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The association of demographic and socioeconomic factors with COVID-19 during pre- and post-vaccination periods

A cross-sectional study of Virginia

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Abstract

Sociodemographic factors have been found to be associated with the transmission of coronavirus disease 2019 (COVID-19), yet most studies focused on the period before the proliferation of vaccination and obtained inconclusive results. In this cross-sectional study, the infections, deaths, incidence rates, case fatalities, and mortalities of Virginia's 133 jurisdictions during the pre-vaccination and post-vaccination periods were compared, and their associations with demographic and socioeconomic factors were studied. The cumulative infections and deaths and medians of incidence rates, case fatalities, and mortalities of COVID-19 in 133 Virginia jurisdictions were significantly higher during the post-vaccination period than during the pre-vaccination period. A variety of demographic and socioeconomic risk factors were significantly associated with COVID-19 prevalence in Virginia. Multiple linear regression analysis suggested that demographic and socioeconomic factors contributed up to 80% of the variation in the infections, deaths, and incidence rates and up to 53% of the variation in the case fatalities and mortalities of COVID-19 in Virginia. The demographic and socioeconomic determinants differed during the pre- and post-vaccination periods. The developed multiple linear regression models could be used to effectively characterize the impact of demographic and socioeconomic factors on the infections, deaths, and incidence rates of COVID-19 in Virginia.

Abbreviations: COVID-19 = coronavirus disease 2019, SVI = social vulnerability index.

Keywords: demographic, socioeconomic, multiple linear regression, prevalence, vaccination, modeling

1. Introduction

Since the first case of severe acute respiratory syndrome coronavirus 2 was reported in America on January 21st, 2020, the coronavirus disease 2019 (COVID-19) pandemic has posed unprecedented challenges to the health of the American people.[1] Despite the availability of COVID-19 vaccination since mid-December 2020, the number of new infections and deaths remained high.[2,3] More than a year and a half after COVID-19 vaccination has been made freely available, as of the drafting of this manuscript on July 2nd, 2022, 592,509,318 doses have been administered and 221,924,152 Americans (67.36% of the population) are fully vaccinated.[4] However, this country has still witnessed 87,822,179 confirmed infection cases and 1017,818 deaths since the beginning of the pandemic.[4] Therefore, it is reasonable to assume that some non-biological factors had significantly impacted the transmission of coronavirus in America, and it is of great importance to determine them.

Many studies have been conducted to characterize the variations in COVID-19's prevalence across jurisdictions and explore their possible causes. The associations between environmental factors, such as meteorological factors and air pollutants, and COVID-19 have been discussed globally.[5–7] In America, the maximum temperature, minimum relative humidity, and precipitation were determined to be the most significant meteorological risk factors.[8] However, some researchers believed that these variations were driven by demographic and socioeconomic factors.[9,10] A cross-sectional study investigated the associations of race/ethnicity and food insecurity with cumulative COVID-19 infection rates in 3133 American counties.[11] The results suggested that in July 2020, race/ethnicity was significantly associated with increased COVID-19 infection rates. In December 2020, high prevalence of food insecurity among minority ethnic groups (Black, Hispanic, and American Indian and Alaska Native) was associated with increased infection rates. County-level income inequality was also found to be associated with COVID-19 incidence rates.[12] A positive correlation between Gini coefficients, an indicator of income inequality, and county-level COVID-19 cases was found.

While some studies have highlighted the association between meteorological, demographic, and socioeconomic factors and COVID-19 incidence rates,[13–15] a modeling study based on

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The datasets generated during and/or analyzed during the current study are publicly available.

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data from New York City suggested that comorbidities such as type 2 diabetes and hypertension were the most important risk factors for hospitalization and severe outcomes regardless of patient race or socioeconomic status.[16] In addition, due to differences in time points, population, potential risk factors, and endpoints, the impact of demographic and socioeconomic risk factors on COVID-19 incidence rates varied across studies. Few studies have been conducted to compare the risk factors of COVID-19 transmission before and after the proliferation of vaccination. Therefore, this study was carried out to identify and characterize the demographic and socioeconomic determinants of cumulative infections, deaths, incidence rates, case fatalities, and mortalities of COVID-19 in the 9 months before the vaccines were first made available in Virginia and in the 9 months immediately after. Pertinent results could provide helpful references for policymakers and health professionals to flatten the curve of COVID-19 and better prepare for similar diseases in the future.

2. Data and Methods

2.1. Data and sources

All data used in this cross-sectional study were retrieved or derived from publicly available databases. Since the first confirmed case of infection was reported in Virginia in March of 2020,[17] and vaccines were available in mid-December 2020,[18] the time periods from March to December 2020 and January to September 2021 were designated as the pre-vaccination and post-vaccination periods, respectively. Original data of cumulative infections, deaths, incidence rates, and case fatalities of COVID-19 in all 133 counties and cities of Virginia were accessed from the GitHub repository of the Center for Systems Science and Engineering at Johns Hopkins University.[19,20] Mortalities during pre-vaccination and post-vaccination periods were derived from original raw csv data. The demographic and the majority of the socioeconomic data were retrieved from the US Census Bureau based on the 2019 American community survey's 5-year estimates.[21] Part of the socioeconomic data, reflecting the social vulnerability index (SVI, hereafter) were obtained from the centers for disease control and prevention as reported previously.[21] Because all data used in this study were retrieved or derived from publicly available databases, and no patient's information was involved, ethical approval and informed consent were not necessary.

2.2. Statistical analysis

Continuous variables following normal distributions were reported as mean ± standard deviation. Non-normally distributed variables were expressed as a median with interquartile range. Categorical variables were presented as frequency (percentage). Differences in the prevalence of COVID-19, including infections, deaths, incidence rates, case fatalities, and mortalities during the 2 observational periods were tested by the Wilcoxon signed rank test. All potential demographic and socioeconomic risk factors were included in a stepwise multiple linear regression analysis to investigate the associations between them and the prevalence of COVID-19 in Virginia. All statistical analyses were 2-tailed (unless specified) and performed with Statistical Package for the Social Sciences (SPSS, version 26.0, IBM, US). A $P < .05$ was considered statistically significant, and a $P < .01$ was considered highly significant.

3. Results

3.1. The prevalence of COVID-19 in Virginia

The earliest confirmed cases of COVID-19 in Virginia were reported on March 8th, 2020, in Fairfax County.[22] Since then, infections and deaths have been reported in each of Virginia's 133 cities and counties, though the numbers of infections and deaths varies by jurisdiction (Fig. 1). The cumulative infections, deaths, incidence rates, case fatalities, and mortalities during post-vaccination were significantly higher (all P values < .01) than during the pre-vaccination period (Table 1).

3.2. Association of socioeconomic and demographic factors with COVID-19

In total, 55 demographic and socioeconomic factors were included in this study (Table 2). They characterized 6 major areas, including demographics, living conditions, education, health and insurance, economy, and commute to work. Many of these factors were highly associated with cumulative infections, deaths, incidence rates, case fatalities, and mortalities of COVID-19 during the observed periods.

Stepwise multiple linear regression analysis was performed to identify the demographic and socioeconomic determinants of COVID-19 in Virginia. Among them, the risk factors of infections and deaths during the study periods were largely the same. Within a jurisdiction, the percentage of Asian and persons under the age of 5, and the number of households positively impacted the infections in Virginia. However, the total annual payroll, the percentage of the population that belonged to 2 or more races, the percentage of the population over 16 in the civilian labor force, and single parent households with children under the age of 18 (2014–2018) were negatively correlated with the number of infections and deaths to varying degrees during both periods studied (Tables 3 and 4).

The demographic and socioeconomic determinants of incidence rates differed between the 2 study periods (Table 5). Essentially, during the pre-vaccination period, the median gross rent (2015–2019), persons per household, and the percentage of the population aged 65 and above that was uninsured, and the percentage of the population that belonged to 2 or more races helped to reduce incidence rates. However, during the post-vaccination period, the percentage of the population that was foreign-born, persons living in same house for >1 year, and the median value of the owner-occupied housing units (2015–2019) were the factors that similarly reduced incidence rates.

The demographic and socioeconomic determinants of case fatalities were different between the 2 study periods (Table 6). During the pre-vaccination period, the percentage of the population under the age of 65, and the percentage of the population under the age of 5 reduced case fatalities. However, during the post-vaccination period, the percentage of the population under the age of 18, and the total annual payroll (2019) persons were the factors that reduced case fatalities.

During the pre-vaccination period, the percentage of households without a vehicle and the population aged ≥25 without a high school diploma had a significant positive effect on mortalities; the percentage of the population living in poverty and the population aged 65 and under without health insurance had a significant negative effect on mortalities. During the post-vaccination period, the percentage of the population under the age of 18 positively impacted mortalities and the number of persons per household, the percentage of the population living in group quarters, the median gross rent, and the percentage of people living in mobile homes had a significant negative impact on mortalities (Table 7).

3.3. Predictive models of COVID-19 in Virginia

Based on the stepwise multiple linear regression analysis, 10 regression models were established to predict the cumulative infections, deaths, incidence rates, case fatalities, and mortalities of COVID-19 in Virginia. As shown in Table 8, demographic and socioeconomic factors contributed from 56% to 80% of

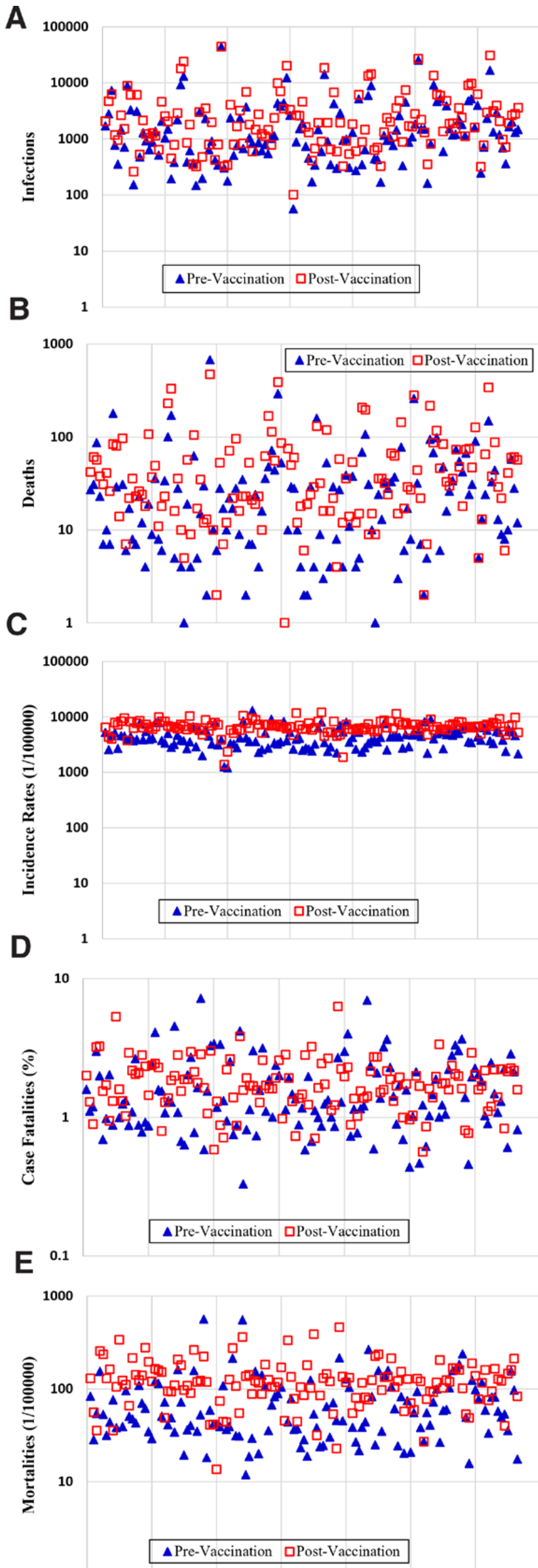

Figure 1. The distribution of COVID-19 infections, deaths, incidence rates, case fatalities, and mortalities in Virginia's 133 jurisdictions. (A) COVID-19 infections in Virginia during pre- and post-vaccination periods. (B) COVID-19 deaths in Virginia during pre- and post-vaccination periods. (C) COVID-19 incidence rates in Virginia during pre- and post-vaccination periods. (D) COVID-19 case fatalities in Virginia during pre- and post-vaccination periods. (E) COVID-19 mortalities in Virginia during pre- and post-vaccination periods. The values of all variables are logarithmically plotted. Blue filled triangles represent pre-vaccination values. Red unfilled squares represent post-vaccination values. COVID-19 = coronavirus disease 2019.

the variation in the cumulative infections and deaths, and incidence rates among Virginia's 133 jurisdictions. However, their contribution to the variation in case fatalities and mortalities were relatively low, ranging from 25% to 53%.

4. Discussion

Considering the effectiveness of COVID-19 vaccines, many expected the pandemic to be quickly contained.[23] However, the results of this study demonstrated that the cumulative infections deaths, incidence rates, case fatalities, and mortalities of COVID-19 in the 133 jurisdictions of Virginia were significantly higher during the post-vaccination period than those of the pre-vaccination period. The results of this study suggested that demographic and socioeconomic factors have played important roles in the spread of the pandemic.

Compared to the pre-vaccination period, the medians of cumulative infections and deaths during the post-vaccination period increased by 63.9% and 73.7%, respectively. The percentage of Asians and people under the age of 5 and the number of households and total employment were the risk factors for infections and deaths. The post-vaccination period had 1 more risk factor than the pre-vaccination period–total employment for infections and households for deaths. As the pandemic continued, quarantine regulations were lifted, and the economic burden on Virginians increased to unprecedented levels,[24] prompting many to return to the labor force. Even though people could reduce their likelihood of contracting COVID-19 or developing severe illness from inoculating themselves, many were hesitant. Counties with higher employment and more households had greater economic activity, necessarily having higher community transmission of COVID-19, thereby increasing the number of infections and deaths.

A number of studies have sought to determine the demographic and socioeconomic risk factors of infections and deaths of COVID-19 in a jurisdiction.[25,26] A study on the state of New Mexico during the pre-vaccination months found that areas with greater percentages of American Indians and Alaska Natives had greater numbers of confirmed cases.[27] Another study of America concluded that counties with higher proportions of Black and Hispanic residents tended to have greater numbers of total deaths.[28] These results were not replicated in this study during either the pre-vaccination or the post-vaccination period. The differences in demographics and socioeconomics between the study populations could be the major reason, which should caution policymakers to not simply apply results from studies, instead curating a plan for their specific jurisdiction.

Similar to some of the findings reported previously,[29,30] this study found that the percentages of Hispanics or Latinos and Native Hawaiian and other Pacific islander significantly and positively impacted incidence rates of COVID-19 in Virginia. This may be due to the overrepresentation of ethnic minorities in occupations that do not provide adequate protection from COVID-19, increasing their risk of exposure, contraction, and transmission of the virus.[31] During pre-vaccination months, there was substantial evidence of secondary infections from household contacts in the states of Utah, Wisconsin, and Tennessee, which may significantly contribute to COVID-19 transmission within households and in turn COVID-19 incidence rates.[32,33] This is especially problematic for households living in overcrowded housing, one of the 4 variables of poor housing conditions considered by a study that determined that the percentage of poor housing in a jurisdiction was a significant risk factor of COVID-19.[34] This study also determined that the burden of housing cost is a risk factor of COVID-19 incidence, a result corroborated by a study that discovered that COVID-19 incidence increased across the board when eviction moratoria were lifted, that is, tenants can be evicted for not being able to pay rent.[35] The lifting of eviction moratoria and the increases in housing prices during the pandemic displaced many

Table 1

The major indicators of COVID-19 prevalence in Virginia.

Indicator	Mar–Dec 2020*	Jan–Sep 2021*	Test statistic	*P* value
Infection	1141.0 (597.5, 2489.0)	1870.0 (848.5, 3584.0)	8463.0	*P* < .01
Death	19.0 (7.0, 36.0)	33.0 (16.0, 64.0)	7265.5	*P* < .01
Incidence rate (1/1,00,000)	3974.2 (3214.2, 5267.6)	6607.7 (5874.2, 7559.4)	8476.0	*P* < .01
Case fatality (%)	1.29 (0.90, 2.13)	1.71 (1.31, 2.21)	5604.0	*P* < .01
Mortality (1/1,00,000)	53.25 (35.00, 97.66)	118.7 (82.3, 155.3)	7333.0	*P* < .01

* Data were expressed as median with interquartile range (IQR).
COVID-19 = coronavirus disease 2019.

Table 2

Potential demographic and socioeconomic risk factors of COVID-19 in Virginia.

SN	Variable	Median (IQR)	SN	Variable	Median (IQR)
1	Total population (2019 estimation)	26,586.0 (14,618.0, 54,312.5)	29	Persons <5, %	5.20 (4.50, 6.05)
2	Population density (person/km^2)	41.07 (18.80, 382.79)	30	Persons <65, %	54.10 (52.30, 56.15)
3	Persons <18, %	19.70 (17.80, 22.35)	31	Female, %	50.90 (50.00, 51.80)
4	Persons aged ≥65, %	20.10 (16.15, 23.20)	32	White alone, %	79.40 (65.30, 90.10)
5	Black or African American alone, %	14.60 (5.50, 29.15)	33	Asian alone, %	1.00 (0.60, 2.30)
6	American Indian and Alaska native, %	0.50 (0.40, 0.60)	34	2 or more races, %	2.30 (1.70, 3.05)
7	Persons per household (2015–2019)	2.45 (2.35, 2.57)	35	Hispanic or Latino, %	3.80 (2.60, 6.90)
8	Gini index of income inequality	0.44 (0.41, 0.46)	36	Foreign-born persons, %	3.40 (1.80, 6.15)
9	Total employer establishments (2019)	550.00 (282.00, 1438.00)	37	Veterans, %	7.37 (6.28, 8.63)
10	Total employment (2019)	7582.0 (2790.0, 20,991.5)	38	Mobile homes (2014–2018), %	7.50 (1.40, 16.05)
11	Person uninsured (2015–2019), %	9.30 (7.20, 10.95)	39	Median gross rent (2015–2019)	861.00 (702.50, 1121.50)
12	Persons worked from home, %	4.51 (3.31, 6.54)	40	Households (2015–2019)	9923.0 (5512.5, 22,659.0)
13	Households with a computer (2015–2019), %	85.80 (81.00, 91.15)	41	Persons in poverty, %	12.30 (8.40, 18.15)
14	Unemployment rate (2014–2018), %	5.30 (3.90, 6.60)	42	Persons carpooled, %	8.78 (7.14, 10.41)
15	Persons living in same house >1 yr (2015–2019), %	87.70 (83.50, 90.10)	43	White alone (not Hispanic or Latino), %	73.90 (59.20, 86.65)
16	Households with broadband internet subscription (2015–2019), %	74.90 (69.10, 83.35)	44	Native Hawaiian and other Pacific islander, %	0.10 (0.10, 0.13)
17	Persons aged >25 with high school or higher diploma (2015–2019), %	87.00 (82.75, 91.00)	45	Median value of owner-occupied housing units (2015–2019)	194,000.0 (1,29,350.0, 2,57,550.0)
18	Persons aged >25 with bachelor's degree or higher (2015–2019), %	23.40 (17.25, 33.30)	46	Total annual payroll (×$1000) (2019)	2,78,396.0 (1,02,809.5, 9,50,030.5)
19	Female civilian labor force in aged >16 (2015–2019), %	55.10 (51.30, 59.95)	47	Persons aged <65 with a disability (2015–2019), %	10.00 (7.90, 12.25)
20	Median household income in 2019 dollars (2015–2019)	55,708.0 (45,804.0, 71,329.0)	48	Persons aged <65 without health insurance, %	10.60 (9.60, 12.50)
21	Per capita income in past 12 mo (2015–2019)	30,054.0 (24,158.5, 35,633.5)	49	Civilian labor force in aged >16 (2015–2019), %	58.80 (53.60, 63.00)
22	Persons aged >5 speak language other than English at home (2015–2019), %	4.80 (2.75, 8.85)	50	Persons aged >25 with no high school diploma (2014–2018), %	13.60 (9.80, 17.55)
23	Persons commute by public transportation (excluding taxicab), %	0.50 (0.24, 1.45)	51	Persons aged >5 speak English "less than well" (2014–2018), %	0.60 (0.30, 1.55)
24	Persons commute by public transportation (including taxicab), %	0.58 (0.26, 1.66)	52	Housing in structures with ≥10 units (2014–2018), %	3.30 (1.55, 9.95)
25	Occupied housing units with more people than rooms (2014–2018), %	1.40 (0.90, 1.90)	53	Households with no vehicle available (2014–2018), %	6.10 (4.10, 8.50)
26	Civilian noninstitutionalized population with a disability (2014–2018), %	14.70 (12.10, 17.85)	54	Persons in group quarters (2014–2018), %	2.20 (0.85, 4.95)
27	Single parent households with children <18 (2014–2018), %	7.70 (6.00, 9.60)	55	Mean travel time (min) to work (2015–2019)	27.30 (23.05, 33.00)
28	Minority (all persons except white, non-Hispanic) (2014–2018), %	25.90 (12.80, 40.20)			

COVID-19 = coronavirus disease 2019, IQR = interquartile range.

Americans, forcing them into living in crowded housing that increases their risk of contracting COVID-19.[36,37] This study determined that the percentage of persons in group quarters was another important risk factor during both pre-vaccination and post-vaccination periods.

From a socioeconomic standpoint, a few factors have been found to contribute to the case fatality of COVID-19. In Georgia, case fatalities in rural areas were higher than in urban areas.[38] After investigating >300 American counties from 7 states all over America during the pre-vaccination period, a weak but significant positive association between median household income and case fatality was determined.[39] This study discovered that the percentage of households without a vehicle was positively, while the total annual payroll was negatively associated with case fatalities in Virginia. It was likely difficult for families without vehicles, especially those in rural areas, to receive health

Table 3

Demographic and socioeconomic determinants of infections of COVID-19 in Virginia.

Variable	Coefficient (95% CI)	*t*	*P* value
Infection (Mar–Dec 2020)			
Constant	627.20 (−3543.39, 4797.79)	0.2976	NS
Asian alone, %	1075.31 (853.30, 1297.31)	9.586	*P* < .01
Persons under 5, %	2034.54 (1422.08, 2647.01)	6.574	*P* < .01
Households (2015–2019)	0.110 (0.083, 0.137)	8.131	*P* < .01
Total annual payroll (×$1000) (2019)	−1.14E-3 (−1.37E-3, −9.11E-4)	−9.834	*P* < .01
Single parent households with children under 18 (2014–2018), %	−385.44 (−577.29, −193.60)	−3.976	*P* < .01
Civilian labor force in age 16 + (2015–2019), %	−108.62 (−192.40, −24.83)	−2.566	*P* < .05
Two or more races, %	−1212.40 (−1953.63, −471.17)	−3.237	*P* < .01
Infection (Jan–Sep 2021)			
Constant	10,351.40 (−393.59, 21,096.39)	1.907	NS
Asian alone, %	1114.48 (811.79, 1417.17)	7.289	*P* < .01
Persons under 5, %	2139.58 (1493.35, 2785.81)	6.554	*P* < .01
Households (2015–2019)	0.359 (0.195, 0.523)	4.334	*P* < .01
Total employment (2019)	0.140 (0.062, 0.219)	3.558	*P* < .01
Total annual payroll (×$1000) (2019)	−2.74E-3 (−3.42E-3, −2.05E-3)	−7.857	*P* < .01
Single parent households with children under 18 (2014–2018), %	−367.31 (−576.02, −158.60)	−3.484	*P* < .01
Civilian labor force in age >16 (2015–2019), %	−100.32 (−192.54, −8.09)	−2.153	*P* < .05
Population density	−2.570 (−3.844, −1.296)	−3.993	*P* < .01
Female, %	−258.23 (−499.02, −17.44)	−2.123	*P* < .05
Total population (2019 estimation)	−0.090 (−0.144, −0.036)	−3.297	*P* < .01

CI = confidence interval, NS = not significant.
COVID-19 = coronavirus disease 2019.

Table 4

Demographic and socioeconomic determinants of deaths of COVID-19 in Virginia.

Variable	Coefficient (95% CI)	t	*P* value
Death (Mar–Dec 2020)			
Constant	48.04 (−28.80, 124.87)	1.237	NS
Asian alone, %	14.33 (10.75, 17.91)	7.923	*P* < .01
Persons <5, %	27.56 (18.10, 37.02)	5.763	*P* < .01
Total employment (2019)	1.81E-3 (1.13E-3, 2.50E-3)	5.220	*P* < .01
Total annual payroll (×$1000) (2019)	−2.63E-5 (−3.46E-5, −1.80E-5)	−6.253	*P* < .01
Single parent households with children under 18 (2014–2018)	−7.42 (−11.01, −3.82)	−4.086	*P* < .01
Two or more races, %	−31.19 (−42.49, −19.89)	−5.464	*P* < .01
White alone, %	−0.82 (−1.42, −0.23)	−2.739	*P* < .01
Death (Jan–Sep 2021)			
Constant	26.42 (−34.97, 87.81)	0.852	NS
Asian alone, %	11.03 (6.81, 15.25)	5.178	*P* < .01
Persons <5, %	24.22 (15.43, 33.00)	5.457	*P* < .01
Total employment (2019)	4.65E-3 (2.80E-3, 6.50E-3)	4.965	*P* < .01
Households (2015–2019)	4.52E-3 (2.33E-3, 6.71E-3)	4.082	*P* < .01
Total annual payroll (×$1000) (2019)	−4.91E-5 (−6.02E-5, −3.80E-5)	−8.774	*P* < .01
Single parent households with children under 18 (2014–2018)	−3.96 (−6.89, −1.03)	−2.677	*P* < .01
Total population (2019 estimation)	−1.13E-3 (−1.92E-3, −3.45E-4)	−2.847	*P* < .01
Civilian labor force in age >16 (2015–2019), %	−1.82 (−3.02, −0.63)	−3.026	*P* < .01
Total employer establishments (2019)	−0.032 (−0.060, −0.004)	−2.286	*P* < .05
Housing in structures with 10 or more units (2014–2018), %	−2.40 (−3.66, −1.14)	−3.772	*P* < .01

CI = confidence interval, COVID-19 = coronavirus disease 2019, NS = not significant.

checkups, COVID-19 tests, and vaccination on time; in the case of infection, those families may not be able to receive immediate medical attention, which may have led to higher case fatalities. This delay in receiving treatment has understandably led to higher case fatalities.

While some studies demonstrated that case fatalities tended to be higher in communities with a greater proportion of Black people or a larger population size,[40,41] this study found that the proportion of Asian and American Indian and Alaska Native was the primary risk factor during the pre-vaccination period. However, during the post-vaccination period, ethnicity was no longer one of the risk factors. A joint report by the US Department of Health and Human Services and the centers for disease control and prevention determined that overall, vaccine coverage in counties with higher percentages of mobile homes tended to be lower than in counties with lower percentages of mobile homes, raising the risks of those dying from COVID-19.[42] Similarly, this study uncovered that the percentage of mobile homes, median gross rent, and total population became significant risk factors during the post-vaccination period, which suggested that in Virginia, during the post-vaccination period, case fatality was less affected by racial differences than by socioeconomic differences.

Table 5

Demographic and socioeconomic determinants of incidence rates of COVID-19 in Virginia.

Variable	Coefficient (95% CI)	t	*P* value
Incidence rate (Mar–Dec 2020)			
Constant	16,701.43 (12,217.19, 21,185.67)	7.372	*P* < .01
Hispanic or Latino, %	169.73 (99.96, 239.50)	4.816	*P* < .01
Native Hawaiian and other Pacific islander, %	3681.76 (−193.60, 7557.12)	1.881	*P* < .05
Person uninsured (2015–2019), %	181.16 (57.28, 305.04)	2.895	*P* < .01
Persons in group quarters (2014–2018), %	53.02 (15.83, 90.21)	2.822	*P* < .01
Persons aged ≥65, %	−163.14 (−230.65, −95.62)	−4.783	*P* < .01
Two or more races, %	−556.28 (−924.41, −188.15)	−2.991	*P* < .01
Persons under age 65 without health insurance, %	−239.53 (−390.59, −88.47)	−3.139	*P* < .01
Persons per household (2015–2019)	−1975.34 (−3342.59, −608.09)	−2.860	*P* < .01
Median gross rent (2015–2019)	−3.70 (−5.13, −2.28)	−5.146	*P* < .01
Incidence rate (Jan–Sep 2021)			
Constant	7865.05 (3180.24, 12,549.86)	3.322	*P* < .01
White alone, %	17.18 (3.91, 30.45)	2.562	*P* < .05
Persons under 5, %	727.69 (500.00, 955.37)	6.325	*P* < .01
Persons in group quarters (2014–2018), %	44.02 (7.14, 80.90)	2.362	*P* < .05
Foreign-born persons, %	−128.98 (−176.35, −81.61)	−5.389	*P* < .01
Median value of owner-occupied housing units (2015–2019)	−5.13E-3 (−7.54E-3, −2.71E-3)	−4.205	*P* < .01
Persons living in same house >1 yr (2015–2019), %	−53.89 (−98.79, −9.00)	−2.376	*P* < .05

CI = confidence interval, COVID-19 = coronavirus disease 2019.

Table 6

Demographic and socioeconomic determinants of case fatalities of COVID-19 in Virginia.

Variable	Coefficient (95% CI)	t	*P* value
Case fatality (Mar–Dec 2020)			
Constant	7.50 (4.88, 10.13)	5.665	*P* < .01
Asian alone, %	0.08 (0.02, 0.14)	2.594	*P* < .05
American Indian and Alaska native, %	0.30 (0.01, 0.60)	2.066	*P* < .05
Households with no vehicle (2014–2018), %	0.15 (0.09, 0.20)	5.382	*P* < .01
Persons under 65, %	−0.10 (−0.14, −0.06)	−4.798	*P* < .01
Persons under 5, %	−0.32 (−0.51, −0.13)	−3.286	*P* < .01
Case fatality (Jan–Sep 2021)			
Constant	7.50 (4.88, 10.13)	5.780	*P* < .01
Total population (2019 estimation)	0.30 (0.01, 0.60)	−2.228	*P* < .05
Median gross rent (2015–2019)	0.15 (0.09, 0.20)	−8.091	*P* < .01
Mobile homes (2014–2018), %	0.08 (0.02, 0.14)	−2.563	*P* < .05
Persons under 18, %	−0.32 (−0.51, −0.13)	3.334	*P* < .01
Total annual payroll (×$1000) (2019)	−0.10 (−0.14, −0.06)	3.864	*P* < .01

CI = confidence interval, COVID-19 = coronavirus disease 2019.

Table 7

Demographic and socioeconomic determinants of mortality of COVID-19 in Virginia.

Variable	Coefficient (95% CI)	t	*P* value
Mortality (Mar–Dec 2020)			
Constant	21.92 (−33.19, 77.04)	0.787	NS
Persons age >25 with no high school diploma (2014–2018), %	8.38 (5.26, 11.50)	5.314	*P* < .01
Households with no vehicle (2014–2018), %	11.18 (6.65, 15.71)	4.883	*P* < .01
Persons in poverty, %	−4.54 (−7.68, −1.41)	−2.869	*P* < .01
Persons under age 65 without health insurance, %	−6.86 (−12.90, −0.81)	−2.245	*P* < .05
Mortality (Jan–Sep 2021)			
Constant	208.64 (91.54, 325.73)	3.526	*P* < .01
Persons <18, %	10.58 (6.40, 14.77)	5.005	*P* < .01
Persons under age 65 with a disability (2015–2019), %	4.55 (1.09, 8.00)	2.605	*P* < .05
Persons in group quarters (2014–2018), %	2.47 (0.94, 3.99)	3.204	*P* < .01
Persons per household (2015–2019)	−80.48 (−134.35, −26.60)	−2.956	*P* < .01
Median gross rent (2015–2019)	−0.13 (−0.18, −0.09)	−5.450	*P* < .01
Mobile homes (2014–2018), %	−2.36 (−3.84, −0.88)	−3.146	*P* < .01

CI = confidence interval, COVID-19 = coronavirus disease 2019, NS = not significant.

Table 8

Summary of multiple linear regression analysis of COVID-19 prevalence in Virginia.

COVID-19 prevalence	R	R^2	Adjusted R^2	Durbin-Watson
Confirmed cases (Mar–Dec 2020)	0.845	0.714	0.699	1.836
Confirmed cases (Jan–Sep 2021)	0.892	0.796	0.779	1.962
Deaths (Mar–Dec 2020)	0.801	0.641	0.621	1.750
Deaths (Jan–Sep 2021)	0.859	0.737	0.716	2.290
Incidence rate (Mar–Dec 2020)	0.775	0.601	0.572	2.415
Incidence rate (Jan–Sep 2021)	0.749	0.561	0.540	1.972
Case fatality (Mar–Dec 2020)	0.507	0.257	0.228	1.834
Case fatality (Jan–Sep 2021)	0.635	0.403	0.380	1.977
Mortality (Mar–Dec 2020)	0.595	0.354	0.334	2.106
Mortality (Jan–Sep 2021)	0.729	0.532	0.509	1.907

COVID-19 = coronavirus disease 2019.

SVI score has been identified as a significant risk factor in COVID-19 mortality in America.[21] It is comprised of 4 subindices, notably socioeconomic status, household composition and disability, minority status and language, and housing type and transportation. In this study, 4 SVI variables, the percentage of households without vehicles, persons aged 25 and over without a high school diploma, persons under age 65 with a disability, and persons in group quarters were significant risk factors of COVID-19 mortality in Virginia. Without a vehicle, commuters may need more time to commute to work by using public transportation or walking, both of which can put them in contact with more people and increase their risks of contracting COVID-19 and bringing it home to their family members, potentially raising mortality rates.[43] Adults without high school diplomas tend to work in industries that remained open during the pandemic, increasing their risk of contracting COVID-19 and spreading it to their family members.[44] It has been reported that counties with higher percentages of the population under the age of 18 and/or living with a disability tend to have significantly lower vaccine coverage than counties with lower percentages of the population under the age of 18 and/or disabled,[42] contributing to increased mortality among the former counties. With the aforementioned socioeconomic risk factors, it should be easy to understand why the median of mortalities in Virginia during the post-vaccination period is 2.23 times that of the pre-vaccination period. The increased vulnerability of Virginia as the pandemic continued demands the vigilance of policymakers.

Different models have been developed to characterize and predict the incidence rates of COVID-19.[45–47] Mollaloet al developed a multiscale geographically weighted regression model to study the impact of environmental, socioeconomic, topographic, and demographic variables on COVID-19 incidence rate in the continental US. The multiscale geographically weighted regression model could explain up to 68.1% of the variation in incidence rates.[48] In another study, a least absolute shrinkage and selection operator regression model was developed to explore the socioeconomic determinants of COVID-19 incidence rates in Georgia. Even though the model could identify risk factors and differentiate their impact, the model only explain approximately 45% of the variation in incidence rates between counties in Georgia.[49] Through stepwise multiple linear regression analysis, this study demonstrated that some demographic and socioeconomic factors were strongly associated with cumulative infections, deaths, incidence rates, case fatalities, and mortalities. Ten multiple linear regression models were developed, 1 characterizing the demographic and socioeconomic risk factors of each of the 5 indicators during both the pre-vaccination and post-vaccination periods in Virginia. Demographic and socioeconomic factors contributed up to 80% of the variation in infections, deaths, and incidence rates and up to 53% of the variation in case fatalities and mortalities, suggesting that they had greater impacts on cumulative infections and deaths, as well as the incidence rates, than on case fatalities and mortalities.

The majority of the data of the potential risk factors was collected from the 2015 to 2019 American community survey, recent enough for discuss their impacts on COVID-19 transmission in 2020. However, the pandemic likely altered the data significantly during the 2 pandemic years.[50] Therefore, the developed regression models may not be able to fully characterize the socioeconomics and demographics of Virginians during the pandemic years. In addition, it is arguable that other non-biological factors, such as the often-changed and inconsistent health policies, medical resources, personal hygiene practice, public health knowledge and education, and attitudes towards vaccination also affected the pandemic to varying degrees.[51–54] However, they may be correlated with some of the demographic and/or socioeconomic factors included in this study. Thus, the impacts of demographic and socioeconomic risk factors, and their interaction with other impact factors on COVID-19, require further study.

5. Conclusions

The cumulative infections, deaths, incidence rates, case fatalities, and mortalities of COVID-19 in Virginia during post-vaccination period were significantly higher than those of the pre-vaccination period. Some demographic and socioeconomic factors were strongly associated with the cumulative infections, deaths, incidence rates, case fatalities, and mortalities of COVID-19 in Virginia both pre- and post-vaccination, explaining up to 80% of the variation of cumulative infections, deaths, and incidence rates, and up to 53% of the variation in case fatalities and mortalities. Even with the proliferation of effective therapeutics and vaccination, to prevent and control COVID-19 and similar emergent pandemics in the future, policymakers must carefully examine these demographic and socioeconomic risk factors to understand their root causes and guide policy design for the future.

Author contributions

Conceptualization: Wanli Tan.
Data curation: Wanli Tan.
Investigation: Wanli Tan.
Methodology: Wanli Tan.
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