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Article

Maternal mortality rates in the United States correlated with social determinants of health

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SUMMARY

Maternal mortality rates (MMRs) are valuable benchmarks for measuring the quality of a nation's healthcare and social outcomes. Variable MMRs within a country often reflect disparities in social determinants such as income, access to healthcare, and education. In this study, we hypothesized that race, income, education, and health insurance access correlate with MMRs within the United States (US). We utilized retrospective data from the National Vital Statistics System and Center for Disease Control and Prevention for the period 2018-2022 to compute US state-level MMR by race. US Census Bureau state-level data from the American Community Survey provided information on median household income, college education, and health insurance coverage by race. In addition, we used regression analyses to understand the association between MMRs and these factors. Per our analysis, race, median income, and healthcare uninsured rates had a statistically significant relationship with MMRs, while education level was not statistically related with MMRs after adjusting for other factors. MMRs decreased by 1.04% for every $1K increase in median annual income and increased by 2.00% for every 1 percentage point increase in uninsured rate, regardless of race. Additionally, MMRs in the Black population were 1.99 times that of the White population, while MMRs in the Hispanic population were 0.66 times that of White population after adjusting for differences in median income and the uninsured rate. More research is needed to better understand the effect of various social determinants on maternal mortality in the United States. Disparities in maternal mortality continue to exist within the US and multi-faceted efforts are required to ensure better maternal health outcomes for all.

INTRODUCTION

Taking the best steps to prioritize a mother's health and outcomes during pregnancy is important to protect the lives of mothers and infants (1, 2). The Centers for Disease Control and Prevention (CDC) and the World Health Organization (WHO) define maternal mortality rate (MMR) as the ratio of maternal deaths to live births within the same period (3, 4). The WHO defines maternal deaths based on the cause of death and timeframe: deaths that occur during pregnancy or within 42 days after pregnancy and are a result of factors related to the pregnancy or its management, are counted as maternal deaths (3, 4). MMRs vary in different parts of the world (5). According to published data from the CDC and the Organization for Economic Co-operation and Development (OECD), in 2018, the US MMR was 17.4 deaths per 100,000 live births, whereas countries such as the United Kingdom and Canada had much better MMRs of 6.5 and 8.6, respectively (5). The OECD Health Data 2020 report stated that the US healthcare system has a limited number of midwives, as well as fewer benefits such as health care visits at home and paid time off after childbirth, compared to other developed nations such as UK and Canada, which may contribute to the higher MMRs in the US (5). Furthermore, the US MMR has worsened from 9.9 in 1999 to 32.9 in 2021 (3, 6, 7). To monitor MMRs, several US states have measures in place such as maternal mortality review committees (MMRCs) that conduct detailed reviews of maternal deaths (8). The most recently published MMRC review for the period 2017-2019 reports data from 36 US states and shows that the majority of the deaths were preventable (8). These findings suggest that prompt and comprehensive action is necessary to address maternal mortality in the US.

It has been reported that maternal mortality is affected by several factors including race, income level, accessibility to health insurance, and education level (9, 10). The WHO defines social determinants of health (SDH) as living conditions that affect people's health and well-being such as income, education, housing, social inclusion, and access to affordable health care (11). Notably, SDH are an important area of focus for the US federal initiative called Healthy People 2030, which aims to improve overall health by promoting better social conditions, including availability of medical facilities, financial status, education, and other factors (12, 13).

Additional studies are required to understand the full effect of SDH on maternal mortality. At both state and national levels within the US, disparities in maternal mortality have existed within racial groups for several decades (14, 15). Amongst different races within the US, the non-Hispanic Black population is reported to have more than two times the MMR of non-Hispanic White women (14-17). While the relationship of race with MMR has been extensively reported, the relationships between other SDH and MMR have yet to be fully explored. For instance, Black populations tend to have lower incomes and education rates in comparison to White populations in the US, which can affect MMR (18). In the present study, we sought to determine whether mothers from various racial populations across different US states have similar MMR outcomes if we adjust for the differences in their SDH.

We hypothesized that various SDH including race, income, education level, and healthcare uninsured rates correlate with MMRs in different US states. We further assessed whether these SDH variables were statistically related with MMRs in the study dataset. In the study results, race, median income, and uninsured rate had a statistically significant association with increased MMRs. MMRs decreased with increased median annual income and increased with increased uninsured rate regardless of race. Black populations had higher MMRs than White populations, while Hispanic populations had lower MMRs than White populations after adjusting for differences

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in median income and uninsured rates. Hence, addressing social determinants appears to be important to improve maternal mortality in the US.

RESULTS

To test our hypothesis that SDH variables may correlate with MMR, we analyzed MMR data for US states from the CDC National Vital Statistics System (NVSS) and their corresponding SDH data from the American Community Survey (ACS) over the 5-year period 2018-2022. Data from women of three different races were analyzed: non-Hispanic Black (henceforth termed as Black population), non-Hispanic White (henceforth termed as White population), and Hispanic (henceforth termed as Hispanic population). We tabulated results for the US states where the MMR could be calculated from the available CDC NVSS data for each of the three races above. This resulted in an analysis of 16 US states as MMR data was not available due to data suppression by the CDC for confidentiality purposes in some states and races where the numbers were small.

Racial Analysis

To study the effect of socio-economic variables on MMRs, we first tabulated the MMR by state for Black, Hispanic, and White populations along with the key demographic variables of median income, uninsured rate, and percent college educated (**Table 1**). Our data revealed disparate MMRs by state. For example, New Jersey (NJ), with 76 deaths per 100,000 live births in 2018-2022, had one of the highest MMRs in the Black population among the 16 states. NJ had MMRs of 27 and 14 deaths per 100,000 live births in the Hispanic and White populations, respectively (**Table 1**). On the other hand, with MMRs of 33, 9, and 8 in Black, Hispanic, and White populations, respectively, California had one of the lowest overall MMRs for various races (**Table 1**).

In general, we found that MMR was highest in the Black population among the three races across most states (**Table 1, Figure 1**). For example, in NJ, the Black population had an MMR of 76 compared to 27 and 14 for Hispanic and White populations, respectively. At the same time, the Black population in New Jersey also had the lowest median annual income of $59K, followed by the Hispanic population at $64K and the White population at $102K. The Black population also had lower college education levels and a higher uninsured rate than the White population across US states (**Table 1**). While the Hispanic population also had lower college education levels and a higher uninsured rate than the White population, their MMRs were closer to the White population and better than the Black population across the states analyzed (**Table 1, Figure 1**). Overall, the data suggests that higher incomes,

	MMR (per 100,000 live births)			Median annual income ($K)			Uninsured rate (%)			% College Educated		
State	Black	Hispanic	White	Black	Hispanic	White	Black	Hispanic	White	Black	Hispanic	White
Arizona	54	34	18	53	56	72	10	17	6	30	17	39
California	33	9	8	59	67	96	6	12	4	28	16	47
Florida	50	17	18	46	56	68	15	18	9	23	28	37
Georgia	54	13	24	50	57	76	13	31	10	28	23	38
Illinois	40	14	15	43	64	80	8	16	4	25	18	41
Indiana	48	30	30	38	54	66	10	17	7	21	20	30
Maryland	32	17	19	73	80	102	6	21	3	33	25	48
Massachusetts	41	15	14	61	52	97	5	6	2	32	23	50
New Jersey	76	27	14	59	64	102	8	18	4	29	23	48
New York	68	14	15	54	56	86	6	10	3	28	23	47
North Carolina	53	19	20	43	50	68	11	29	8	25	18	39
Oklahoma	66	25	25	39	50	62	14	26	11	23	14	30
Pennsylvania	41	14	14	42	49	73	7	12	5	22	20	36
Tennessee	78	26	33	42	51	63	12	31	8	22	20	32
Texas	51	24	28	51	55	82	15	27	10	29	18	42
Virginia	64	21	27	55	76	87	9	23	5	28	29	45

Table 1: Distribution of MMR and SDH in various US states. MMR (Maternal Mortality Rate for every 100,000 live births) and SDH of median household income (in thousands of dollars), uninsured rates, and percent college-educated are shown individually for the 16 states in the US which have MMR data for each of the 3 groups: Black, White and Hispanic populations. The source of the datasets is CDC WONDER, 2018-2022 and ACS, 2017-2021. Darker shades of blue represent more favorable values for maternal health, and darker shades of red represent less favorable values, with lighter shades of both colors representing intermediate values. For example, higher values for MMR and uninsured rates were darker shades of red (higher values are unfavorable indicators) and higher values of median income and percent college-educated were shades of blue (higher values are favorable indicators).

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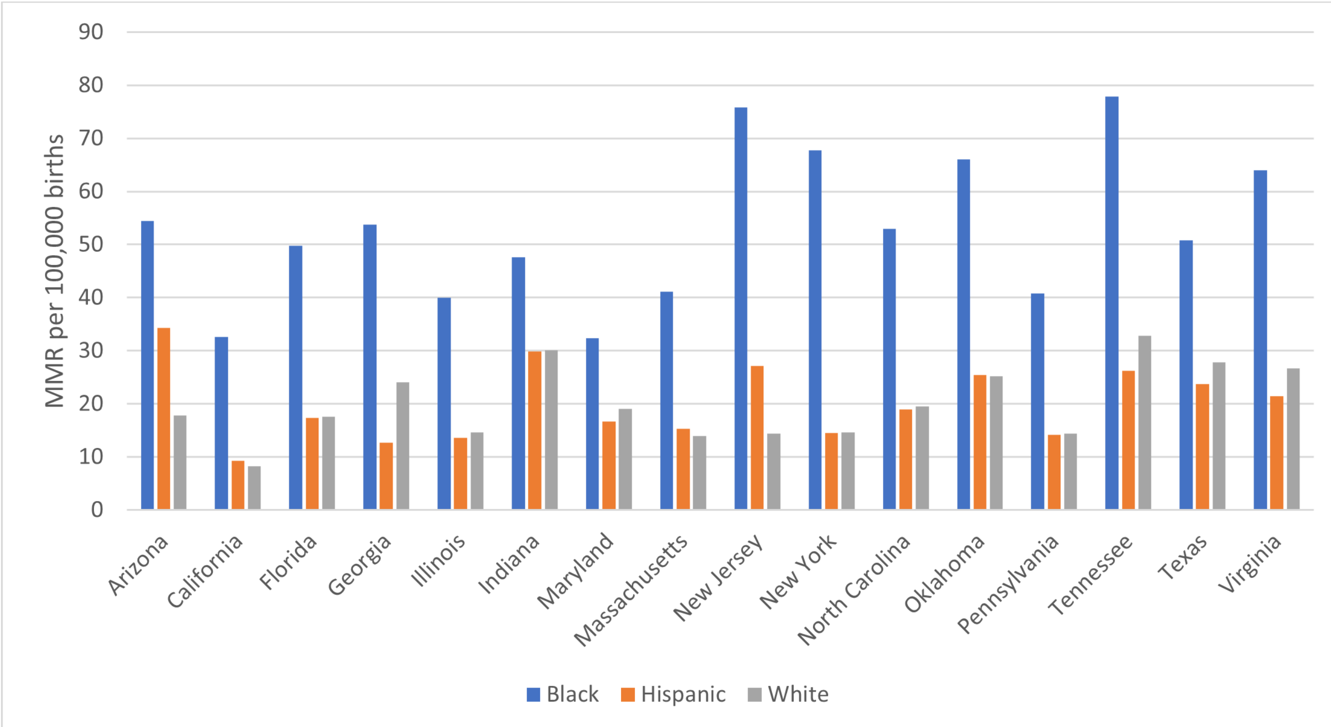

Figure 1: Distribution of MMR by state and race in the US. Histogram showing MMR (per 100,000 live births) in 16 US states where we have available data for all three groups of Black, White, and Hispanic populations. Source: CDC WONDER

higher education levels, and lower uninsured rates may be associated with better MMRs. In addition, there may still be differences in MMRs across races that may be due to reasons other than observable SDH.

Bivariate Analysis of Each SDH and MMR

To further study the effect of each SDH variable on MMR, we plotted MMRs against each SDH variable individually. In addition to the 16 states where we were able to calculate the MMR for each of the 3 races, there were 13 states where the MMR could be computed only for 2 races and 12 states where the MMR could be computed only for 1 race. We utilized all these data points and compared the MMR with the SDH variables for the respective state/race combination.

First, we plotted the MMR by race for each state along with the median annual income for the matching state and race combinations (**Figure 2**). MMRs were generally higher in states and races with lower median annual incomes. MMRs for Black populations were the highest of all races even when median annual incomes were similar, suggesting that race could be associated with changes in MMR.

Then, we plotted MMR by race for each state based on the percentage of the population that was uninsured (**Figure 3**). As the uninsured rate decreased within a race, the MMR generally decreased. Interestingly, while Hispanic populations had some of the highest uninsured rates, their MMRs were generally lower than Black populations.

Finally, we plotted MMR by race for each state with the percentage of the population that was college educated (**Figure 4**). In general, higher college education rates were associated with a trend of decreasing MMR within the same race. However, Hispanic and White populations had similar MMRs despite the lower college education rates in Hispanics, while Black populations had comparatively higher MMRs as well as lower college education rates than White populations.

Overall, the data suggested a negative correlation of MMRs with median income and education level, and a posi-

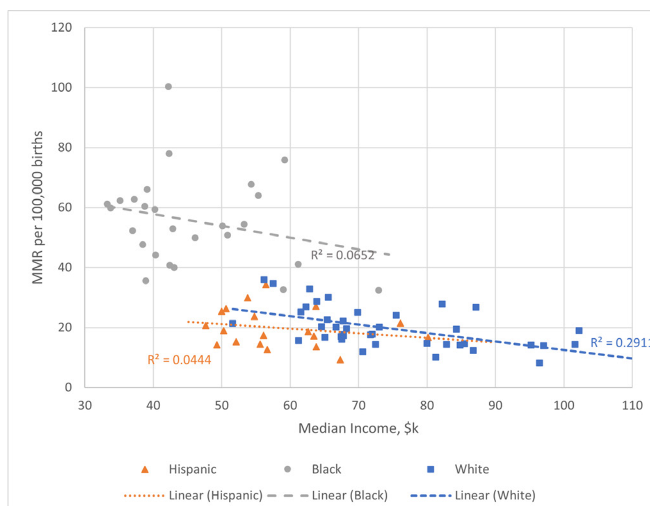

Figure 2: Distribution of MMR by race and median household income across various US states. The data includes all US States with available MMR data amongst any of the three groups of Black, White, and Hispanic populations. Every state and race combination with available data is represented by a dot in the figure. The negative trendlines suggest an inverse relationship between MMR and median income.

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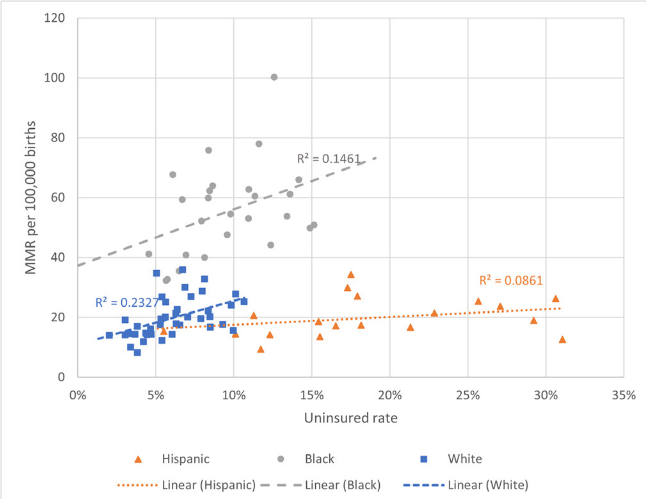

Figure 3: Distribution of MMR by race and uninsured rate across US states. The data includes all US States with available MMR data amongst any of the three groups of Black, White, and Hispanic populations. Every state and race combination with available data is represented by a dot in the figure. The positive trendlines suggest a direct relationship between MMR and uninsured rate.

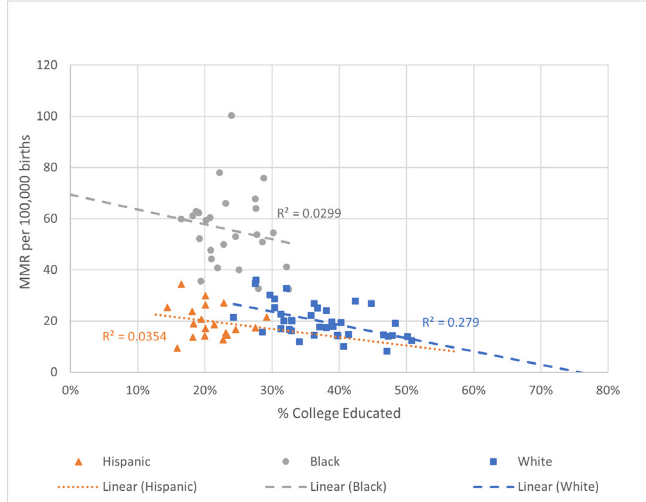

Figure 4: Distribution of MMR and College Completion Percentages in various US states. The data includes all US States with available MMR data amongst any of the three groups of Black, White and Hispanic populations. Every state and race combination with available data is represented by a dot in the figure and the negative trendlines suggest an inverse relationship between MMR and percent college educated population.

tive correlation of MMRs with uninsured rate in the population. MMRs were generally lower with higher median income and education level and higher with higher uninsured rate in the population. MMRs were also higher in Black populations as compared to White and Hispanic populations.

Regression Analysis

After studying the relationships between MMR and each of the SDH variables individually, we conducted a multi-step regression analysis to understand the overall relationship between the SDH factors and MMR using our datasets from CDC and ACS. MMR was the dependent variable for our study, while the SDH factors of race, college education, household income, and uninsured rate were the four independent variables (**Table 2**). The *p*-value cut-off of <0.05 was pre-specified to determine statistical significance. Upon analysis, Black and Hispanic races and uninsured rates had statistically significant relationships with changes in MMR after controlling for other variables (*p*-value < 0.001, < 0.001, and = 0.01, respectively). Median annual income and percent college educated were not significantly related with changes in MMR (*p*-value = 0.086 and = 0.82, respectively).

Independent Variable	Coefficients	Standard Error	p-value	Lower 95% C.I.*	Upper 95% C.I.*
Black	0.684	0.104	**4.00E-09**	0.478	0.890
Hispanic	-0.435	0.157	**7.11E-03**	-0.748	-0.122
Median Annual Income	-0.009	0.005	0.086	-0.020	0.001
Uninsured Rate	1.978	0.756	**0.011**	0.474	3.482
Percent College Educated	-0.241	1.053	0.820	-2.336	1.855

Table 2: First regression analysis of SDH against MMR. The SDH factors of race, education, household income, and uninsured rate were the four independent variables used. The *p*-values shown in bold are the ones that met the *p*-value cutoff of <0.05 for statistical significance. *C.I. stands for Confidence Interval.

Following appropriate steps for a backwards stepwise regression, a second regression analysis was conducted after excluding the least significant independent variable—the percent college educated—from the first regression (*p*-value = 0.82). Both the race and the uninsured rate variables remained significant in the second regression (**Table 3**). In addition, the median annual income was found to be a significant independent variable associated with MMR (*p*-value < 0.001). Also, a high positive coefficient from the second regression analysis for Black populations suggested a higher MMR in Black populations compared to White populations for the same levels of median income and uninsured rates. Finally, a negative regression coefficient for Hispanic race suggested a lower MMR for Hispanic populations versus White populations for the same level of median income and uninsured rates (**Table 3**).

To quantify the effect of these independent variables on MMR, a sensitivity analysis was conducted based on the results of the second regression. We first computed the

Independent Variable	Coefficients	Standard Error	p-value	Lower 95% C.I.*	Upper 95% C.I.*
Black	0.686	0.103	**2.79E-09**	0.481	0.890
Hispanic	-0.412	0.121	**1.06E-03**	-0.653	-0.171
Median Income	-0.010	0.003	**3.57E-04**	-0.016	-0.005
Uninsured Rate	1.982	0.751	**0.010**	0.487	3.476

Table 3: Second regression analysis using the statistically significant variables of race, median income and uninsured rate from the first regression analysis. The percent college educated variable was dropped from analysis as it had a *p*-value greater than the cut-off. The *p*-values shown in bold are the ones that met the *p*-value cutoff for statistical significance of <0.05. All SDH used in this regression met the *p*-value cut-off and no further regression was needed for the multi-step regression analysis. *C.I. stands for Confidence Interval.

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Median Annual Income, $K	Uninsured Rate (%)	White MMR	Black MMR	Hispanic MMR	% MMR Change / $1K Higher Median Income	% MMR Change / 1 PP Higher Uninsured	Black / White MMR	Hispanic / White MMR
50	0.05	23.6	46.9	15.7				
50	0.1	26.1	51.8	17.3				
50	0.15	28.8	57.2	19.1				
60	0.05	21.3	42.3	14.1				
60	0.1	23.5	46.7	15.6	-1.04%	2.00%	1.99	0.66
60	0.15	26.0	51.6	17.2				
70	0.05	19.2	38.1	12.7				
70	0.1	21.2	42.1	14.0				
70	0.15	23.4	46.4	15.5				

Table 4: Sensitivity Analysis for the effects of race, median income, and uninsured rate on MMR. The table shows estimated values of MMR for varying levels of median income and uninsured rates across races based on the regression model. Effects of each individual variable on the MMR are quantified.

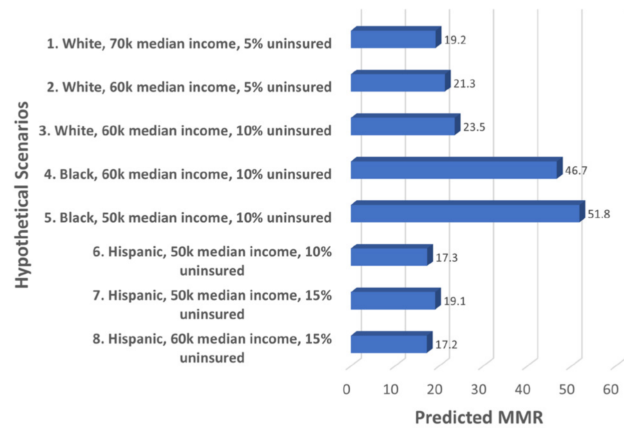

Figure 5: Predicted MMR as a function of median income, uninsured rate, and race. Visualization of the results from the second regression model for hypothetical scenarios. Note that only one input SDH variable changes between adjacent scenarios to visualize the individual effects of different SDH on MMR.

MMR for varying levels of median annual incomes ($50K, $60K, and $70K) and uninsured rates (5%,10%, and 15%) using the coefficients derived from the second regression. We found that the MMR had a 1.04% decline for every $1K increase in median annual income. Similarly, the MMR had a 2.00% increase for every 1 percentage point increase in uninsured rate, regardless of race (**Table 4**). With respect to race, Black populations had a MMR 1.99 times that of White populations while Hispanic populations had a MMR 0.66 times that of White populations for the same median incomes and uninsured rates (**Table 4**). Hence, our analysis suggests that the SDH factors of median income and uninsured rate may correlate with MMR and that race appears to matter even after adjusting for those factors.

We present several scenarios to help visualize the effects of each of the significant variables on MMR **(Figure 5).** We first estimated the MMR for White women with a median annual income of $70K and uninsured rate of 5% to be 19.2. For each successive scenario, we changed one variable at a time to visualize the magnitude of the different effects on MMR. When the median annual income was reduced by $10K, keeping all other variables the same, the estimated MMR increased by about 10% from 19.2 to 21.3. We then increased the uninsured rate by 5%, which again caused the MMR to increase by about 10% from 21.3 to 23.5 (2% effect for every 1% point change in uninsured rate). We then changed the race from White to Black, which resulted in almost doubling MMR from 23.5 to 46.7.

DISCUSSION

The study analysis supports our original hypothesis that SDH correlate with MMRs in various US states. The study results show a statistically significant association between MMR and race, as well as median income and health insurance coverage, but no significant relationship between MMR and college education level, after adjusting for other variables. Additionally, for the same insurance coverage status and median income, our results suggest that Black populations have about two times the MMR of White populations, and Hispanic populations have slightly better MMRs than White populations.

Published literature have demonstrated that maternal mortality is affected by factors including race, income level, overall access to education and health insurance (9, 10). Previous reports suggest that long-term socioeconomic inequities can result in premature aging and other adverse health outcomes, especially in racial minority groups such as Black populations (19). For example, poorer individual or regional financial status was associated with higher adverse outcomes in birth outcomes, hypertension, and other health conditions associated with chronic inflammation (19). This phenomenon may explain some of the worse outcomes observed for Black populations in our study. Our study also suggests that MMR increases with an increase in uninsured rate, regardless of race. Hence, an extensive approach to address racial disparities as well as broaden insurance coverage appears to be needed to improve MMRs within the US.

After the Affordable Care Act, all United States Marketplace and Medicaid health insurance plans are required to cover medical treatments for pregnant women. As of 2021, only 3.9% of pregnant women were self-paying, while the rest had some form of insurance coverage (20). However, medical conditions were still the leading cause of maternal deaths in the 2017–2019 MMRC data in the US (8). The uninsured rate in our dataset could also pertain to women who, before pregnancy, had significant pre-existing chronic health conditions that were possibly left untreated, which may have affected their pregnancy. Studies suggest that optimal health care for women before pregnancy can be important for improving maternal mortality outcomes (17).

The SDH factor of college education level did not show a significant relationship with MMR in our results. Of note, we used overall population-level ACS data for SDH because specific college education level data for mothers who died versus others was not available publicly. Future studies could utilize detailed data about SDH in pregnant mothers for a more specific analysis. Furthermore, college-educated and higher-income women are more likely to have advanced maternal age, which is reported to result in increased MMR (3, 21, 22). The higher age in educated mothers may be balanced by the fact that less educated mothers can often have inadequate finan-

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cial resources and health care access. Several other factors such as maternal age, geography (rural versus urban environment), and pre-existing health conditions also play a role in the MMR of different regions and can confound our analysis (3, 8).

Notably, Hispanic populations had comparable MMRs to White populations in our study, despite having lower median incomes, higher uninsured rates, and lower education levels. Hence, a previously reported phenomenon known as the "Hispanic paradox" was also demonstrated in our study (23). The "Hispanic paradox" is a phenomenon describing the observation that US Hispanic populations tend to have a health status similar to US non-Hispanic White populations despite having worse socioeconomic status (23, 24). This has been found in several health outcome measures such as deaths from cancer and heart disease (24). It is possible that the relatively better outcomes in Hispanic populations may be linked to the benefits of cooperative living and other factors related to Hispanic culture (24, 25).

We also looked at MMR in various US states in this study. California had one of the lowest MMRs in the current dataset (**Table 1**). California developed the California Maternal Quality Care Collaborative (CMQCC) in 2006, which has significantly reduced maternal mortality through various initiatives (26). Several measures have been implemented in California, such as detailed research and tracking of maternal health, financial support to increase healthcare access for more women, steps to address social factors that affect health outcomes, and designation of specific national targets, resulting in improved maternal health indices (27).

In contrast, NJ had one of the highest MMRs in our study (**Table 1**). NJ has also been implementing several measures to reduce maternal mortality recently (28, 29). Nurture NJ was started in 2019 to improve the health of all infants and mothers. The program aims to promote the highest quality of health care access for all women as well as better living conditions in various stages of their lives including before pregnancy and postpartum care (29, 30). Nurture NJ also focuses on creating support systems in the community with the help of various sectors such as government, health policy and businesses to improve health outcomes. It expands data sharing and utilization across state to create awareness and devise better solutions (29,30). Nurture NJ can further inform its initiatives with lessons learnt through CMQCC and other more developed plans in the coming years.

Our study has several limitations. The analyses are limited by constraints around the extent of public data available from CDC and ACS for analysis and the inherent restrictions of data collection with the NVSS. We utilized population-level socioeconomic data from ACS for our analyses. If more specific socioeconomic data for mothers with live births and for mothers who died can be available for future analyses, this can further explain the relationship between social determinants and maternal mortality. Another limitation is that our study data does not include all states and races/ethnicities within the US. We analyzed MMR data from race/ethnic populations that comprised the majority of the dataset. The National Center for Health Statistics (NCHS) masks numbers in some states and populations with small numbers for patient confidentiality. For example, MMR based on fewer than ten deaths are masked for privacy reasons, and MMR for fewer than 20 deaths are labeled as unpredictable data (31). Furthermore, differences in implementation of data collection across various US states can also lead to heterogeneity (32). Another constraint of data collection by NCHS is that death certificates marked yes for pregnancy option without a maternal ICD-10 code are counted as maternal deaths (33). This can potentially include deaths unrelated to pregnancy and result in over-reporting (34).

There are more detailed and rigorous maternal mortality reviews such as the Pregnancy Mortality Surveillance System (PMSS) and the MMRCs (35, 36). This study did not utilize PMSS and MMRC data as these systems tend to be slower reporting, are not available readily for public, and don't have data beyond 2019 in current available records.

Our study suggests that racial disparities, median income and insurance coverage may play an important role in the maternal mortality outcomes for various US states. Government initiatives to address racial disparities as well as enhance median income and health insurance coverage access can lead to improved maternal mortality rates across regions. We suggest future research examining the effect of various SDH on maternal mortality in more specific and comprehensive datasets and dedicated initiatives to promote excellent health for all mothers in the United States.

MATERIALS AND METHODS

Data Collection

We identified published literature and datasets with relevance to MMR through a systematic search of PubMed, Google Scholar, and Medline. We accessed retrospective data for live births and maternal deaths from the CDC NVSS using the CDC Wide-ranging Online Data for Epidemiologic Research (WONDER) as of November 13, 2023 and used it to compute MMR per 100,000 live births (37–40). Per standard NCHS guidelines, we selected International Statistical Classification of Diseases, 10th Revision (ICD-10) codes of A34, O00–O95, and O98–O99 to derive maternal deaths from the overall mortality data (39). We utilized individual data for the various US states and the races of Black, White, and Hispanic for study analyses. The 2018–2021 finalized mortality data and the 2022 provisional mortality data available as of November 13, 2023 were used as a representation of MMR for the most recently available 5-year period of 2018–2022 (38–40).

Of note, maternal mortality data was not available for every US state and race combination even after combining five years of data. For example, in our dataset, the data on Asian populations was sparse, with only 160 maternal deaths recorded across 50 states in 5 years, and only 3 states had individual state-wise non-suppressed maternal mortality data for Asian populations (California, New York, and Texas). For racial analysis, data was analyzed for the 3 races with the most data, which were Black, White, and Hispanic populations, and 16 US states based on available data for all 3 races. The population in the 16 US states with available data generally accounts for about two-thirds of the US population, and we expect it to be representative of the behavior across US for these three races. The 16 US states included were Arizona, California, Florida, Georgia, Illinois, Indiana, Maryland, Massachusetts, New Jersey, New York, North Carolina, Oklahoma, Pennsylvania, Tennessee, Texas, and Virginia. The three races reported in our study have also been exclusively presented in previous NCHS reports (3).

We accessed the most recent US Census Bureau state-level data on November 13, 2023 from the American Community Survey (ACS) for the following factors: race, education, household income, and health insurance coverage (41). We looked at ACS data for median household income, education by percentage of people with college completion over 25 years age (bachelor's degree or higher), and percentage of people without health insurance by race and state within the US (42–44). ACS publishes these as a five-year rate, and we used the most recently available (2017-2021) as the most relevant five–year period for our MMR data from 2018–2022. Data over several years was utilized as opposed to single-year data to have a larger dataset for our statistical analyses and to minimize the effect of limited data due to suppressed values of MMR by NCHS. Of note, the three subgroups reported by race are mutually exclusive for both CDC WONDER and ACS datasets: Non-Hispanic Black, Non-Hispanic White, and Hispanic (the latter includes all US populations of Hispanic origin regardless of race). As all the CDC and ACS data used was in anonymized form and publicly available, no ethics approval was obtained.

Data Analyses

To study the effect of each of the SDH variables on MMR, we plotted MMR versus each of the three demographic variables graphically, one at a time. In addition to the 16 states where we were able to calculate MMR for each of the 3 races, there were 13 states where MMR could be computed for 2 races and 12 states where MMR could be computed for 1 race. A dataset was compiled with all the available MMR data per state: there were 86 different combinations of state and race where MMR data was not suppressed in the CDC database. We plotted all data points on a graph with the SDH variables against the respective state and race combination. We conducted log-linear regression analyses in Microsoft Excel.

Statistical Analyses

In our regression analyses, MMR was the dependent variable while race, median income, percent college educated, and uninsured rates were the independent variables. Black and Hispanic races were used as variables with two possible values of 0 and 1 to capture the effect of race on MMR compared to White race as the baseline. The threshold of p value <0.05 was used to determine statistical significance for every single variable in all regressions. We performed the first regression analysis using all independent SDH variables. The following equation was used to run the regression model:

$$\ln(MMR) = c0 + (c1 * Black) + (c2 * Hispanic) + (c3 * Median\ Income) + (c4 * Uninsured\ rate) + (c5 * Collge\ Educated\ rate)$$

Note that c0-c5 are coefficients estimated by the regression.

A second regression analysis was conducted after omitting the independent variable of percent college-educated as it had the highest p-value of 0.82 among the non-significant variables in the first regression analysis.
The following equation was used to run the regression model:

$$\ln(MMR) = c0 + (c1 * Black) + (c2 * Hispanic) + (c3 * Median\ Income) + (c4 * Uninsured\ rate)$$

Note that c0-c4 are coefficients estimated by the regression.

Subsequently, the coefficient results of the second regression analysis were used to conduct a sensitivity analysis between the independent variables and MMR. We pre-specified median annual incomes of $50K, $60K, and $70K and uninsured rates at the levels of 5%, 10%, and 15%, and then we compared the model's estimated MMR for White, Hispanic, and Black populations in our sensitivity analysis. A final bar chart with several scenarios was presented to convey the effects of different SDH on MMR.

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REFERENCES

1. King, Jeffrey C. "Maternal mortality in the United States - Why is it Important and What are we Doing About it?" *Seminars in Perinatology,* vol. 36, no.1, Feb. 2012, pp. 14-18. https://doi.org/10.1053/j.semperi.2011.09.004.
2. Douthard, Regine A., *et al*. "U.S. Maternal Mortality Within a Global Context: Historical Trends, Current State, and Future Directions." *Journal of Women's Health,* vol. 30, no. 2, 2 Feb. 2021, pp. 168-17. https://doi.org/10.1089/jwh.2020.8863.
3. Hoyert, Donna L. *Maternal Mortality Rates in the United States, 2021*. NCHS Health E-Stats, Centers for Disease Control and Prevention, March 2023, cdc.gov/nchs/data/hestat/maternal-mortality/2021/maternal-mortality-rates-2021.htm. Pamphlet.
4. "Maternal Deaths." *World Health Organization*. www.who.int/data/gho/indicator-metadata-registry/imr-details/4622. Accessed 24 Feb.2024.
5. "Maternal Mortality and Maternity Care in the United States Compared to 10 Other Developed Countries." *The Commonwealth Fund.* www.commonwealthfund.org/publications/issue-briefs/2020/nov/maternal-mortality-maternity-care-us-compared-10-countries. Accessed 24 Feb. 2024.
6. Joseph, K.S., *et al*. "Factors Underlying the Temporal Increase in Maternal Mortality in the United States." *Obstetrics and Gynecology,* vol. 129, no.1, Jan. 2017, pp. 91-100. https://doi.org/10.1097/AOG.0000000000001810.
7. Singh, Gopal K. "Trends and Social Inequalities in Maternal Mortality in the United States, 1969-2018." *International Journal of MCH and AIDS,* vol. 10, no.1, Dec. 2020, pp. 29-42. https://doi.org/10.21106/ijma.444.
8. Trost, Susanna, *et al*. *Pregnancy-Related Deaths: Data from Maternal Mortality Review Committees in 36 US States, 2017-2019*. Centers for Disease Control and Prevention, US Department of Health and Human Services,

2022, cdc.gov/maternal-mortality/media/pdfs/Pregnancy-Related-Deaths-Data-MMRCs-2017-2019-H.pdf. Pamphlet.
9. Wang, Eileen, *et al*. "Social Determinants of Pregnancy-Related Mortality and Morbidity in the United States: A Systematic Review." *Obstetrics and Gynecology,* vol. 135, no. 4, Apr. 2020, pp. 896-915. https://doi.org/10.1097/AOG.0000000000003762.
10. Crear-Perry, Joia *et al*. "Social and Structural Determinants of Health Inequities in Maternal Health." *Journal of Women's Health,* vol. 30, no.2, Feb. 2021, pp. 230-235. https://doi.org/10.1089/jwh.2020.8882.
11. "Social Determinants of Health." *World Health Organization*. www.who.int/health-topics/social-determinants-of-health#tab=tab_1. Accessed 24 Feb. 2024.
12. "Priority Areas." *Healthy People 2030*. www.health.gov/healthypeople/priority-areas. Accessed 24 Feb. 2024.
13. "Social Determinants of Health." *Healthy People 2030.* www.health.gov/healthypeople/priority-areas/social-determinants-health. Accessed 24 Feb. 2024.
14. Fleszar, Laura G., *et al*. "Trends in State-Level Maternal Mortality by Racial and Ethnic Group in the United States." *JAMA,* vol. 330, no.1, 3 Jul. 2023, pp. 52-61. https://doi.org/10.1001/jama.2023.9043.
15. Petersen, Emily E., *et al*. "Racial/Ethnic Disparities in Pregnancy-Related Deaths - United States, 2007-2016." *MMWR, Morbidity and Mortality Weekly Report,* vol. 68, no.35, 6 Sep. 2019, pp. 762-765. https://doi.org/10.15585/mmwr.mm6835a3.
16. Declercq, Eugene and Laurie Zephyrin. "Maternal Mortality in the United States: A Primer.", *Commonwealth Fund,* Dec. 2020. https://doi.org/10.26099/ta1q-mw24.
17. Howell, Elizabeth A. "Reducing Disparities in Severe Maternal Morbidity and Mortality." *Clinical Obstetrics and Gynecology,* vol. 61, no. 2, Jun. 2018, pp. 387-399. https://doi.org/10.1097/GRF.0000000000000349.
18. Cuevas, Adolfo G., *et al*. "Education, Income, Wealth, and Discrimination in Black-White Allostatic Load Disparities." *American Journal of Preventive Medicine, 5* Mar. 2024, pp. 1-8. https://doi.org/10.1016/j.amepre.2024.02.021.
19. Forde, Allana T *et al*. "The Weathering Hypothesis as an Explanation for Racial Disparities in Health: a Systematic Review." Annals of Epidemiology, vol. 33, May 2019, pp. 1-18. https://doi.org/10.1016/j.annepidem.2019.02.011.
20. "Characteristics of Mothers by Source of Payment for the Delivery: United States, 2021." *Centers for Disease Control and Prevention.* www.cdc.gov/nchs/products/databriefs/db468.htm#ref1. Accessed 24 Feb. 2024.
21. "The Age That Women Have Babies: How a Gap Divides America." *NY Times.* www.nytimes.com/interactive/2018/08/04/upshot/up-birth-age-gap.html. Accessed 24 Feb. 2024.
22. Hochler, Hila *et al*. "The Impact of Advanced Maternal Age on Pregnancy Outcomes: A Retrospective Multicenter Study." *Journal of Clinical Medicine,* vol. 12, 1 Sep. 2023, no. 17, pp. 1-15, https://doi.org/10.3390/jcm12175696.
23. Franzini, L. *et al*. "Understanding the Hispanic paradox." *Ethnicity & Disease,* vol. 11, no.3 Oct. 2001, pp. 496-518.
24. Markides, Kyriakos S., and Jeannine Coreil. "The Health of Hispanics in the Southwestern United States: an Epidemiologic Paradox." *Public Health Reports,* vol. 101, no. 3, May-Jun. 1986, pp. 253-65.
25. Shaw, Richard J, and Kate E Pickett. "The Health Benefits of Hispanic Communities for Non-Hispanic Mothers and Infants: Another Hispanic Paradox." *American Journal of Public Health,* vol. 103, no.6, Jun. 2013, pp. 1052-7. https://doi.org/10.2105/AJPH.2012.300985.
26. "California Maternal Quality Care Collaborative." *CMQCC*. www.cmqcc.org. Accessed 24 Feb. 2024.
27. Nichols, Chloe R, and Alison K Cohen. "Preventing Maternal Mortality in the United States: Lessons from California and Policy Recommendations." *Journal of Public Health Policy,* vol. 42, no.1, Dec. 2020, pp. 127-144, https://doi.org/10.1057/s41271-020-00264-9.
28. "Maternal and Child Health." *State of New Jersey Department of Health*. www.nj.gov/health/fhs/maternalchild/mchepi/mortality-reviews. Accessed 24 Feb. 2024
29. "Strategic Plan At-A-Glance Year One Plan Resources." *Nurture NJ.* nurturenj.nj.gov. Accessed 24 Feb. 2024.
30. "9 Action Areas & Recommendations." *Nurture NJ.* nurturenj.nj.gov/9-action-areas/. Accessed 24 Feb. 2024.
31. "Underlying Cause of Death, Assurance of Confidentiality." *Centers for Disease Control and Prevention*. wonder.cdc.gov/wonder/help/ucd-expanded.html#Assurance%20of%20Confidentiality. Accessed 13 Nov. 2023.
32. Maternal Deaths and Mortality Rates by State, 2018-2021. NCHS National Vital Statistics System, cdc.gov/nchs/maternal-mortality/mmr-2018-2021-state-data.pdf. Pamphlet.
33. Hoyert, Donna L. and Arialdi M. Miniño. "Maternal Mortality in the United States: Changes in Coding, Publication, and Data Release, 2018." *National Vital Statistics Reports: from the Centers for Disease Control and Prevention, National Center for Health Statistics, National Vital Statistics System,* vol. 69, no.2, Jan. 2020, pp. 1-18.
34. Hoyert, Donna L. *et al*. "Evaluation of the Pregnancy Status Checkbox on the Identification of Maternal Deaths." *National Vital Statistics Reports: from the Centers for Disease Control and Prevention, National Center for Health Statistics, National Vital Statistics System,* vol. 69, no.1, Jan. 2020 pp. 1-25.
35. "Pregnancy Mortality Surveillance System." *Centers for Disease Control and Prevention*. www.cdc.gov/reproductivehealth/maternal-mortality/pregnancy-mortality-surveillance-system.htm. Accessed 24 Feb. 2024.
36. "Enhancing Reviews and Surveillance to Eliminate Maternal Mortality (ERASE MM)." *Centers for Disease Control and Prevention.* www.cdc.gov/reproductivehealth/maternal-mortality/erase-mm/index.html. Accessed 24 Feb. 2024.
37. "Natality Information, Live Births." *Centers for Disease Control and Prevention*. wonder.cdc.gov/natality.html. Accessed 13 Nov. 2023.
38. "National Center for Health Statistics Mortality Data on CDC WONDER." *Centers for Disease Control and Prevention.* wonder.cdc.gov/ucd-icd10-expanded.html. Accessed 13 Nov. 2023.
39. "Cause-of-death classification and definition of maternal deaths." *Centers for Disease Control and Prevention.* www.cdc.gov/nchs/nvss/vsrr/provisional-maternal-

https://doi.org/10.59720/24-147

deaths.htm#causeOfDeath. Accessed 13 Nov. 2023.

40. "National Center for Health Statistics Mortality Data on CDC WONDER." *Centers for Disease Control and Prevention.* wonder.cdc.gov/mcd-icd10-provisional.html. Accessed 13 Nov. 2023.
41. "American Community Survey". *United States Census Bureau*. www.census.gov/programs-surveys/acs. Accessed 13 Nov. 2023.
42. "B19013/Median Household Income in the Past 12 Months (in 2021 Inflation-Adjusted Dollars)." *United States Census Bureau.* data.census.gov/table/ACSDT5YSPT2021.B19013?q=B19013:+MEDIAN+HOUSEHOLD+INCOME+IN+THE+PAST+12+MONTHS+(IN+2021+INFLATION-ADJUSTED+DOLLARS)&t=400:451:453:455:457:459:461&g=010XX00US$0400000. Accessed 13 Nov. 2023.
43. "B27001/Health Insurance Coverage Status by Sex by Age." *United States Census Bureau.* data.census.gov/table/ACSDT5YSPT2021.B27001?q=Health+Insurance+coverage&t=400:451:453:455:457:459:461&g=010XX00US$0400000. Accessed 13 Nov. 2023.
44. "B15002/Sex by Educational Attainment for the Population 25 years and Older". *United States Census Bureau.* data.census.gov/table/ACSDT5YAIAN2021.B15002?q=Educational+Attainment&t=002:004:006:012:01A:070:400&g=010XX00US$0400000. Accessed 13 Nov. 2023.