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Major Article

The effectiveness of vaccination on the COVID-19 epidemic in California

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Background: The COVID-19 pandemic has caused overwhelming morbidity, mortality, and hospitalization worldwide, including in the state of California. Vaccination efforts have been an important measure in curtailing the adverse outcomes of COVID-19.

Methods: To quantify the effectiveness of COVID-19 vaccinations in California, we conducted a retrospective cohort study investigating how vaccination has impacted the extent of COVID-19 contraction, hospitalizations, and death totals. We compared outcomes of the Delta Wave, Omicron Wave, and Pre-Delta Period.

Results: Vaccinated individuals have far-lower incidence risk ratio (IRR) of and odds of contracting a COVID-19 case (Delta IRR: 0.197) being hospitalized from COVID-19 (Delta IRR: 0.105), and dying from COVID-19 compared with an unvaccinated individual (Delta IRR: 0.0941). The preventive fraction of the unexposed and population-preventive fractions for cases, deaths, and hospitalizations also showed significant proportions. All tests showed $P < .001$.

Discussion: Vaccination was most effective in the Delta Wave, then in the Omicron Wave, and least effective in the Pre-Delta Period. Deaths were the most prevented outcome, followed by hospitalizations, then cases.

Conclusions: This study exposes the massive impact of vaccinations in California in reducing COVID-19 outcomes and the potential for fewer adverse outcomes had there been greater vaccination compliance, demonstrating the need to increase vaccination efforts.

BACKGROUND

COVID-19 is a respiratory disease with symptoms such as fever, cough, chest pain, sore throat, and rhinorrhea.[1] The COVID-19 pandemic has spread around the world, causing massive disruption to educational, technological, financial, agricultural, and health care sectors.[2] Several COVID-19 vaccines by different pharmaceutical companies were developed to prevent and mitigate the effects of the disease and have been shown to be extremely effective.[3] To combat and limit the damage wreaked by the pandemic, the US Department of Defense and Department of Health and Human Resources launched Operation Warp Speed, which accelerated the development and manufacturing of COVID-19 vaccines.[4] The three vaccines made available at the time were from Pfizer-BioNTech, Moderna, and Johnson & Johnson/Janssen,[5] with an efficacy of 95%, 94%, and 54% to 72%, respectively,[3] against the SARS-CoV-2 virus.

This worldwide pandemic has impacted the state of California heavily, manifesting in COVID-19 cases, hospitalizations, and deaths.[6] These three outcomes were convenient measures of the spread and severity of the epidemic and help to elucidate the impact of vaccinations on public health.[7] The number of COVID-19 cases is a straightforward measure of the pandemic, and the number of hospitalizations and of deaths helps us to gauge the severity of each outbreak.[8] As the SARS-CoV-2 virus evolved, new strains, such as Delta and Omicron, were each responsible for surges in COVID-19 outcomes during the pandemic.[9] This study provides key metrics to determine the importance of vaccination during the COVID-19 pandemic, encouraging policies that promote vaccination among the general public.

METHODS

We conducted a retrospective population-based cohort study for the COVID-19 epidemic in California to investigate the differences in

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(1) cases, (2) hospitalizations, and (3) deaths among vaccinated and unvaccinated individuals. Each of these COVID-19 outcomes in California was sourced from a dataset released publicly by the California Department of Public Health (CDPH),[10] using data collected from February 2021 to June 2022. The dataset contained the number of outcomes (cases, hospitalizations, deaths) and the dates for vaccinated and unvaccinated populations. Each case was laboratory-confirmed, and each vaccinated individual was defined as any person with a complete primary COVID-19 vaccine series; conversely, unvaccinated individuals were defined as having no record of any doses of a COVID-19 vaccine. Thus, there is a portion of the population that received partial vaccination (eg, one dose only) that was not included in our analysis. The vaccinated and unvaccinated populations were graphed over the entire span of the dataset, with the periods we analyzed marked out in highlights. The CDPH obtained the information from (1) CalREDIE, the California state disease reporting system (testing and number of cases), (2) the National Vital Statistics System (number of deaths), (3) special surveys hospitals filled out every week and delivered to the CDPH (number of hospitalizations), (4) California Department of Finance (number of unvaccinated people), and (5) the California Immunization Registry (number of vaccinated individuals).[6] COVID-19 outcomes were analyzed in three different periods: (1) the Pre-Delta Period, ranging from March 2021 to May 2021, (2) the Delta Wave, from July 2021 to September 2021, and (3) the Omicron Wave, from December 2021 to February 2022. We considered the exposed cohort to be individuals belonging to the vaccinated group, and the unexposed cohort to be individuals with no records of COVID-19 vaccine. We analyzed the number of COVID-19 cases, associated hospitalizations, and deaths in each cohort during the periods selected. Line graphs of each outcome by vaccination status were created, and the analyzed periods highlighted in different colors. Statistical tests were performed with RStudio version 2022.12.0+353 using the tidyverse and epiR packages. Two-by-two tables, categorized by vaccine exposure and specified outcome, were used to calculate each statistic and perform χ^2 tests. Total outcomes were aggregated across each period to calculate incidence risk ratio (IRR), odds ratio (OR), preventive fraction of the unexposed (PFU), population-prevented fraction (PPF), attributable risk reduction, and number needed to treat (NNT). Values were expressed as a mean or a percentage plus a 95% confidence interval (CI); P values < .05 were considered significant.

RESULTS

At the start of the Pre-Delta Period, vaccinations were still beginning, so only 5.70% of the California population had been vaccinated. However, by the onset of the Delta Wave, due to the speed of vaccine rollout, the proportion had increased to 64.2%, and by the beginning of the Omicron Wave, the number has reached 76.3%. This allowed most Californians to experience the immunity stimulated by the COVID-19 vaccine (Fig 1).

Figure 2 shows the number of cases, hospitalizations, and deaths during the Pre-Delta Period, Delta Wave, and Omicron Wave. Figure 2A shows the number of cases (vaccinated and unvaccinated) increased in each period, where the Omicron Wave has the greatest peak. Figure 2B depicts the number of hospitalizations, with unvaccinated individuals showing higher numbers than vaccinated. A similar situation is illustrated in Figure 2C, for the number of deaths. During the Pre-Delta Period, the number of unvaccinated deaths far exceeded the vaccinated ones, and during the Delta Wave, deaths increased in both populations, with the unvaccinated being more seriously affected. Finally, during the Omicron Wave, there was another spike in fatalities, and again, the unvaccinated population had a higher toll.

Table 1 shows the values for vaccinated and unvaccinated individuals separated by outcome during the three periods. Table 2 shows the summary statistics, they include measures of association, public health risk, and absolute risk.

IRR and OR

When evaluating the measures of association, IRR and OR indicate that vaccinations are highly protective against COVID-19 cases, hospitalizations, and deaths, in every time period analyzed. For the Delta and Omicron waves, IRRs and ORs decreased according

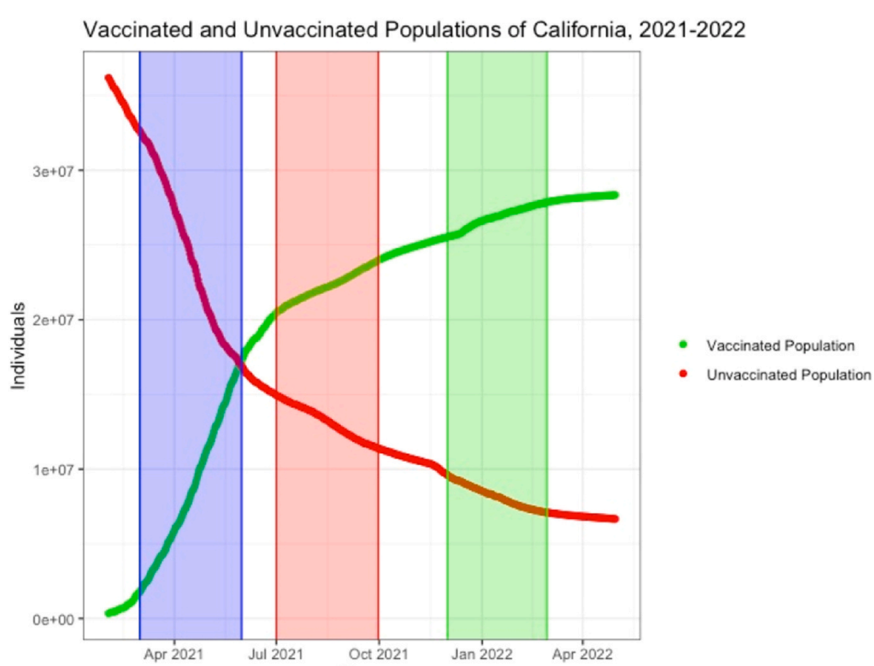

Fig. 1. The Pre-Delta Period is enclosed within the blue area, the Delta Wave is enclosed within the red area, and the Omicron Wave is enclosed within the green area.

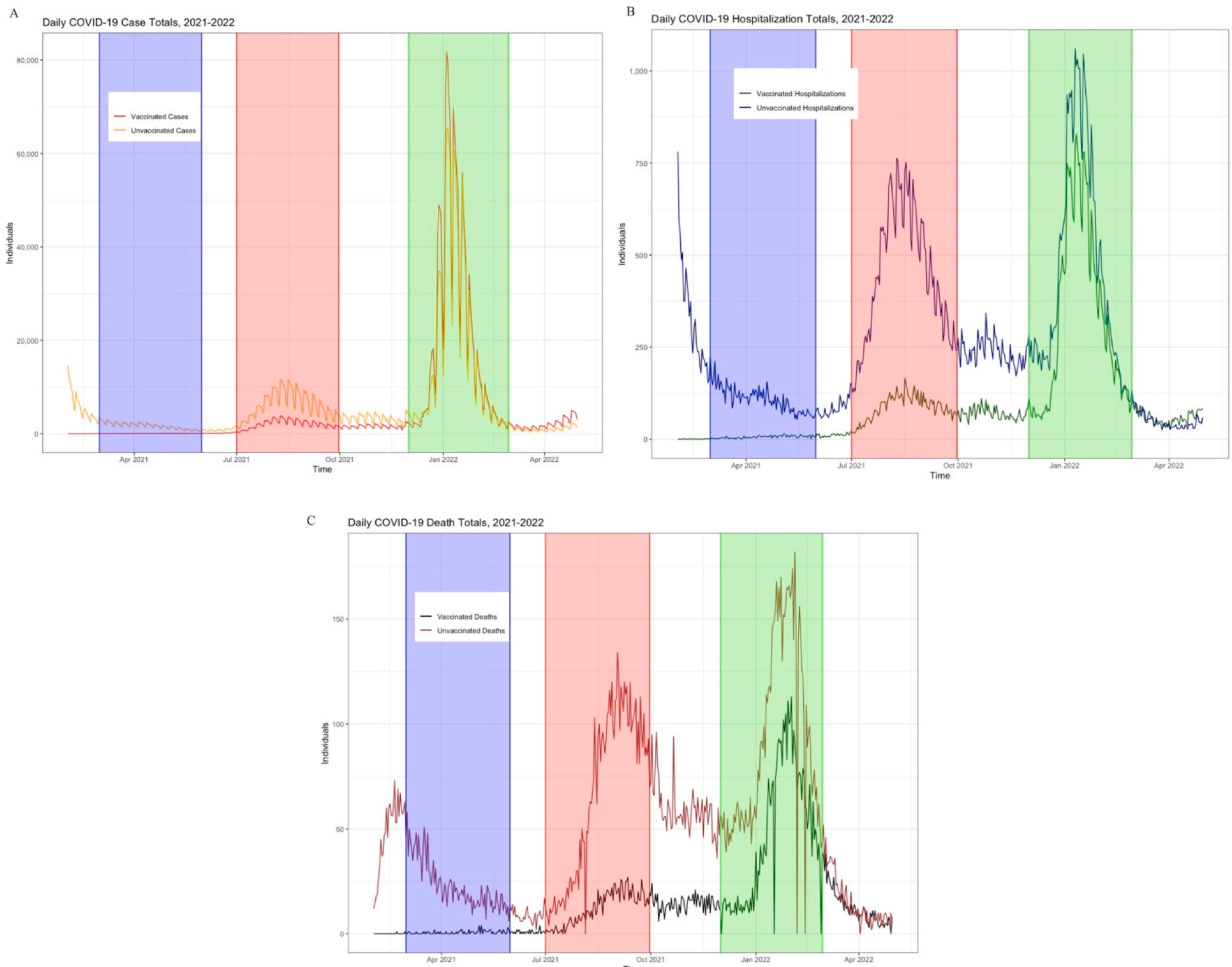

Fig. 2. (A) Vaccinated and unvaccinated COVID-19 cases, (B) hospitalizations, and (C) deaths in California during 2021 to 2022.

Table 1
Number of cases, hospitalizations, and deaths for vaccinated and unvaccinated individuals

		Vaccinated			Unvaccinated	
		Outcome			Outcome	
		Positive	Negative		Positive	Negative
Pre-Delta Period						
Totals	1,756,777			29,082,997		
Cases		3,335	1,753,442		117,071	28,965,926
Hospitalizations		297	1,756,480		7,668	29,075,329
Deaths		24	1,756,753		2,624	29,080,373
Delta Wave						
Totals	20,302,803			11,335,256		
Cases		177,312	20,125,491		503,266	10,831,990
Hospitalizations		7,532	20,295,271		40,088	11,295,168
Deaths		990	20,301,813		5,876	11,329,380
Omicron Wave						
Totals	20,531,396			6,358,506		
Cases		1,260,195	19,271,201		1,235,711	5,122,795
Hospitalizations		20,980	20,510,416		39,851	6,318,655
Deaths		3,109	20,528,287		8,328	6,350,178

Table 2
Measures of association, public health risk, and absolute risk of California COVID-19 vaccinations

	Incidence risk ratio	Odds ratio	Preventive fraction of unexposed	Population-prevented fraction	Absolute risk reduction	Number needed to treat
Pre-Delta Period						
Cases	0.647 (0.630, 0.664)	0.646 (0.629, 0.663)*	35.3 (33.6, 37.0)	34.0 (32.3, 35.7)	1.76×10^{-1} (1.67×10^{-1}, 1.85×10^{-1})	1 in 5.68×10^{2} (5.41×10^{2}, 5.98×10^{2})
Hospitalizations	0.890 (0.816, 0.971)	0.890 (0.816, 0.971)**	11.0 (2.88, 18.4)	10.4 (2.70, 17.5)	3.75×10^{-3} (1.09×10^{-3}, 6.42×10^{-3})	1 in 2.67×10^{4} (1.56×10^{4}, 9.21×10^{4})
Deaths	0.319 (0.247, 0.411)	0.319 (0.247, 0.411)*	68.1 (58.9, 75.3)	66.9 (57.4, 74.2)	7.31×10^{-3} (6.36×10^{-3}, 8.25×10^{-3})	1 in 1.37×10^{4} (1.21×10^{4}, 1.57×10^{4})
Delta Wave						
Cases	0.197 (0.196, 0.198)	0.190 (0.189, 0.191)*	80.3 (80.2, 80.4)	59.4 (59.2, 59.6)	3.57×10^{0} (3.55×10^{0}, 3.58×10^{0})	1 in 2.80×10^{1} (2.80×10^{1}, 2.80×10^{1})
Hospitalizations	0.105 (0.102, 0.108)	0.105 (0.102, 0.107)*	89.5 (89.2, 89.8)	75.4 (74.8, 75.9)	3.17×10^{-1} (3.13×10^{-1}, 3.20×10^{-1})	1 in 3.16×10^{2} (3.12×10^{2}, 3.19×10^{2})
Deaths	0.094 (0.088, 0.101)	0.094 (0.088, 0.101)*	90.6 (89.9, 91.2)	77.5 (76.2, 78.8)	4.70×10^{-2} (4.56×10^{-2}, 4.83×10^{-2})	1 in 2.13×10^{3} (2.07×10^{3}, 2.19×10^{3})
Omicron Wave						
Cases	0.316 (0.315, 0.317)	0.271 (0.270, 0.272)*	68.4 (68.3, 68.5)	33.9 (33.8, 34.0)	1.33×10^{1} (1.33×10^{1}, 1.33×10^{1})	1 in 8.00×10^{0} (8.00×10^{0}, 8.00×10^{0})
Hospitalizations	0.163 (0.160, 0.166)	0.162 (0.160, 0.165)*	83.7 (83.4, 84.0)	54.8 (54.3, 55.3)	5.24×10^{-1} (5.18×10^{-1}, 5.31×10^{-1})	1 in 1.91×10^{2} (1.88×10^{2}, 1.93×10^{2})
Deaths	0.116 (0.111, 0.121)	0.116 (0.111, 0.120)*	88.4 (88.0, 88.9)	64.4 (63.3, 65.4)	1.16×10^{-1} (1.13×10^{-1}, 1.19×10^{-1})	1 in 8.63×10^{2} (8.43×10^{2}, 8.85×10^{2})

NOTE. Values for incidence risk ratio, odds ratio, and number needed to treat presented as a mean accompanied by the 95% confidence interval; preventive fraction of the unexposed, population-prevented fraction, and absolute risk reduction are percentages accompanied by the 95% confidence interval.
*$P < .001$.
**$P < .05$.

to the increasing severity of the outcome, that is, the highest values were for cases, and the lowest values were for deaths, highlighting the concept that vaccinations decrease the severity of cases. For instance, the IRRs during the Delta Wave were 0.197 (95% CI 0.196, 0.198) for cases, 0.105 (95% CI 0.102, 0.108) for hospitalizations, and 0.094 (95% CI 0.088, 0.101) for deaths. The Pre-Delta Period did not follow this pattern, as hospitalizations had a higher value, than cases or deaths (cases' IRR: 0.647 [95% CI 0.630, 0.664], hospitalizations' IRR: 0.890 [95% CI 0.816, 0.971], and deaths' IRR: 0.319 [95% CI 0.247, 0.411]). A similar result was obtained for the OR. All tests showed $P < .05$ (Table 2).

PFU and PPF

When evaluating measures of public health risk, both the PFU and the PPF showed large percentages of preventable outcomes, and they tended to have higher fractions for worse outcomes. The Delta Wave had a high-case PFU (80.3%, 95% CI 80.2%, 80.4%), with an even higher hospitalization PFU (89.5%, 95% CI 89.2%, 89.8%) and death PFU (90.6%, 95% CI 89.9%, 91.2%). The Pre-Delta Period had lower hospitalization values for both PFU (10.4%, 95% CI 2.70%, 17.5%) and PPF (11.0%, 95% CI 2.90%, 18.4%) than for either cases or deaths (Table 2).

Absolute risk reduction and NNT

Measures of absolute risk appear to show a smaller effect of vaccinations on adverse outcomes. The effect of vaccination is most pronounced in reducing the risk of cases, as 13.3 cases per 100 individuals (95% CI 13.3, 13.3) were avoided during the Omicron Wave, and 3.57 cases per 100 individuals (95% CI 3.55, 3.58) during the Delta Wave. The NNT for these values corresponds to one in eight individuals and one in 28 individuals, respectively. The lowest value for absolute risk reduction was for deaths during the Pre-Delta Period with 7.31×10^{-3} deaths prevented per 100 individuals (95% CI 6.36×10^{-3}, 8.25×10^{-3}), or one in 13.7×10^{4} individuals (95% CI 1.21×10^{4}, 1.57×10^{4}) (Table 2).

DISCUSSION

Measures of association and of public health risk showed significant variation among the three different time periods (Table 2). According to the CDPH data, approximately 100,000 more people were vaccinated between the beginning of the Delta Wave to the beginning of the Omicron Wave,[6] but according to our findings, vaccinations appeared to still be less effective during the subsequent Omicron Wave. This could mean that either vaccinations were more effective in a small to moderately sized outbreak such as the Delta Wave versus a larger outbreak such as the Omicron Wave, or that vaccines were less effective at targeting the Omicron viral variant as compared with the Delta variant. Research has shown that Omicron variant was much more transmissible but less deadly than the Delta variant, causing a larger spike in cases but a lower mortality rate in comparison.[11] Interestingly, while our findings show that vaccinations were highly effective at preventing deaths during the Delta Wave in California (Table 2), the Delta Wave was shown to have a higher mortality than the Omicron Wave across the United States.[12] Other studies have shown that vaccines, including in California, were more effective for the Delta variant than for the Omicron variant.[13,14] Taken together, vaccines seemed to have prevented fewer outcomes in a more contagious Omicron Wave than in a more deadly Delta Wave.

Across the three periods, the Pre-Delta Period consistently had higher IRRs and ORs as well as lower preventive fractions among the unexposed compared with the Delta and Omicron Waves (Table 2). This may be due to vaccinations having a greater effect against adverse outcomes when transmission is higher during wave periods.

Alternatively, the Pre-Delta Period is when many people first began receiving vaccines. With a much smaller fraction of vaccinated individuals in the population, there were far too few vaccinated people to achieve herd immunity, and thus COVID-19 transmission may not have slowed by a significant pace, producing more COVID-19 outcomes among both vaccinated and unvaccinated populations. Some vaccinated people may also not have exercised proper precautions for reducing COVID-19 exposure (ie, masking, and social distancing) after receiving vaccination, and may have experienced COVID-19 outcomes despite their vaccination status.

An unusual finding was that the Pre-Delta Period did not follow the trend of gradually more extreme values for more severe COVID-19 outcomes. The hospitalization IRR and OR were higher than the case and death IRRs and ORs (Table 2). A possible reason could be that the particular strain of virus during this period was more virulent and caused more hospitalizations in breakthrough cases. There has been shown to be a trade-off relationship between transmissibility and virulence, specifically in the SARS-CoV-2 virus.[15] Alternatively, the vaccine, while effective in preventing cases and deaths, may have waned in effectiveness against hospitalizations while people had not yet received booster shots. Indeed, studies have shown the effectiveness against hospitalization wanes rapidly after receiving the vaccine.[16]

The measures of absolute risk, attributable risk reduction, and NNT, show results that are not as dramatic compared with the findings from other statistics (Table 2). Because of these modest results, it would appear that vaccinations do not reduce risk of outcomes significantly, and that there needs to be an enormous number of vaccinations that need to be administered before seeing a prevented outcome. However, this phenomenon is attributed to the low-baseline risk of hospitalization[17] and an extremely low-baseline risk of death from COVID-19.[18] There is significant benefit from vaccination against all outcomes of COVID-19, but because risk of these outcomes before vaccinations, aside from that of cases, is already exceedingly low, the attributable risk reduction and NNT appear to have relatively minor effect sizes.

The study shows that vaccinations have been extremely beneficial to the population of California; however, the effectiveness of vaccination may have varied in other states or nations, and the continued evolution of the SARS-CoV-2 virus[19] may present new and unforeseen challenges to vaccination as a public health intervention. New developments in vaccine development and new virus strains may also influence the effectiveness of vaccinations against the COVID-19 pandemic.

This study is vulnerable to limitations suffered by all cohort studies. One major limitation is variation of measurement of exposure. Our dataset indicates vaccination status of each individual, but factors such as the manufacturer of vaccine, number of booster shots of the vaccinated, and time of each vaccine inoculation are not recorded. Each of these factors could have potentially had an impact on the outcomes of interest. Variation of vaccine exposure may have overestimated the results or masked heterogeneity of effectiveness among different vaccine brands, booster shot doses, or vaccine inoculation schedules. In addition, the measurement of the outcomes may not be completely accurate. Many COVID-19 cases may have gone unreported or unconfirmed. The dataset explicitly states that only confirmed COVID-19 cases were reported. The dataset used sources the California Immunization Registry and the California Department of Finance. The California Department of Finance itself uses "[a]dministrative records such as births, deaths, driver license address changes, tax return data, Medicare and Medi-Cal enrollment, immigration reports, school enrollments, and group quarters population" for a robust estimate of population.[20] According to the CDPH, the dataset should include the entire population of California. However, the dataset may have potentially missed data on undocumented immigrants in California, as it is difficult to obtain records of this approximately 5% segment of the population (1.85 million individuals in 2021).[21] Other studies have addressed the increased vulnerability of undocumented immigrants in California to COVID-19 outcomes.[22,23] Finally, confounding variables, such as comorbidities, social status, and so on, may impact both the exposure and the outcomes, potentially influencing the relationship between vaccination and COVID-19 cases, deaths, and hospitalizations.

Vaccinations have been shown to be an excellent way of preventing adverse outcomes of COVID-19, but the best public health intervention of all is education. A good understanding of COVID-19 would spur people and communities to engage in mask-wearing, covering their coughs, social distancing, and awareness of others after knowing how the disease is spread. A vaccination campaign without educating the public is doomed to fail, as people would not know why they need to be vaccinated. It is also important to remember that informing the public as to what the vaccine can do for them, as well as any precautions and risks they should consider, will greatly increase the acceptance of vaccines within communities. Community centers, libraries, schools, or other public venues in the community can be places of dissemination of vaccine education.

CONCLUSIONS

The data show that COVID-19 vaccinations in California achieved their greatest effect during the Delta Wave, followed by Omicron Wave, and then by the Pre-Delta Period. In addition, vaccinations significantly decreased cases, dramatically lowered the number of hospitalizations, and had the greatest effect in reducing death counts. Therefore, it is recommended that state and local governing bodies create and enact legislation that encourages or enforces COVID-19 vaccination among the general populace. Similar policies can be enacted by any organization, requiring one to have been vaccinated to enter parties, concerts, and other social functions. Vaccinations and booster shots should continue to be administered to curtail further ongoing effects of the COVID-19 epidemic, such as long COVID and potential new outbreaks.

References

1. Chen N, Zhou M, Dong X, et al. Epidemiological and clinical characteristics of 99 cases of 2019 novel coronavirus pneumonia in Wuhan, China: a descriptive study. *Lancet.* 2020;395:507–513.
2. Nicola M, Alsafi Z, Sohrabi C, et al. The socio-economic implications of the coronavirus pandemic (COVID-19): a review. *Int J Surg.* 2020;78:185–193.
3. Chirico F, da Silva JAT, Tsigaris P, Sharun K. Safety & effectiveness of COVID-19 vaccines: a narrative review. *Indian J Med Res.* 2022;155:91.
4. AJMC Staff. A timeline of COVID-19 vaccine developments in 2021. AJMC. Published June 3, 2021. Accessed September 4, 2022. https://www.ajmc.com/view/a-timeline-of-covid-19-vaccine-developments-in-2021.
5. Overview of COVID-19 vaccines | CDC. Accessed December 21, 2023. https://www.cdc.gov/coronavirus/2019-ncov/vaccines/different-vaccines/overview-COVID-19-vaccines.html.
6. California S of. Tracking COVID-19 in California. Accessed September 24, 2023. https://www.cdph.ca.gov/Programs/CID/DCDC/Pages/Respiratory-Viruses/RespiratoryDashboard.aspx.
7. Steele MK, Couture A, Reed C, et al. Estimated number of COVID-19 infections, hospitalizations, and deaths prevented among vaccinated persons in the US, December 2020 to September 2021. *JAMA Netw Open.* 2022;5:E2220385.
8. Martins-Filho PR, de Souza Araújo AA, Quintans-Júnior LJ, et al. Dynamics of hospitalizations and in-hospital deaths from COVID-19 in northeast Brazil: a retrospective analysis based on the circulation of SARS-CoV-2 variants and vaccination coverage. *Epidemiol Health.* 2022;44:e2022036.
9. Doll MK, Waghmare A, Heit A, et al. Acute and postacute COVID-19 outcomes among immunologically naive adults during delta vs omicron waves. *JAMA Netw Open.* 2023;6:e231181.

10. COVID-19 Post-Vaccination Infection Data (ARCHIVED) - Datasets - California Health and Human Services Open Data Portal. Accessed September 24, 2023. https://data.chhs.ca.gov/dataset/covid-19-post-vaccination-infection-data.
11. Duong BV, Larpruenrudee P, Fang T, et al. Is the SARS CoV-2 Omicron variant deadlier and more transmissible than delta variant? *Int J Environ Res Public Health.* 2022;19:4586.
12. Tabatabai M, Juarez PD, Matthews-Juarez P, et al. An analysis of COVID-19 mortality during the dominancy of Alpha, Delta, and Omicron in the USA. *J Prim Care Community Health.* 2023;14:21501319231170164.
13. Tseng HF, Ackerson BK, Luo Y, et al. Effectiveness of mRNA-1273 against SARS-CoV-2 Omicron and Delta variants. *Nat Med.* 2022;28:1063.
14. Buchan SA, Chung H, Brown KA, et al. Estimated effectiveness of COVID-19 vaccines against Omicron or Delta symptomatic infection and severe outcomes. *JAMA Netw Open.* 2022;5:E2232760.
15. Xu Z, Wei D, Zeng Q, et al. More or less deadly? A mathematical model that predicts SARS-CoV-2 evolutionary direction. *Comput Biol Med.* 2023;153:106510.
16. European Centre for Disease Prevention and Control. Interim analysis of COVID-19 vaccine effectiveness against hospitalisation and death using electronic health records in six European countries. Stockholm: ECDC; 2023. Accessed January 8, 2024. https://www.ecdc.europa.eu/en/publications-data/interim-analysis-covid-19-vaccine-effectiveness-against-hospitalisation-and-death.
17. Taylor CA, Patel K, Patton ME, et al. COVID-19–associated hospitalizations among U.S. adults aged ≥65 years — COVID-NET, 13 states, January–August 2023. *MMWR Morb Mortal Wkly Rep.* 2023;72:1089–1094.
18. CDC. Coronavirus Disease 2019 (COVID-19). Centers for Disease Control and Prevention. Published February 11, 2020. Accessed October 9, 2023. https://www.cdc.gov/coronavirus/2019-ncov/science/data-review/risk.html.
19. Markov PV, Ghafari M, Beer M, et al. The evolution of SARS-CoV-2. *Nat Rev Microbiol.* 2023;21:361–379.
20. Estimates-E1 | Department of Finance. Accessed March 13, 2024. https://dof.ca.gov/forecasting/demographics/estimates-e1/.
21. La L. Two ways California aids undocumented immigrants. *CalMatters*. Published January 24, 2024. Accessed March 13, 2024. https://calmatters.org/newsletter/california-immigrants-undocumented-aid/.
22. Torres-Pinzon DL, Solorzano W, Kim SE, Cousineau MR. Coronavirus disease 2019 and the case to cover undocumented immigrants in California. *Health Equity.* 2020;4:500.
23. Bhuiyan MTH, Khan IM, Jony SSR, et al. The disproportionate impact of COVID-19 among undocumented immigrants and racial minorities in the US. *Int J Environ Res Public Health.* 2021;18:12708.