Original article

COVID-19 and stroke mortality in the United States: A quantitative analysis on the impact of COVID-19 and its policies

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Abstract
Spreading rapidly across the globe, the COVID-19 pandemic had an unprecedented impact on the global population, devastating healthcare systems and negatively impacting those experiencing stroke. The aim of this study was to reveal the relationship between COVID-19 cases and stroke mortality rate in the US at national and state levels to assess the impact of COVID-19 on stroke mortality and to investigate how COVID-19 policies of individual states impact this relationship. A secondary quantitative analysis of the US and in the states of California, Iowa, and Vermont was conducted using the ordinary least squares regression model to examine the relationship between COVID-19 cases and stroke mortality rate for the period 2020-2022. The result of the study indicates a statistically significant positive relationship between COVID-19 cases and stroke mortality rate throughout the period 2020-2022 in the US as a whole. When stratified by different COVID-19 restriction policies of select states, we found notably different coefficients and significance of the relationship. In 2020-2022, the stroke mortality rate increased by 3.6 deaths per 100,000 in Iowa, 4.7 deaths per 100,000 in California, 2.4 deaths per 100,000 in Vermont, and 3.9 deaths per 100,000 in the US. Therefore, we concluded that COVID-19 cases potentially affect stroke mortality rates, with the degree of impact influenced by multiple factors such as COVID-19 restriction policies and COVID-19 cases, where higher COVID-19 cases and restriction levels increase the stroke mortality rate. This underscores the need for further research and suggests the importance of developing future policies which mitigate the impact of similar pandemics on stroke mortality rates.

Keywords
COVID-19, Stroke, Stroke mortality, Stroke mortality rate, US healthcare system, COVID-19 restriction, Public health policy

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Introduction

The identification of the first case of COVID-19 in the United States was on January 21, 2020, marking the onset of the pandemic's rapid spread across the country, resulting in more than 100 million cases and 1.1 million deaths by the end of January 2023 (1, 2). As COVID-19 continues to plague the United States, it has been recognized as one of the most significant impediments to the prosperity and growth of the US following the Great Depression (3). Experts project that COVID-19 will deprive the United States of a staggering 16 trillion US dollars, devastating the economy and shaking almost every industry down towards recession and distress (3). The fatality of the virus continues to significantly impact countless individuals. Those who did not contract the virus also grapple with the repercussions of the pandemic, including the grief of witnessing the loss of life, fear for personal safety, anxiety and distress about their financial stability, and a decrease in their overall mental health caused by the solidarity during lockdowns.

To preserve the health of its population, the U.S. government mobilized vast amounts of resources across the country to restructure its healthcare system and centered it all around the containment and prevention of COVID-19 (4); however, the US neglected other sectors of the healthcare industry (5). Many states implemented a multitude of measures in hopes of combating the virus, including travel restrictions, lockdowns, mandatory mask requirements, etc. (6). Unfortunately, facilities and services related to stroke care were among those severely impacted by such systems-level shifts. Since the emergence of the pandemic, there was a notable 30% decrease in stroke hospitalizations. However, contrary to the decline in stroke hospitalizations, there was a significant increase in severe stroke hospitalizations (7, 8).

Stroke is one of the leading causes of death, accounting for 1 in 6 deaths of cardiovascular diseases in 2020 (9, 10). A total of 53 billion US dollars was spent on stroke-related services in 2017-2018 alone. Furthermore, stroke risk tends to increase with age, potentially doubling every ten years after age 55 (11).

Multiple risk factors actively increase the risks of having a stroke and the severity of a stroke, including hypertension, high blood pressure, high cholesterol, heart disease, obesity, sickle cell disease, etc. (12). During the COVID-19 pandemic, opportunities to decrease the risk of stroke were severely limited due to various COVID-19 restrictions implemented both at the national and state level. The level of restriction implemented in each state varied greatly, impacting the citizens of each state in unique facets (13).

Currently, no study has analyzed the consequences of COVID-19 cases on stroke mortality rates at both the state and national levels. Therefore, this study aims to unveil the relationship between the number of COVID-19 cases and stroke mortality rates between 2020-2022 and compare the change in national stroke mortality rates and the mortality rates in a few selected states such as California, Vermont, and Iowa during the COVID-19 pandemic. The findings of this study will shed light on the impacts of COVID-19 on the stroke mortality rate and raise awareness of the undiscovered effects of COVID-19. In addition, it will reveal any setbacks that may assist the government and healthcare authorities in improving healthcare measures for future potential pandemics similar to COVID-19.

Methods

The data were obtained from various sources, including the CDC NCHS mortality database, CDC COVID-19 Response, US Census Bureau, Wallet Hub, and JHU CCSE (6, 13-16). The CDC NCHS provided the crude and age-adjusted rates of all causes of death in all fifty states and in the District of Columbia from 2020-2022. The NCHS calculated the "3-month period" and the "12-month ending with quarter" (16). For this study, the age-adjusted "12 months ending with quarter" stroke mortality rate was utilized, which is regarded as a more reliable measure due to its high level of accuracy. This is due to the expectation that projections for the "12-month period" will be less than 0.5% off the actual rate, whereas the "3-month period" is less than 1.0% off the actual rate. "CDC COVID-19 Response" was a source of the daily reported COVID-19 cases from state and jurisdictional partners from 2020-2022 (15). This study used the "confirmed cases" and the date that marks one day after the end of a quarter (3 months) for analysis (e.g., 4/1/2022-7/1/2022 for 2022 Quarter 2 (Q2)). The U.S. Census Bureau collected the population estimate of the United States and was used to determine the population in 2022 Quarter 2 (Q2) (17). The JHU CCSE collected the number of COVID-19 cases worldwide from multiple sources, and this study utilized the total COVID-19 cases in the US one day after the end of each quarter for analysis (14). Additionally, this study referenced WalletHub's analysis of the ranking and scoring of COVID-19 restrictions of each state across specific dates in 2020-2021 (6). The average of the COVID-19 rankings of each state across the period of 2020-2021 was taken to estimate the overall rankings of the COVID-19 state restrictions.

Data analysis

Specific states were chosen using the average level of COVID-19 restriction and the number of COVID-19 cases as of 2022 Q2. States were selected according to these criteria: the highest COVID-19 restriction level, the lowest restriction level, the highest number of COVID-19 cases, and the lowest number of COVID-19 cases. By examining the highest and lowest restriction levels, it allows the study to examine the potential impacts of the stringency of restrictions on stroke mortality rate. Similarly, by comparing states with the highest and lowest cases, it would also reveal the influence of the severity of the COVID-19 outbreak on stroke mortality. This determination was based on the data provided by "Wallet Hub" and "CDC COVID-19 response" (6, 15). Then, the stroke mortality rate and the number of COVID-19 cases of each quarter from 2020 Q1-2022 Q2 in selected states and the US were grouped into a dataset. A quarter (Q) is defined as one-fourth of a year and begins in January. A linear regression model was performed for each state and the US using Python 3.10.11. The model was fitted with ordinary least squares (OLS) regression to examine and describe the relationship between COVID-19 cases and stroke mortality rate across the quarters. The stroke mortality rate and the number of COVID-19 cases were continuous variables, while the time period was categorical. The independent variable for this study was the number of COVID-19 cases, whereas the dependent variable was the stroke mortality rate. In addition, the period of 2020-2022 and age were used as controlled variables. The statistical significance of the results was assessed through the confidence interval, standard error, and P-value. A P-value of less than 0.05 was considered statistically significant in this study.

Results

Table 1. Average COVID-19 Restriction Levels, Number of COVID-19 Cases, and Stroke Mortality Rate from 2022 Q2 to Present

State	Number of COVID-19 Cases in 2022 Q2	Average COVID Restriction Rankings	Stroke Mortality Rate (Per 100,000) in 2022 Q2
US	*87,832,253*	*NA*	*41*
Alabama	*1,360,717*	15.75	*53.4*
Alaska	*261,987*	8.25	*41.2*
Arizona	*2,125,567*	28.75	*36.1*
Arkansas	*866,816*	22.9	*47.4*
California	*10,143,414*	48.25	*41.9*
Colorado	*1,551,507*	39.75	*35.4*
Connecticut	*831,880*	41	*30.2*
Delaware	*285,403*	37.5	*58*
District of Columbia	*157,303*	47.5	*45*
Florida	*6,504,402*	6.5	*47.3*
Georgia	*2,647,568*	18	*46*
Hawaii	*301,246*	44.75	*44.5*
Idaho	*464,094*	7.75	*36*

Illinois	*3,435,405*	32.25	*43.1*
Indiana	*1,775,886*	19.5	*44*
Iowa	*798,174*	2.5	*34.5*
Kansas	*806,934*	17.75	*38.8*
Kentucky	*1,415,549*	30.5	*46.1*
Louisiana	*1,233,000*	23.25	*50.8*
Maine	*270,333*	42.75	*30.6*
Maryland	*1,137,909*	25.25	*46.8*
Massachusetts	*1,926,543*	45.5	*25.5*
Michigan	*2,606,431*	32.25	*46.2*
Minnesota	*1,554,243*	34.5	*34.8*
Mississippi	*836,757*	18	*56.6*
Missouri	*1,509,862*	9.75	*40.4*
Montana	*287,145*	15.25	*30.9*
Nebraska	*500,574*	16.75	*35.2*
Nevada	*776,984*	26.5	*42.2*
New Hampshire	*332,364*	23.25	*30.2*
New Jersey	*2,492,366*	39.5	*31.4*
New Mexico	*564,678*	39.5	*38.8*
New York	*3,004,942*	40.5	*25.7*
North Carolina	*2,882,313*	37.5	*45.7*
North Dakota	*250,319*	12.75	*29.6*
Ohio	*2,848,453*	24.75	*49*
Oklahoma	*1,079,454*	4	*42.6*
Oregon	*813,051*	37.75	*47.5*
Pennsylvania	*3,009,121*	36.25	*37.7*
Rhode Island	*383,404*	36.25	*31.1*
South Carolina	*1,555,601*	9.5	*47.4*

South Dakota	*244,523*	3	*34.4*
Tennessee	*2,125,582*	15.5	*48*
Texas	*7,108,183*	25.25	*43.4*
Utah	*982,895*	8.5	*34.3*
Vermont	*126,307*	46.75	*31.2*
Virginia	*1,872,624*	47.25	*41.6*
Washington	*1,666,408*	42.5	*38.1*
West Virginia	*533,213*	24.5	*42*
Wisconsin	*1,728,344*	11.75	*36.3*
Wyoming	*164,456*	12.5	*32.5*

Based on the data presented in Table 1, California, Iowa and Vermont were selected according to the criteria mentioned above. Table 1 indicates that California had the highest average restriction level, with an average rank of 48.25, and Iowa had the lowest, with an average rank of 2.5. In addition, from 2022 Q2 to the present, California had the highest number of COVID-19 cases, with 10,143,414, while Vermont had the least, with 126,307. Vermont had an average restriction level of 44.75. Among these states, California, Iowa, and Vermont each had a stroke mortality rate of 41.9 deaths per 100,000, 34.5 deaths per 100,000, and 31.2 deaths per 100,000, respectively.

Table 2. COVID-19 Cases and Stroke Mortality Rate from 2020 Q1 - 2022 Q2

DATE	**Number of COVID-19 Cases**				**Stroke Mortality Rate (Per 100,000)**			
Population Estimate on 2022 Q2	**US**	**California**	**Vermont**	**Iowa**	**US**	**California**	**Iowa**	**Vermont**
	333,287,557	**39,029,342**	**647,064**	**3,200,517**	**333,287,557**	**39,029,342**	**3,200,517**	**647,064**
2020 Q1	227903	8155	300	549	37.1	37.2	30.9	28.8
2020 Q2	2698127	232657	1110	29458	37.4	37.2	31.4	27.9
2020 Q3	7292562	813687	1613	90009	38.1	38.3	31.3	30
2020 Q4	20397398	2292568	7133	282664	38.8	39.1	31.9	28.3
2021 Q1	30656330	3570660	18238	351795	38.8	39.7	31	28.2
2021 Q2	33797251	3712152	22841	374009	41.1	42.4	33	30.3
2021 Q3	43694428	4705915	31411	455579	41.2	42.4	33	30.8

2021 Q4	55099948	5477529	61294	582348	41.1	42.1	33.8	31.9
2022 Q1	80252748	9095256	108249	759048	41.3	42.1	34.9	32
2022 Q2	87832253	10143414	126307	798174	41	41.9	34.5	31.2

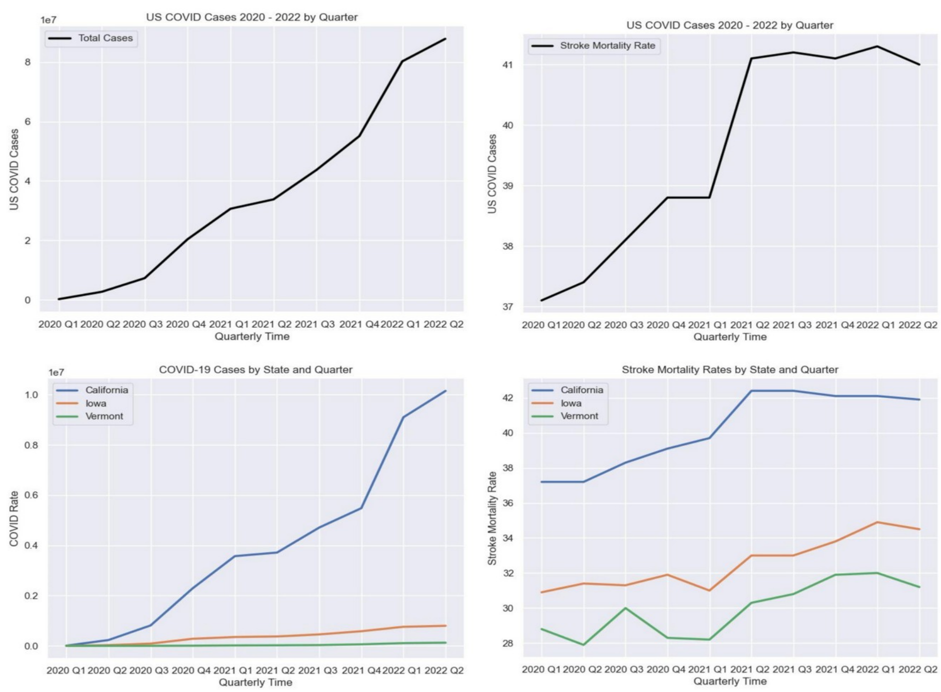

Figure 1. Four graphs depicting Stroke Mortality Rates and COVID-19 cases. The figure at the top left represents the increase in total COVID-19 cases from 2020-2022 in the US. The figure at the top right represents the Stroke Mortality Rate from 2020-2022 in the US. The figure at the bottom left portrays a comparison of the COVID-19 cases in Vermont, Iowa, and California from 2020-2022. The figure at the bottom right indicates the difference in stroke mortality rate in Vermont, Iowa, and California from 2020-2022. The y-axis units for the top left and bottom left graphs are in tens of millions of cases, while the y-axis units for the top right and bottom right graphs are in deaths per 100,000 people.

In 2020 Q1 - 2022 Q2, all states witnessed a significant increase in COVID-19 cases. In the US, COVID-19 cases increased from 227,903 in 2020 Q1 to 87,832,253 in 2022 Q2. Out of the total US population, 26.35% was infected. In California, the state with the highest restriction level (Table 1), COVID-19 cases increased from 8,155 in 2020 Q1 to 10,143,414 in 2022 Q2. As of 2022 Q2, California had the most COVID-19 cases, accounting for 11.5% of the total cases in the US. Approximately 25.98% of its population was infected. In Iowa, the state with the lowest restriction level (Table 1), COVID-19 cases increased from 549 in 2020 Q1 to 798,174 in 2022 Q2. As of 2022 Q2, Iowa accounted for around 0.9% of the total COVID-19 cases in the US. A total of 19.52% of its population was infected. In Vermont, COVID-19 cases increased from 300 in 2020 Q1 to 126,307 in Q2 2022. Vermont, the state with the least COVID-19 cases, accounted for only around 0.144% of the total cases in the US in 2022 Q2. 24.94% of its population was infected.

In the US, the stroke rate steadily increased, from 37.1 deaths per 100,000 in 2020 Q1 to 41 deaths per 100,000 in 2022 Q2, with the highest point at 41.3 deaths per 100,000. There was a total increase of 3.9 deaths per 100,000, a 10.5% increase in stroke rate. In California, the stroke rate was slightly higher than the national rate. The stroke rate increased from 37.2 deaths per 100,000 in 2020 Q1 to 41.9 deaths per 100,000 in 2022 Q2, with its highest point at 42.4 deaths per 100,000 in 2021 Q2. An increase of 4.7 deaths per 100,000 increase was observed, which denoted a 12.6% increase in stroke rate. In Iowa, the stroke rate increased slightly less than the national rate. The stroke mortality rate increased from 30.9 deaths per 100,000 in 2020 Q1 to 34.5 deaths per 100,000 in 2022 Q2, with its highest point at 34.9 deaths per 100,000 in 2022 Q1. An increase of 3.6 deaths per 100,000 was observed, which indicated an 11.65% increase in stroke mortality rate. Vermont showed the smallest increase in the stroke rate and had a relatively unstable trend, fluctuating from 28.8 deaths per 100,000 in 2020 Q1 to 31.2 deaths per 100,000 in 2022 Q2, with the highest point at 32 deaths per 100,000 in 2022 Q1. An increase of 2.4 deaths per 100,000 was observed, which was an 8.3% increase in the stroke mortality rate. There was a slight decrease in stroke mortality rate in 2022 Q2 both nationally and in the states, with the most notable reduction in Vermont with a 0.8 deaths per 100,000 drop.

Table 3. Linear Regression of Stroke Morality Rate and COVID-19 Cases

Stroke Mortality rate for every additional COVID-19 case	***B(95% CI)***	***SE***	***p***
US (Nationally)	5.683e-08 (3.93e-08, < 7.43e-08)	8.03e-09	<0.001
California	5.987e-07 (3.81e-07, < 8.17e-07)	1e-07	<0.001
Iowa	3.13e-06 (1.35e-06, < 4.91e-06)	8.18e-07	0.002
Vermont	2.616e-05 (1.23e-05, < 4e-05)	6.37e-06	0.001

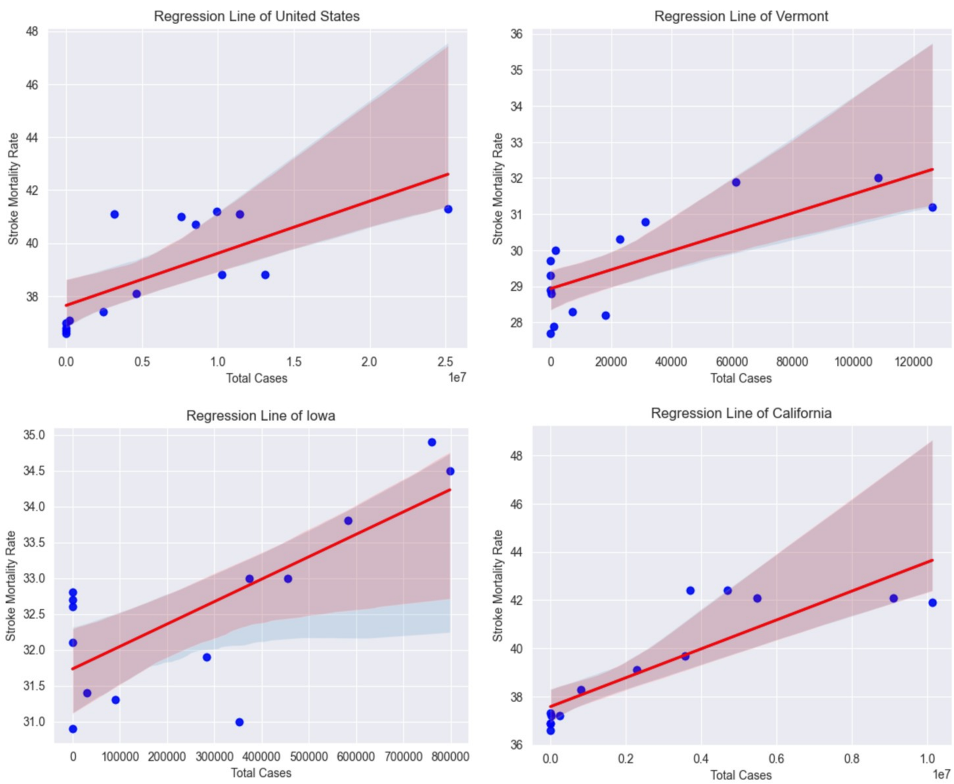

Figure 2. Four linear regression visualizations showing the relationship between COVID-19 Cases and Stroke Mortality Rate. The figure on the top left indicates the linear regression line of the United States. The figure on the top right shows the linear regression line of Vermont. The figure on the bottom left indicates the linear regression line for Iowa, and the graph on the bottom right displays the linear regression line for California.

The linear regression analysis revealed a significant positive relationship between COVID-19 cases and stroke mortality rate nationally and across specific states such as California, Iowa, and Vermont. This result indicated the significance of COVID-19 cases as a predictor of stroke mortality rate in each region, with *p-values* ranging from < 0.001 to 0.002. Nationally, for every additional COVID-19 case, there was an increase of 5.683e-08 deaths per 100,000 (SE = 8.03e-09, p < 0.001) in stroke mortality rate. This denoted that for every additional 17,596,339.9 COVID-19 cases, there would be an increase in the stroke mortality rate by one death per 100,000. The coefficient of increase in California was 5.987e-07 (SE = 1e-07, p < 0.001). This indicates that for every additional 1,670,285.6 COVID-19 cases, there was an increase of 1 death per 100,000 in stroke mortality rate. In Iowa, the coefficient of the relationship was 3.13e-06 (SE = 8.18e-07, p = 0.002). This indicated that for every additional 319,488.8 COVID-19 cases, there was an increase of 1 death per 100,000 in stroke mortality rate. In Vermont, the coefficient was 2.616e-05 (SE =

6.37e-06, p = 0.001). This suggested that for every additional 38,226.2 COVID-19 cases, there was an increase of 1 death per 100,000 in stroke mortality rate. The analysis revealed that the impact of COVID-19 cases on stroke mortality rate was most pronounced in Vermont, followed by Iowa and California, while the effect in the US as a whole was comparatively less.

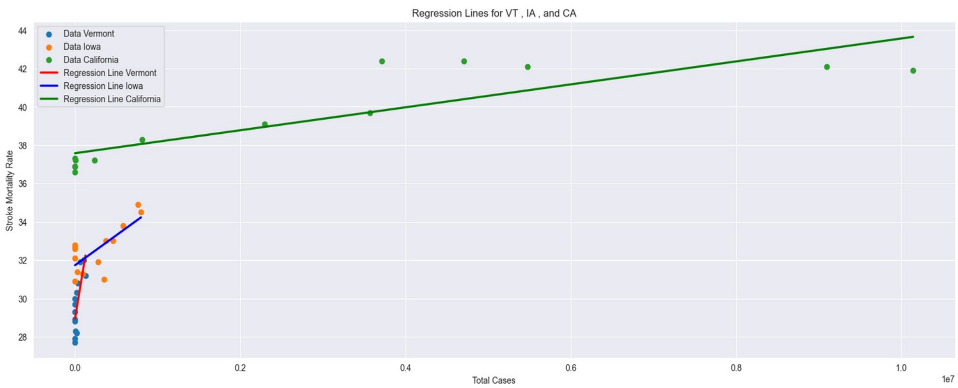

Figure 3. A comparison of the three linear regression lines of Iowa, California, and Vermont.

Discussion

The result of our findings supports the study's hypothesis and provides significant insight into the correlation between the increase in COVID-19 cases and the increase in the stroke mortality rate in the US. The results of our study indicate a statistically significant positive relationship in the selected states and the United States. This study hypothesizes that a few factors can explain the positive relationship between COVID-19 cases and stroke mortality rate.

As suggested by the result of this study, COVID-19 restriction levels may be a contributing factor that increases the risks of stroke and the stroke mortality rate by negatively impacting physical and mental health. Policies like mask mandates, social distancing, and quarantines would delay the identification of stroke, which may prolong the duration of treatment, therefore increasing stroke risk (18). The isolation caused by COVID-19 restrictions like quarantine and social distancing also negatively impacts the mental health of many due to unemployment, physical and social inactivity, unhealthy diet behaviors, and poor sleep quality (19). Poor mental health leads to unhealthy diet behaviors and increased alcohol consumption, which also contribute to the increase in stroke risk and mortality (20-22). In addition, due to the allocation of resources from other health sectors like stroke to combat COVID-19, the stroke care system of the US was also affected negatively. Multiple studies have proven that stroke admissions and the quality of care have taken a notable decrease due to the collateral impact of COVID-19 (23-26). This includes delays in stroke hospital arrival times, decreased ambulance services, and limited treatment available due to shutdowns. These issues were exacerbated by the social distancing and quarantine measures implemented throughout the country. The quality and availability of stroke care have been proven to be significantly associated with stroke mortality, provoking the hypothesis that insufficiency of stroke care was a significant factor in increasing the stroke mortality rate during COVID-19 (27). In addition, previous studies have indicated that there has been an overall decline in stroke admission rates during the period of COVID-19 (23). Milder, moderate, and transient cases of stroke admission are seen to have significantly decreased during the period of COVID-19, while cases of severe strokes have increased (23). The severity of stroke is associated with increased chances of mortality, and the increase in the severity of stroke admission is highly likely to be significantly associated with COVID-19 (28).

Studies have also monitored and examined patients with COVID-19 and observed an increased stroke risk in COVID-19 patients. The increase in stroke in COVID-19 patients is multifactorial and is often exacerbated by other factors such as acute injury and hepatic and respiratory failure (29). Patients infected by COVID-19 witness the activation of the coagulation pathway, hypercoagulation, excessive cytokine, protease release, and downregulation of RAS, vastly increasing the risk of stroke in COVID-19 patients (30-35). Therefore, we speculate that the increase in COVID-19 cases caused an increase in stroke and stroke mortality rates.

In addition, the varying results of the linear model among the states shown in Figures 2 and 3 also indicated a different trend between each state. Vermont had the steepest regression line, and California had the most stagnant. This trend can be explained by the population of each state. With a smaller population, it would require fewer COVID-19 cases to observe a significant impact on the stroke rate of the local population, as each case will account for a higher percentage of increase in cases. However, despite the varying population, the COVID-19 infection percentage of California and Vermont were relatively close, with Iowa slightly less than the other two. Therefore, this study utilized the overall increase in stroke mortality rate in the period 2020-2022 as a benchmark for comparison. Contrary to the results above, California observed the highest increase in the stroke mortality rate, followed by Iowa and Vermont, with considerable variability between the magnitude of increase between states. This result indicates that other underlying factors associated with COVID-19 cases seem to affect the extent to which stroke mortality rates are impacted.

This study hypothesizes that a multitude of possible factors influences the impact of COVID-19 cases on the stroke mortality rate of each state. Two explanations for the different increases in stroke mortality arise; the direct impact of COVID-19 in increasing stroke risk in COVID-19 patients; the impact of COVID-19 policies on stroke care, and the mental and physical health of the population. As discussed above, COVID-19 restriction levels impact stroke mortality rate. Comparing California and Iowa, it can be noticed that California, with the overall highest restriction level (average ranking: 48.25) throughout 2020-2021, saw a higher increase in the stroke mortality rate of 4.7, while Iowa, with the overall lowest restriction level (average ranking: 2.5) observed less of an increase of 3.6. Both California and Iowa implemented COVID-19 mask mandates at the beginning of 2020, with Iowa lifting the mask mandate in March 2021 and California lifting its mask mandates in May 2021 (36-40). In addition, Iowa shut down most bars and restaurants along with some businesses throughout 2020, while California shut down businesses starting in late 2020 and used a four-colored tier system that assesses the individual restrictions of each county depending on COVID-19 rates and hospitalizations. However, unlike California, Iowa did not implement stay-home orders. In California, statewide stay-home orders, where all non-essential workers were required to stay home, were implemented in March 2020. This order was relieved and tightened throughout 2020-2021, depending on the county and state COVID-19 cases. Eventually, Iowa and California relieved most of their restrictions in early and late 2021, respectively. This study hypothesizes that the mask mandates implemented by the states impede the identification of stroke signs, which may increase the chances of severe stroke and stroke mortality. Common signs like the drooping of the face and slurred speech are often neglected or identifiable due to mask coverings (41). This may delay the treatment time and exacerbate the severity of the stroke. Stroke recognition in patients is significantly associated with the risk of death (42). In addition, multiple researchers have discovered that there has been a decrease in light, moderate, and vigorous physical activity and an increase in sedentary behavior due to COVID-19 restrictions like stay-home orders for all ages (43, 44). Constant moderate physical activity is a significant factor in decreasing the risk of stroke, and the majority of the population was deprived of this opportunity due to the COVID-19 restrictions (45). According to the analysis of the COVID-19 restriction policies implemented in California and Iowa, it can be deduced that the tighter restrictions in California, like mandatory stay-home orders, may have contributed to a higher stroke mortality rate compared to Iowa. However, the extent of its effects is unknown and will require further research.

Another factor that may impact stroke mortality rates is the increased risk of stroke in COVID-19 patients. Ischemic stroke is the most prevalent stroke type in COVID-19 patients, and stroke often occurs in younger, male, and non-white populations (46-48). Studies also suggest that Asian populations have the highest occurrence of stroke rates among COVID-19 patients (35, 49). These factors directly influence the stroke rates of each state, depending on the ethnicity ratio and the number of COVID-19 cases. California has the highest ratio of Asian Americans, while Vermont and Iowa have a significantly lower ratio of Asians, respectively (50). This aligns with our study's results, where California, with the highest ratio of Asians and COVID-19 cases, witnessed the most significant increase in stroke mortality and COVID-19 cases. This is also partially consistent with Iowa and Vermont, where Iowa, with a higher amount of COVID-19 cases but the smallest ratio of Asians, saw a higher increase in mortality rate than Vermont, which witnessed fewer amounts of COVID-19 cases but has a higher ratio of Asians than Iowa. In addition, we posit that different states experienced different extents to which COVID-19 impacted their stroke care. Each state, with different amounts of hospitals, ambulances, and COVID-19 patients, must allocate different resources to combat COVID-19. Studies have shown that hospital strains during COVID-19 have caused excess deaths (51). We speculate that California, with the highest COVID-19 cases, experienced a more significant burden than the other two states, Iowa and Vermont, which have significantly fewer COVID-19 cases. This leads to different extents of decline in the quality of stroke care. However, the extent to which the decrease in stroke admission, the severity of stroke, and the quality of stroke care affected the stroke mortality rate remains unknown and will require further research.

Limitations

Despite the valuable insight derived from our study, certain limitations should be acknowledged and considered. Firstly, our analysis relied on national databases and external sources, which collected the data from multiple sources. Each source varies in data collection methods and reporting, which may introduce some level of measurement error. This may cause a certain extent of error in our analysis. In addition, our study analyzed impacts on the state level, which neglected multiple factors at the individual level, including pre-existing health conditions, sex, socioeconomic status, and more. This limited our ability to examine potential variables affecting the stroke mortality rate associated with COVID-19 at the individual level. There may also be other overlooked variables at the state level that may also have been responsible for our observations. In addition, this study only analyzed the US, California, Iowa, and Vermont and cannot represent the heterogeneity of the other states. We also acknowledge the potential impact of population size on our results, and generalizing our findings for other states should be interpreted with caution. In addition, the situation of the COVID-19 pandemic is constantly evolving. The data utilized for analysis is limited to a specific time frame, with COVID-19 cases and the stroke mortality rate limited to 2022 Q2, while the ranking of COVID-19 restriction levels is limited to 2021. As the dynamic nature of the COVID-19 pandemic continues to evolve, new progress needs to be accounted for and will require further research and long-term monitoring.

Furthermore, this study did not discuss the HIV epidemic due to the lack of robust data to accurately enable a comparison on stroke mortality rates between the two epidemics. The nature of the HIV epidemic and corresponding public health responses differed substantially from COVID-19. Policies enacted during HIV focused on screening, harm reduction, anti-discrimination measures, and travel restrictions for people who tested positive for HIV; Lockdowns and widespread restrictions that were widely implemented during COVID-19 were not feasible for the HIV epidemic given its mode of transmission and progression (52). Unlike COVID-19 policies, which were enforced in a short time span and impacted the entire US population, the HIV policies were implemented over a long period of time and instead primarily impacted the minority HIV population in the US. Previous studies also indicate that stroke mortality rates actually decreased from 1980 to 1990 during the initial spread of HIV, which suggests that there was no clear correlation between the HIV epidemic and stroke mortality rates (53). As such, we believe the HIV epidemic could not provide an ideal benchmark for further examining how secondary effects of restrictions - independent of viral infection itself - could impact stroke mortality. Despite these limitations, this study still contributes to shedding light on the association between COVID-19 and stroke mortality rates, promoting future research that can achieve a more comprehensive understanding of the complex relationship between these factors.

Conclusion

During the COVID-19 pandemic, there was a notable increase in the stroke mortality rate in the US. The study's findings revealed a positive relationship between COVID-19 cases and stroke mortality rate. By examining data at a national scale and in the states of Iowa, California, and Vermont, important factors and patterns that may contribute to the variation in stroke mortality rates among these states were identified. This includes the level of COVID-19 restrictions, the decline in stroke care, and the increase in stroke risk in COVID-19 patients. However, the extent of how each factor affected the mortality rate is unknown. It is evident that there is a complex relationship between COVID-19, stroke risk factors and death, healthcare systems, and COVID-19 restrictions that impact both mental and physical health. To expand our knowledge of the impact of these factors, future research should examine the specific factors more deeply to determine their contributions to the observation, which can provide insights for public health institutions in adjusting policies and allocating resources to minimize the impact of COVID-19 on stroke. This will not only be able to provide implications for the ongoing pandemic for mitigating the adverse impact of COVID-19 on stroke mortality but can also provide insights for future pandemics and health emergencies similar to the current COVID-19 pandemic. In light of the crisis of COVID-19, action must be taken to prevent the worsening of stroke outcomes and to optimize methods of care. Governments should not only address immediate threats but also strive to halt the deterioration of stroke care and prevention incurred by the policies implemented. Policies that sacrifice the quality of stroke care should be curtailed while awareness of stroke risk factors must be raised to mitigate their impacts. Only then can the impact of COVID-19 on the stroke mortality rate in the US be curbed.

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