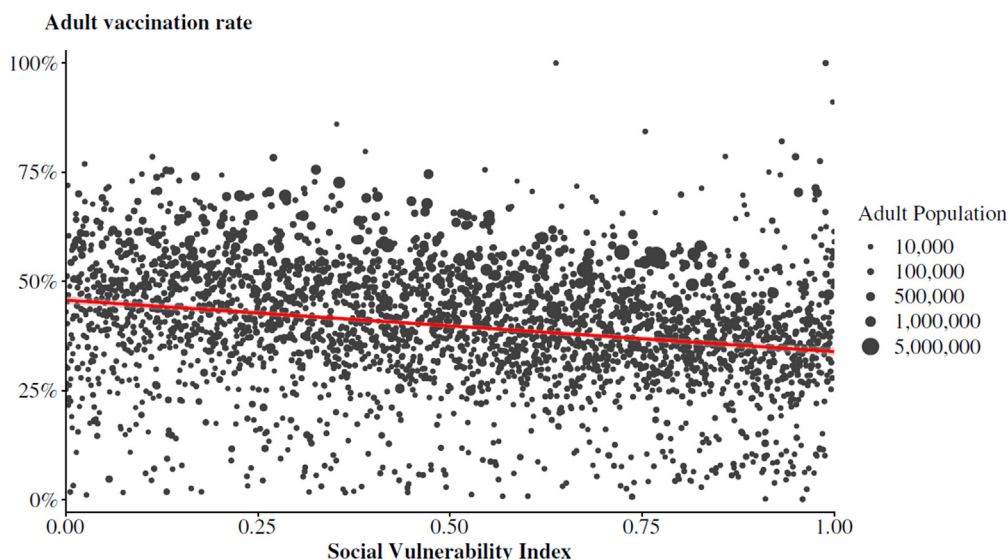
To account for heterogeneity in vaccine uptake across race, the county-by-age steady-state COVID-19 vaccination estimates informed from CDC data were further broken down by race. To do so, the vaccination uptake by race in the United States was weighted by the distribution of races within each county using county-level demographic data from the US Census Bureau (2020). The vaccinated counts across all US counties were summed to estimate the number of unvaccinated adults in the United States by race and age group.

*Estimating COVID-19-related outcomes avoided*

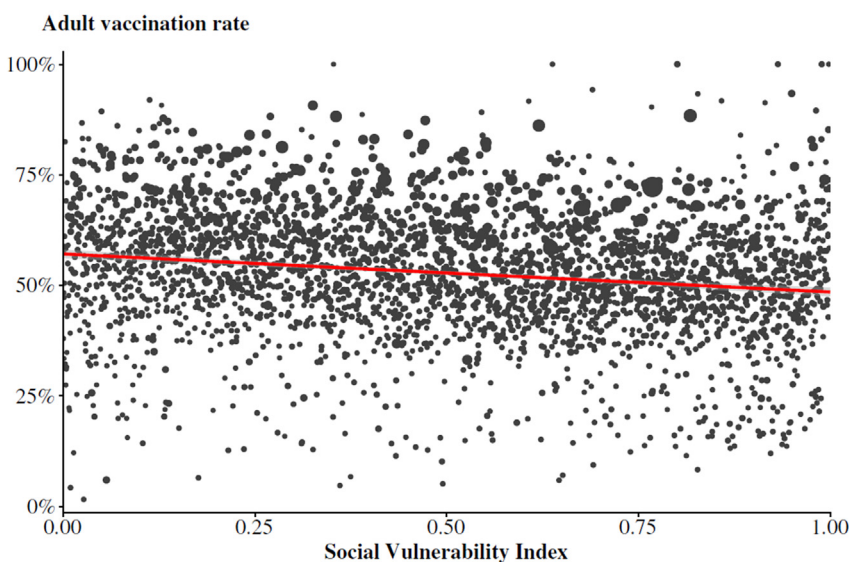
*COVID-19 cases*

To calculate the number of cases avoided by race and age, we first estimated the likelihood of an unvaccinated person in each subgroup contracting COVID-19. CDC data were used to estimate the race- and age-specific cumulative incidence of COVID-19 through September 2021, including cumulative incidence of COVID-19 by age group; COVID-19 infection likelihood multipliers by race relative to the White, non-Hispanic population; and the distribution of COVID-19 cases by race within each age group. The ratio of the average monthly COVID-19 case incidence from May 2021 through September 2021 in the United States to the cumulative incidence through September 2021 in the United States was then applied to the cumulative incidence through September 2021 for each race and age subgroup to estimate the monthly incidence of COVID-19 for each subgroup. We projected these monthly incidences forward linearly over 12 months to estimate the incidence of COVID-19 for each subgroup in 2022. To simplify our model, we did not attempt to incorporate any protective effect from potential previous infection with COVID-19.

a. As of June 2021<sup>a, b</sup>



b. As of October 2021<sup>c</sup>



**Fig. 2.** COVID-19 vaccination rate vs. Social Vulnerability Index by US county as of (a) June 2021 and (b) October 2021. A higher index value indicates greater social vulnerability. Each data point represents an individual county. CDC, Centers for Disease Control and Prevention. Data sources: (1) CDC (2021). COVID-19 vaccinations in the US, county. <https://data.cdc.gov/vaccinations/COVID-19-Vaccinations-in-the-United-States-County/8xxk-amqh>. Accessed June 7, 2021, and October 22, 2021. (2) Texas Department of State (2021). Accessible Vaccine Dashboard Data. <https://dshs.texas.gov/coronavirus/AdditionalData.aspx>. Accessed July 15, 2021, and October 22, 2021. (3) State of Hawai'i – Department of Health, Disease Outbreak Control Division (2021). Hawaii COVID-19 Vaccine Summary. <https://health.hawaii.gov/coronavirusdisease2019/current-situation-in-hawaii/>. Accessed July 15, 2021, and October 22, 2021. (4) CDC (2021). CDC/ATSDR Social Vulnerability Index. <https://www.atsdr.cdc.gov/placeandhealth/svi/index.html>. Accessed January 6, 2022. (5) CDC (2021). Bridged-Race Population Estimates – Data Files and Documentation. [https://www.cdc.gov/nchs/nvss/bridged\\_race/data\\_documentation.htm](https://www.cdc.gov/nchs/nvss/bridged_race/data_documentation.htm). Accessed January 18, 2022. <sup>a</sup>The results of a linear regression indicate a slope of  $-0.118$ , an  $R^2$  of  $0.06$ , an intercept of  $0.46$ , and a  $P$ -value of  $<0.01$ . <sup>b</sup>Vaccination data for all counties except those in Texas and Hawaii was accessed June 7, 2021. Vaccination data for counties within Texas and Hawaii was accessed July 15, 2021. <sup>c</sup>The results of a linear regression indicate a slope of  $-0.086$ , an  $R^2$  of  $0.03$ , an intercept of  $0.57$ , and a  $P$ -value of  $<0.01$ .

We estimated outcomes once an assumed 50% of the steady-state unvaccinated population in each county would get vaccinated in a scenario of increased vaccination. To calculate the number of cases avoided, we multiplied the likelihood of contracting COVID-19 over the next 12 months if unvaccinated by the number of unvaccinated people in each subgroup who would get vaccinated in the scenario of increased vaccination. We then applied a blended vaccine efficacy rate for preventing COVID-19

infection of 69%, representing a weighted average of the Janssen, Moderna, and Pfizer vaccine efficacies against the Delta variant.<sup>8–12,a</sup>

<sup>a</sup> An average of the upper and lower bound efficacies in preventing infection of the COVID-19 Delta variant was used for the Pfizer and Moderna vaccines.



**Table 1**  
Estimated COVID-19 vaccine uptake by race and age.

Age (years)	Race					Total
	White, non-Hispanic	Hispanic/Latino	Black, non-Hispanic	Asian and Native Hawaiian/Pacific Islander, non-Hispanic	American Indian/Alaskan Native, non-Hispanic	
18–29	53%	58%	46%	67%	59%	54%
30–39	53%	58%	46%	67%	60%	54%
40–49	61%	68%	53%	78%	69%	63%
50–64	68%	76%	60%	87%	76%	69%
65–74	78%	79%	66%	87%	88%	78%
75–84	78%	79%	66%	87%	88%	78%
85+	79%	79%	66%	87%	88%	78%
Total	65%	66%	54%	77%	70%	64%

*COVID-19 hospitalizations*

To calculate the number of hospitalizations avoided by race and age, we first used CDC COVID-19 hospitalization multipliers (relative to 18- to 29-year-olds) in conjunction with the likelihood of hospitalization for 18- to 29-year-olds from Bhatia and Klausner<sup>13</sup> to obtain the likelihood of hospitalization given COVID-19 infection for each age group.<sup>b</sup> To adjust for race-specific hospitalization rates, we used additional CDC data including the distribution of COVID-19 cases by race within each age group and COVID-19 hospitalization multipliers by race relative to the White, non-Hispanic population. To calculate the number of hospitalizations avoided, the estimated number of COVID-19 cases avoided was multiplied by the likelihood of hospitalization for each age and race subgroup. A blended vaccine efficacy rate for preventing serious illness of 88% was used, representing the weighted average of the Janssen, Moderna, and Pfizer efficacies against the Delta variant.<sup>12,14</sup>

*COVID-19 deaths*

To calculate the number of deaths avoided by race and age, we first estimated the race- and age-specific likelihood of death given a COVID-19 infection. We used age-specific infection fatality ratios from O’Driscoll et al.,<sup>15</sup> and then used CDC data on the number of COVID-19 cases and deaths to calculate race- and age-specific unadjusted case fatality ratios. We used these unadjusted case fatality ratios to create a likelihood of death multiplier by race relative to the White, non-Hispanic population within each age group. Using these multipliers and the distribution of COVID-19 cases by race within each age group from the CDC, we calculated the likelihood of death, given a COVID-19 infection, for each race and age subgroup. To calculate the number of COVID-19 deaths avoided, we multiplied our estimated number of COVID-19 cases avoided by the likelihood of death for each age and race subgroup, and we used the blended vaccine efficacy rate for preventing serious illness (88%) as described previously. Because vaccines are more effective at preventing deaths than hospitalizations, using this efficacy rate resulted in a conservative estimate of the number of COVID-19 deaths avoided.

*Scenario analysis*

Finally, as the results of this study are based on an assumption in which 50% of the currently unvaccinated US population would receive vaccinations, we conducted a scenario analysis to assess the equity implications of increasing or decreasing vaccine uptake. In our scenario analysis, we estimated COVID-19 outcomes by age and

race in scenarios in which 40% and 60% of the currently unvaccinated US population would receive vaccinations.

**Results**

The estimated steady-state vaccination uptake rates by race and age subgroups are presented in Table 1. Vaccination uptake increased substantially with age, with an estimated 78% of adults aged >65 years being vaccinated compared with 54% of adults between the ages of 18 and 39 years. Vaccination uptake also varied widely by race, with the highest estimated vaccination rate among the Asian and Native Hawaiian/Pacific Islander, non-Hispanic population (77%), and the lowest rate among the Black, non-Hispanic population (54%). Overall, we estimated that 64% of adults in the United States would be vaccinated in the steady state, given vaccination data from the CDC as of October 22, 2021, leaving 91.7 million adults in the United States unvaccinated at the time of the study’s conduct.

Overall, we estimated that vaccinating 50% of the steady-state unvaccinated population would result in the avoidance of 22.09 million cases, 1.38 million hospitalizations, and 150,000 deaths due to COVID-19. The distribution of COVID-19 cases, hospitalizations, and deaths avoided by race within each age group is illustrated in Fig. 3. The counts for each population and the cases, hospitalizations, and deaths avoided by race are presented in more granularity by age group in Supplemental Table 3.

In almost every age group, minorities accounted for a greater share of cases avoided relative to their proportion of the overall US population, indicating that increasing vaccination will help minorities avoid COVID-19 infection slightly more than the White, non-Hispanic population. However, the largest equity implications estimated to result from vaccinating half of the unvaccinated US population were related to hospitalizations and deaths avoided. For 18- to 29-year-olds, minorities compose 45% of the population, but 78% of hospitalizations avoided and 68% of deaths avoided; for 30- to 49-year-olds, minorities compose 43% of the population, but 74% of hospitalizations avoided and 62% of deaths avoided; for 50- to 64-year-olds, minorities compose 33% of the population, but 56% of hospitalizations avoided and 47% of deaths avoided; and for those aged >65 years, minorities compose 24% of the population, but 37% of hospitalizations avoided and 30% of deaths avoided.

The likelihood of dying from COVID-19 is greatly driven by age, with those aged >65 years at much higher risk than those aged <65 years.<sup>15</sup> As the infection fatality ratios for those aged <65 years are less than 1%,<sup>15</sup> we aggregated these age groups to compare COVID-19 deaths avoided per 100,000 population by race for those aged <65 years and ≥65 years (Fig. 4).

For 18- to 64-year-olds, we estimated a larger number of deaths avoided per 100,000 population for the Black, Hispanic/Latino, and American Indian/Alaskan Native populations than we did for the

<sup>b</sup> While Bhatia and Klausner estimate the likelihood of hospitalization for 20 to 29-year-olds, we used this as a proxy for the 18 to 29-year-old age group for our calculations.

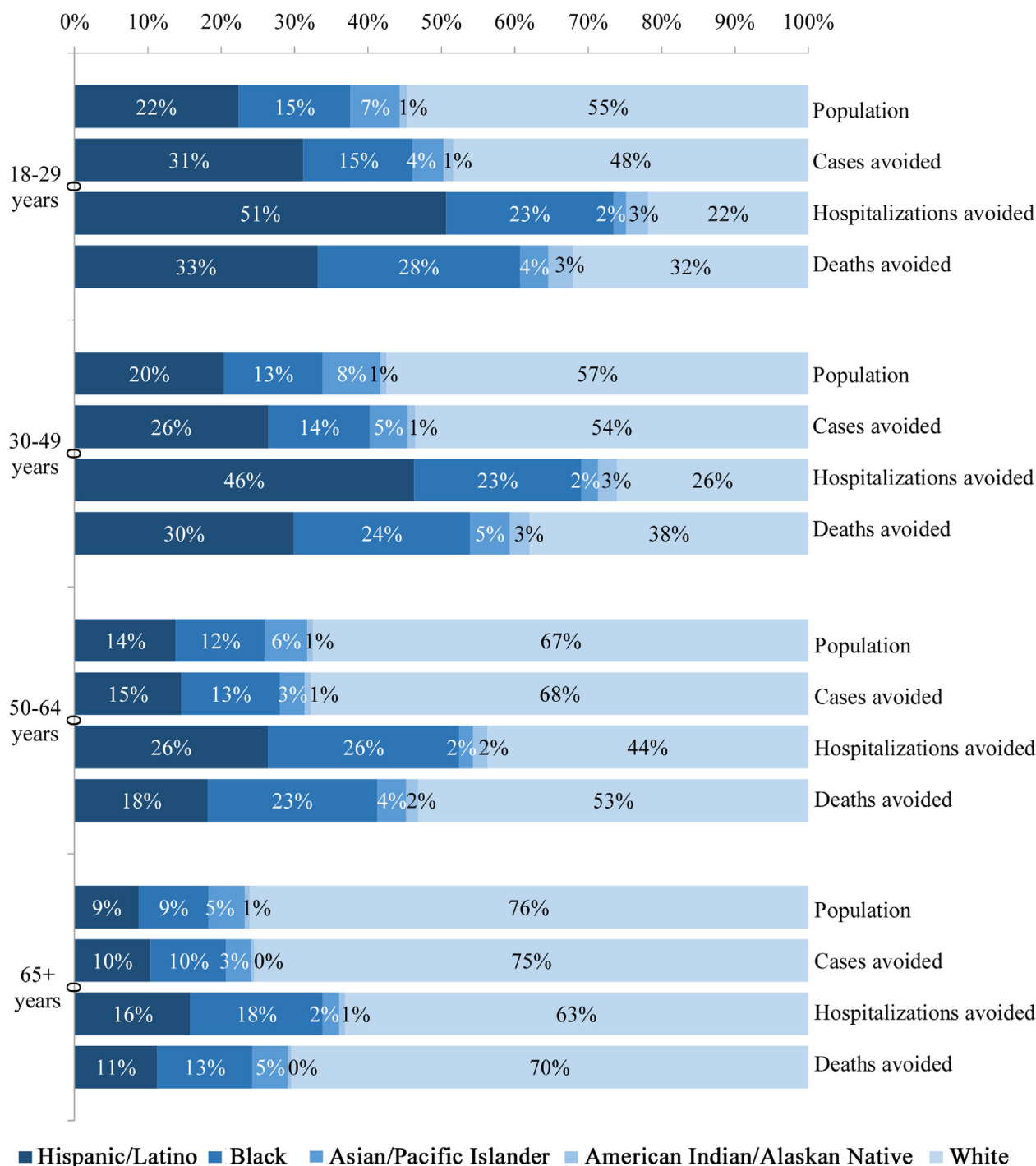


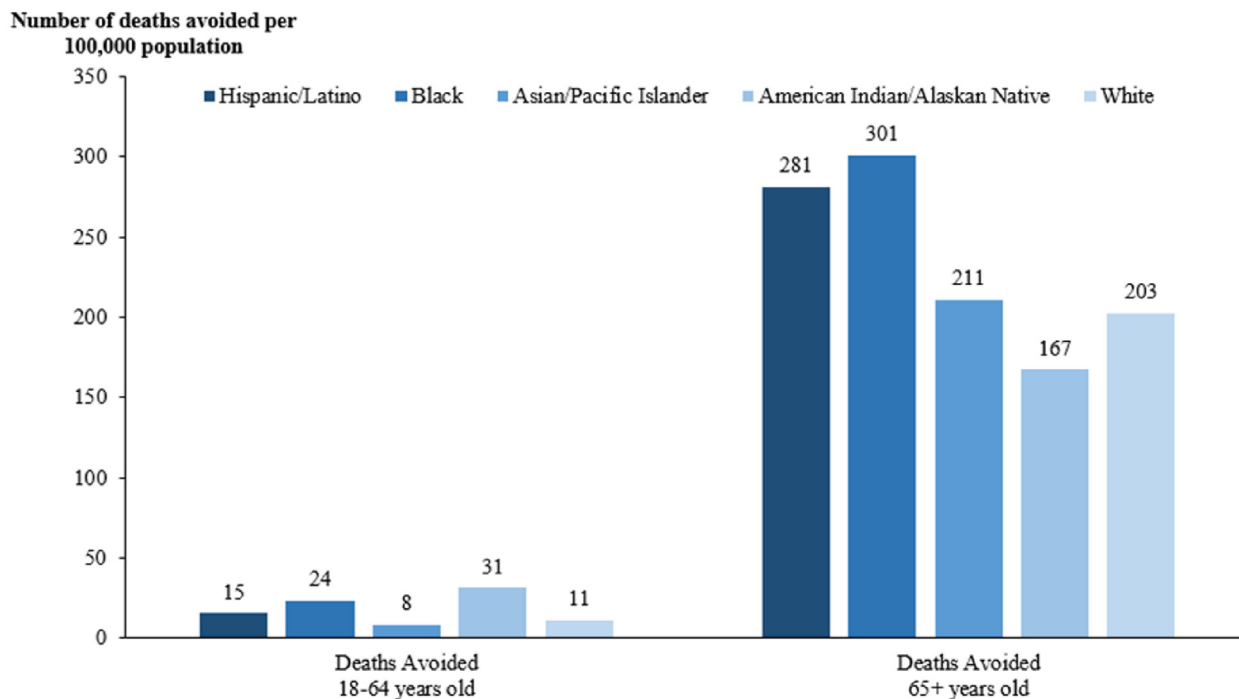
Fig. 3. Distribution of COVID-19 outcomes by race and age group.

White, non-Hispanic population. Most notably, for people aged 18–64 years, vaccinating half of the steady-state unvaccinated White population resulted in 11 deaths avoided per 100,000 population, whereas vaccinating half of the steady-state unvaccinated Black or American Indian/Alaskan Native population resulted in 24 and 31 deaths avoided, respectively, per 100,000 population.

Given the higher death rates associated with COVID-19 among the elderly, our model estimated a greater number of deaths avoided per 100,000 population across all racial groups for those aged ≥65 years. However, Black and Hispanic/Latino populations were estimated to benefit more than White, non-Hispanic people

from increased vaccination. For people aged ≥65 years, vaccinating half of the steady-state unvaccinated White population resulted in 203 deaths avoided per 100,000 population, whereas vaccinating half of the steady-state unvaccinated Hispanic/Latino or Black population resulted in 281 and 301 deaths avoided, respectively, per 100,000 population. This indicates that among older Americans who are at higher risk of death if infected with COVID-19, increased vaccination would especially benefit Black and Hispanic/Latino populations.

Supplemental Figure 1 reports the findings of our scenario analysis by illustrating the number of deaths avoided per 100,000



Abbreviation: US, United States

Fig. 4. COVID-19 deaths avoided per 100,000 US adults by race and age group.

US adults aged  $\geq 65$  years by race relative to the White, non-Hispanic population in scenarios where 40%, 50% (our current base case), and 60% of the currently unvaccinated US population would get fully vaccinated.

As shown in Supplemental Figure 1, adjusting vaccine uptake does not change our result that more deaths are avoided per 100,000 US adults aged  $\geq 65$  years for Hispanic/Latino, Black, and Asian/Pacific Islander populations than for the White, non-Hispanic population. However, increasing vaccine uptake increases the magnitude of these equity implications; in particular, increasing vaccine uptake by 10 percentage points (e.g. from 50% to 60%) results in an additional 15 and 20 deaths avoided per 100,000 US adults aged  $\geq 65$  years for Hispanic/Latino and Black populations, respectively, relative to the White, non-Hispanic population. Increasing (or decreasing) vaccine uptake would also cause our estimates of overall cases, hospitalizations, and deaths avoided to scale proportionately.

### Discussion

Our study estimated that vaccinating half of the remaining unvaccinated US population for COVID-19 would result in the avoidance of 22 million cases, 1.4 million hospitalizations, and 150,000 deaths in 2022. Importantly, our findings indicate that increased vaccination would disproportionately affect outcomes for most minority populations, particularly Black and Hispanic/Latino populations. We estimated that minorities would account for a relatively larger share of COVID-19-associated hospitalizations and deaths avoided, particularly the former.

These results are striking in the context of well-documented evidence regarding COVID-19 outcomes among minority populations. For example, Acosta et al.<sup>16</sup> found that people who were American Indian/Alaskan Native, Hispanic/Latino, Black, or Asian/

Pacific Islander were more likely to be hospitalized, admitted to the intensive care unit, or die compared with non-Hispanic White individuals in the first year of the COVID-19 pandemic (2020). An National Public Radio analysis, using CDC data through September 2020, also found that Black, Hispanic, and Native American populations represented a disproportionate share of COVID-19 cases and deaths relative to their share of population.<sup>17</sup> The CDC has also recognized the impact of racial inequities on minorities' COVID-19 outcomes.<sup>18</sup>

The disproportionate burden of the pandemic on minorities is likely due to both structural and socio-economic factors, including access to health care and differences in types of employment and working conditions.<sup>19–22</sup> Some of these differences manifest as increased exposure to COVID-19, as minorities are disproportionately more likely to live in higher density housing, rely on public transportation, and work in an essential industry requiring them to work in person.<sup>21,23</sup> Other differences, such as reduced access to and trust in the healthcare system, may lead minorities to delay or receive suboptimal treatment. All these factors may increase the prevalence of comorbidities among minorities, which also elevates the risk of hospitalization or death due to COVID-19.<sup>24</sup> However, Rubin-Miller et al. found that underlying medical conditions and sociodemographic factors did not fully explain why minorities experienced increased hospitalization and death rates from COVID-19, suggesting that racism and discrimination negatively affect COVID-19 outcomes through other avenues.<sup>25</sup> These same factors may also help explain why the Black population is less likely to be vaccinated against COVID-19 than other racial groups, as distrust in the healthcare system due to discrimination, lack of healthcare access, inability to take time off from work, and transportation obstacles lead to decreased vaccination uptake.<sup>20</sup> While addressing these underlying sources of inequity is important, in the short term, increasing rates of

vaccination is a direct intervention that can reduce both the overall burden and heterogeneity in outcomes associated with the COVID-19 pandemic. Our findings highlight the urgent need for additional research to identify policies that can increase vaccine uptake in the United States, especially among minority populations.

The results of this study should be considered in light of several limitations. First, as our results are based on data as of October 2021, our model takes into account the Alpha and Delta variants of the COVID-19 virus, but not the Omicron variant, which began circulating in the United States in December 2021.<sup>26</sup> The Omicron variant and future variants could affect the number of individuals who decide to get vaccinated (either for primary or booster vaccination), potentially increasing vaccinations similar to what occurred following the Delta surge in the summer of 2021 and therefore changing the steady-state vaccination rate used in our model. In addition, hospitalization and death rates are lower for Omicron, which may be associated with a reduced impact of increased vaccination on the number of hospitalizations and deaths avoided.<sup>27</sup>

Second, our estimates regarding COVID-19 outcomes also depend on assumptions regarding vaccine efficacy. Vaccine efficacy may diminish as immunity wanes and new variants emerge; for example, breakthrough cases were more common for the Omicron variant than the Alpha and Delta variants, which would lead to fewer cases avoided through increased vaccination in our model.<sup>28</sup> Diminishing vaccine efficacy also gives rise to the need for booster shots, which may complicate the definition of “fully vaccinated.” Future research is warranted to account for newer COVID-19 variants and the associated changes in vaccine efficacy and policies surrounding boosters. Regardless, although our estimates of the absolute numbers of COVID-19 outcomes avoided depend on vaccine efficacy and considerations surrounding boosters, our equity conclusions would not fundamentally change. Adjusting vaccine efficacy would have a similar effect as adjusting the vaccine uptake in our scenario analysis; while it may affect the magnitude of the equity implications, minorities continue to account for a disproportionate share of cases, hospitalizations, and deaths avoided, so closing the vaccination gap is critical to reducing disease burden among those populations.

Third, when projecting future cases avoided due to increased vaccination, we also assumed that monthly incidence of COVID-19 would remain constant over the next 12 months. Although we recognize that this is not realistic and that the number of new cases would surge and decline throughout the next year, we accounted for this variability by averaging the monthly incidence of COVID-19 from May through September 2021 when calculating projected cases avoided per month. May through September 2021 included both highs and lows of COVID-19 case incidence; cases were at a low in May and June, averaging 640,000 new cases per month, while cases were at a high in August and September due to the Delta variant, averaging 4.2 million new cases per month.<sup>29</sup> The average monthly incidence from May through September 2021 of 2.2 million thus represents both the surges and declines in COVID-19 case incidence that may occur in the next year. In addition, when projecting future cases avoided due to increased vaccination, our model was not well suited to address the indirect effects of vaccination related to herd immunity. Because of the uncertainty in the scientific community around how to quantify the indirect effects of vaccination, as well as our primary goal to illustrate the equity implications of increased vaccination, we chose to pursue a simplified model to best present equity results and avoid false precision. Therefore, these findings may underestimate the number of cases, hospitalizations, and deaths avoided due to increased vaccination.

## Conclusion

Overall, we estimated that vaccinating half of the steady-state unvaccinated US population in each age and race subgroup would result in avoiding 22.09 million COVID-19 cases, 1.38 million hospitalizations, and 150,000 deaths. Because minorities are more likely to become seriously sick or die of COVID-19 and because some minorities, particularly Black people, are currently less likely to be vaccinated than their White counterparts, minorities are estimated to compose a disproportionately higher share of avoided COVID-19 outcomes relative to their population. Therefore, US minorities would receive the highest benefit from increases in current rates of COVID-19 vaccination. Further research is warranted to develop policy strategies to improve vaccine uptake in the United States.

## Author statements

### Acknowledgments

Editorial assistance was provided by Shelley Batts, PhD, an employee of Analysis Group, Inc.

### Ethical approval

Data in this study were previously collected from publicly available sources and did not include any identifying information; thus, no ethical review was required.

### Funding

This research was funded by Janssen Scientific Affairs, LLC.

### Competing interests

B.B. and J.K.D. are employees of Janssen, which is a manufacturer of a COVID-19 vaccine. N.K., E.S., J.L., C.F., J.M., Y.S., D.E., and P.L. are employees of Analysis Group, Inc., which received consulting fees from Janssen Scientific Affairs, LLC, for this study.

### Availability of data and materials

The county-level vaccination data set used in the present study was downloaded from the CDC repository on October 22, 2021, and is available from the corresponding author on reasonable request. The data set continues to be updated, and the up-to-date data set is available at <https://data.cdc.gov/Vaccinations/COVID-19-Vaccinations-in-the-United-States-County/8xkx-amqh>. The data on national vaccination uptake by race and, separately, by age used in the present study were downloaded from the CDC repository on November 2, 2021, and are available from the corresponding author on reasonable request. The data set continues to be updated, and the up-to-date data set is available at <https://covid.cdc.gov/covid-data-tracker/#vaccination-demographics-trends>. Data on county-level population demographics are available from the CDC repository at [https://www.cdc.gov/nchs/nvss/bridged\\_race/data\\_documentation.htm](https://www.cdc.gov/nchs/nvss/bridged_race/data_documentation.htm). Data on SVI (Social Vulnerability Index) are available from the CDC repository at [https://www.atsdr.cdc.gov/placeandhealth/svi/data\\_documentation\\_download.html](https://www.atsdr.cdc.gov/placeandhealth/svi/data_documentation_download.html). Other inputs used in the model are presented in the tables in the Supplemental Material. Intermediate data sets created during the present study are available from the corresponding author on reasonable request.



### Authors' contributions

N.K., E.S., J.L., B.B., and P.L. conceived the study. All authors contributed to the study design. C.F. and J.M. led the literature search, data collection, and analysis. C.F., J.M., Y.S., and D.E. conducted data analysis. All authors were involved in the interpretation of the results. J.L., C.F., and J.M. drafted the article, and N.K., E.S., P.L., B.B., and J.K.D. critically revised it. All authors have read and approved the final article.

### Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.puhe.2022.06.019>.

### References

1. United States COVID-19 cases, deaths, and laboratory testing (NAATs) by state, territory, and jurisdiction. Centers for Disease Control and Prevention (CDC); 2022 [31 May 2022]; Available from: [https://covid.cdc.gov/covid-data-tracker/#cases\\_casesper100klast7days](https://covid.cdc.gov/covid-data-tracker/#cases_casesper100klast7days).
2. See how vaccinations are going in your county and state. *N Y Times* 2022 [31 May 2022]; Available from: <https://www.nytimes.com/interactive/2020/us/covid-19-vaccine-doses.html>.
3. Barry V, Dasgupta S, Weller DL, Kriss JL, Cadwell BL, Rose C, et al. Patterns in COVID-19 vaccination coverage, by social vulnerability and urbanicity — United States, December 14, 2020–May 1, 2021. *MMWR Morb Mortal Wkly Rep* 2021;**70**:818–24.
4. Tolbert J, Orgera K, Garfield R, Kates J, Artiga S. Vaccination is local: COVID-19 vaccination rates vary by county and key characteristics. *Kaiser Family Foundation* 2021 [06 Jan 2021]; Available from: <https://www.kff.org/coronavirus-covid-19/issue-brief/vaccination-is-local-covid-19-vaccination-rates-vary-by-county-and-key-characteristics/>.
5. Stewart N, Smittenaar P, Sutermeister S, Coome L, Sgaier S [pre-print in medRxiv]. *Inequities among vulnerable communities during the COVID-19 vaccine rollout*. 2021 [13 Jan 2022]; Available from: <https://www.medrxiv.org/content/10.1101/2021.06.15.21258978v1>.
6. Centers for Disease Control and Prevention (CDC). Social Vulnerability Index (SVI) [06 Jan 2022]; Available from: <https://svi.cdc.gov/Documents/FactSheet/SVIFactSheet.pdf>.
7. COVID-19 vaccinations in the United States, jurisdiction. Centers for Disease Control and Prevention (CDC); 2022 [06 Jan 2022]; Available from: <https://data.cdc.gov/Vaccinations/COVID-19-Vaccinations-in-the-United-States-Jurisdiction>.
8. Johnson & Johnson's Janssen COVID-19 vaccine overview and safety. Centers for Disease Control and Prevention (CDC); 2021 [06 Jan 2022]; Available from: <https://www.cdc.gov/coronavirus/2019-ncov/vaccines/different-vaccines/janssen.html>.
9. Moderna COVID-19 vaccine overview and safety. Centers for Disease Control and Prevention (CDC); 2021 [06 Jan 2022]; Available from: <https://www.cdc.gov/coronavirus/2019-ncov/vaccines/different-vaccines/Moderna.html>.
10. Pfizer-BioNTech COVID-19 vaccine (also known as COMIRNATY) overview and safety. Centers for Disease Control and Prevention (CDC); 2022 [06 Jan 2022]; Available from: <https://www.cdc.gov/coronavirus/2019-ncov/vaccines/different-vaccines/Pfizer-BioNTech.html>.
11. COVID-19 vaccinations in the United States. Centers for Disease Control and Prevention (CDC); 2021 [11 Nov 2021]; Available from: [https://covid.cdc.gov/covid-data-tracker/#vaccinations\\_vacc-total-admin-rate-total](https://covid.cdc.gov/covid-data-tracker/#vaccinations_vacc-total-admin-rate-total).
12. Sakay YN. *Here's how well COVID-19 vaccines work against the Delta variant*. Healthline; 2021 [06 Jan 2022]; Available from: <https://www.healthline.com/health-news/heres-how-well-covid-19-vaccines-work-against-the-delta-variant>.
13. Bhatia R, Klausner J. Estimating individual risks of COVID-19-associated hospitalization and death using publicly available data. *PLoS One* 2020;**15**: e0243026.
14. Self WH, Tenforde MW, Rhoads JP, Gaglani M, Ginde AA, Douin DJ, et al. Comparative effectiveness of Moderna, Pfizer-BioNTech, and Janssen (Johnson & Johnson) vaccines in preventing COVID-19 hospitalizations among adults without immunocompromising conditions — United States, March–August 2021. *MMWR Morb Mortal Wkly Rep* 2021;**70**:1337–43.
15. O'Driscoll M, Santos GRD, Wang L, Cummings DAT, Azman AS, Paireau J, et al. Age-specific mortality and immunity patterns of SARS-CoV-2. *Nature* 2020;**590**:140–5.
16. Acosta AM, Garg S, Pham H, Whitaker M, Anglin O, O'Halloran A, et al. Racial and ethnic disparities in rates of COVID-19-associated hospitalization, intensive care unit admission, and in-hospital death in the United States from March 2020 to February 2021. *JAMA* 2021;**4**:e2130479.
17. Wood D. As pandemic deaths add up, racial disparities persist — and in some cases worsen. *National Public Radio* 2020 [06 Jan 2022]; Available from: <https://www.npr.org/sections/health-shots/2020/09/23/914427907/as-pandemic-deaths-add-up-racial-disparities-persist-and-in-some-cases-worsen>.
18. *Health equity considerations and racial and ethnic minority groups*. Centers for Disease Control and Prevention (CDC); 2021 [06 Jan 2022]; Available from: <https://www.cdc.gov/coronavirus/2019-ncov/community/health-equity/race-ethnicity.html#print>.
19. *COVID-19 vaccine equity for racial and ethnic minority groups*. Centers for Disease Control and Prevention (CDC); 2021 [06 Jan 2022]; Available from: <https://www.cdc.gov/coronavirus/2019-ncov/community/health-equity/vaccine-equity.html>.
20. *COVID-19 vaccine and health equity implications*. US Department of Health and Human Services; 2021 [06 Jan 2022]; Available from: <https://eclkc.ohs.acf.hhs.gov/about-us/coronavirus/covid-19-vaccine-health-equity-implications>.
21. Tai DBG, Shah A, Doubeni CA, Sia IG, Wieland ML. The disproportionate impact of COVID-19 on racial and ethnic minorities in the United States. *Clin Infect Dis* 2021;**72**:703–6.
22. Qeadan F, VanSant-Webb E, Tingey B, Rogers TN, Brooks E, Mensah NA, et al. Racial disparities in COVID-19 outcomes exist despite comparable Elixhauser comorbidity indices between Blacks, Hispanics, Native Americans, and Whites. *Sci Rep* 2021;**11**:8738.
23. Artiga S, Garfield R, Orgera K. *Communities of color at higher risk for health and economic challenges due to COVID-19*. Kaiser Family Foundation; 2020 [06 Jan 2022]; Available from: <https://www.kff.org/coronavirus-covid-19/issue-brief/communities-of-color-at-higher-risk-for-health-and-economic-challenges-due-to-covid-19/>.
24. Hsu HE, Ashe EM, Silverstein M, Hofman M, Lange SJ, Razzaghi H, et al. Race/ethnicity, underlying medical conditions, homelessness, and hospitalization status of adult patients with COVID-19 at an urban safety-net medical center — Boston, Massachusetts, 2020. *MMWR Morb Mortal Wkly Rep* 2020;**69**:864–9.
25. Rubin-Miller L, Alban C, Artiga S, Sullivan S. *COVID-19 racial disparities in testing, infection, hospitalization, and death: analysis of epic patient data*. Kaiser Family Foundation; 2020 [06 Jan 2022]; Available from: <https://www.kff.org/coronavirus-covid-19/issue-brief/covid-19-racial-disparities-testing-infection-hospitalization-death-analysis-epic-patient-data/>.
26. CDC COVID-19 Response Team. SARS-CoV-2 B.1.1.529 (Omicron) variant — United States, December 1–8, 2021. *MMWR Morb Mortal Wkly Rep* 2021;**70**:1731–4.
27. Curley B. *Omicron is 91 percent less likely to cause death than delta variant*. Healthline; 2022 [16 Feb 2022]; Available from: <https://www.healthline.com/health-news/omicron-is-91-percent-less-likely-to-cause-death-than-delta-variant>.
28. Ducharme J. *We need to start thinking differently about breakthrough infections*. Time; 2021 [4 May 2022]; Available from: <https://time.com/6130704/breakthrough-infections-omicron/>.
29. *Trends in number of COVID-19 cases and deaths in the US reported to CDC, by state/territory*. Centers for Disease Control and Prevention (CDC); 2022 [08 Nov 2021]; Available from: [https://covid.cdc.gov/covid-data-tracker/#trends\\_dailytrendscases](https://covid.cdc.gov/covid-data-tracker/#trends_dailytrendscases).