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Remapping racial and ethnic inequities in severe maternal morbidity: The legacy of redlining in California

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Abstract

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AUTHOR CONTRIBUTIONS

XG: Conceptualisation, Methodology, Data Curation, Formal Analysis, Writing - Original Draft; JMS: Conceptualisation, Investigation, Methodology, Writing - Review & Editing; CT: Investigation, Writing - Review & Editing; AA: Conceptualisation, Investigation, Methodology, Writing - Review & Editing; RMF: Conceptualisation, Investigation, Methodology, Writing – Review & Editing; BA: Conceptualisation, Writing - Review & Editing; SLC: Conceptualisation, Data Curation, Resources, Funding acquisition, Writing - Review & Editing; MSM: Conceptualisation, Methodology, Supervision, Writing - Original Draft.

CONFLICT OF INTEREST

The authors report no conflict of interest.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Background: Historical mortgage redlining, a racially discriminatory policy designed to uphold structural racism, may have played a role in producing the persistently elevated rate of severe maternal morbidity (SMM) among racialised birthing people.

Objective: This study examined associations between Home-Owner Loan Corporation (HOLC) redlining grades and SMM in a racially and ethnically diverse birth cohort in California.

Methods: We leveraged a population-based cohort of all live hospital births at ≥20 weeks of gestation between 1997 and 2017 in California. SMM was defined as having one of 21 procedures and diagnoses, per an index developed by Centers for Disease Control and Prevention. We characterised census tract-level redlining using HOLC's security maps for eight California cities. We assessed bivariate associations between HOLC grades and participant characteristics. Race and ethnicity-stratified mixed effects logistic regression models assessed the risk of SMM associated with HOLC grades within non-Hispanic Black, Asian/Pacific Islander, American Indian/Alaskan Native and Hispanic groups, adjusting for sociodemographic information, pregnancy-related factors, co-morbidities and neighbourhood deprivation index.

Results: The study sample included 2,020,194 births, with 24,579 cases of SMM (1.2%). Living in a census tract that was graded as "Hazardous," compared to census tracts graded "Best" and "Still Desirable," was associated with 1.15 (95% confidence interval [CI] 1.03, 1.29) and 1.17 (95% CI 1.09, 1.25) times the risk of SMM among Black and Hispanic birthing people, respectively, independent of sociodemographic factors. These associations persisted after adjusting for pregnancy-related factors and neighbourhood deprivation index.

Conclusions: Historical redlining, a tool of structural racism that influenced the trajectory of neighbourhood social and material conditions, is associated with increased risk of experiencing SMM among Black and Hispanic birthing people in California. These findings demonstrate that addressing the enduring impact of macro-level and systemic mechanisms that uphold structural racism is a vital step in achieving racial and ethnic equity in birthing people's health.

Keywords

ethnic and racial minorities; maternal health; maternal morbidity; systemic racism

1 | BACKGROUND

In the United States, substantial racial and ethnic inequities persist in pregnancy-related outcomes.[1,2] Severe maternal morbidity (SMM) encompasses a spectrum of serious health complications occurring during the antepartum, intrapartum or postpartum periods. SMM has immediate consequences such as risk of death and poor pregnancy outcomes, as well as long-term consequences, including disability and long-term health risk, for birthing people of all gender identities.[3,4] Rates of SMM increased almost threefold from 1993 to 2014 in the U.S., from 49.5 to 144.0 per 10,000 delivery hospitalisations, and rates are persistently elevated among people of colour.[3,5–9] Black birthing people experience SMM at double the rate of White birthing people.[5] Rates among Indigenous, Hispanic and Asian/Pacific Islander birthing people are also elevated.[6–8,10,11] Studies have documented that individual-level factors and hospital-level factors matter for racial and ethnic inequities in SMM;

however, these inequities still persist after accounting for these factors, highlighting the need to examine upstream factors that affect SMM among racialised people.[5,7,8,10,12–16]

Structural racism, the totality of ways societies *historically* and *continuously* foster racial discrimination via inequitable systems, is increasingly recognised as a fundamental cause of health inequities.[17–20] One of these systems involves the many institutional programs and practices, including historical redlining, that perpetuate housing discrimination and racial residential segregation. Redlining is a racially discriminatory policy with lasting influences on neighbourhood social and material conditions. The Federal Home Owners' Loan Corporation (HOLC) security maps, created in the 1930s, formally institutionalised the distribution of mortgage loans on the basis of the racial and ethnic make-up of neighbourhoods; indeed, HOLC area descriptions referred to neighbourhoods with non-White populations as "infiltrating," "low-grade," "subversive" and "racially hazardous."[21] These maps, along with other discriminatory policies and practices, informed lenders' mortgage financing decisions based on a neighbourhood grading system with a 4-point scale: "A" (Best - green), "B" (Still Desirable - blue), "C" (Definitely Declining - yellow) and "D" (Hazardous - red i.e. redlined).[21] Operating alongside other discriminatory practices such as racially restrictive covenants and exclusionary zoning, redlining may have resulted in low levels of homeownership and continuous disinvestment, making neighbourhoods vulnerable to subsequent upheaval and displacement through government-sanctioned programs such as urban renewal, deindustrialisation and the Federal Aid Highway Act, creating adverse neighbourhood conditions today.[22–24] Studies have documented associations between worsening HOLC grades and increased risk of adverse birth outcomes, but there has been no study investigating the impact of historical redlining on SMM, an important gap given the stark racial and ethnic inequities.[25–27]

There are several pathways through which historical redlining could impact present-day SMM risk. The ecosocial theory proposes embodiment as a pathway, structured through societal arrangement of power and production, in which people's social and material contexts become biologically embedded.[28] Applying this theory, manifestations of structural racism, such as redlining, leverage institutional power to create both differential access to resources and exposure to hazards that become biologically embedded through physiological disruption from stress responses.[28–31] Structural racism results in adverse health outcomes among racialised people, including chronic health conditions that increase SMM risk.[18,32,33] Redlining can foster the uneven distribution of amenities and resources across neighbourhoods, which can affect health behaviours during pregnancy or access to healthcare.[12,15,34–36] Chronic stress from residing in a previously redlined neighbourhood can result in increased allostatic load, telomere attrition, inflammation and other forms of physiologic dysregulation, leading to adverse pregnancy outcomes.[37–41] Empirical investigation of the role structural racism plays in shaping the distribution of harms and resources across neighbourhoods has been lacking.

California is a unique setting to examine the legacy of redlining on health given both its history of racialisation and its present-day diversity, which can inform efforts to remedy historical injustices of redlining faced by communities of colour. This study examined associations between historical redlining and SMM among a population-based cohort of

births in California between 1997 and 2017. We assessed associations between historical redlining and SMM among racialised groups who have experienced historical and ongoing systemic marginalisation: Black, Hispanic, Asian and Pacific Islander (API) and American Indian/Alaskan Native (AIAN) pregnant people. This approach actively investigated factors contributing to observed inequities and positioned race and ethnicity as a marker for differential exposure and experiences.[42]

2 | METHOD

2.1 | Study population

The study population is a state-wide population-based sample of all live births that occurred in California hospitals between 1997 and 2017, using the linked birth files from the Department of Health Care Access and Information. The datasets linked vital records (birth and foetal death certificates) with hospital discharge records (pregnancy through 9-month postpartum). Each discharge record included International Classification of Diseases (ICD) codes of procedures and diagnoses. We linked the birth cohort files to parental residential address at infant's birth date. Addresses were then geocoded to link to neighbourhood-level variables.

From a total sample of 10,535,798 births, we excluded births based on these criteria: implausible gestational age (<20 weeks or >45 weeks) (n = 307,429), unable to be linked to a census tract (N = 85,344), delivered by non-Hispanic White birthing people (n = 498,159) or by those who self-reported their race and ethnicity as "Other" due to small sample size (n = 2347). We also excluded those living outside HOLC map coverage (n = 7,543,540), because HOLC maps were only created for cities with populations of at least 40,000 people, which included the following California cities: Fresno, Los Angeles, Oakland-Berkeley, Sacramento, San Diego, San Francisco, San Jose and Stockton.[43] Out of the sample of people meeting inclusion criteria, we removed those who were missing covariate information (n = 78,785). The final analytic sample consisted of 2,020,194 births (Figure S1). Compared to our analytic sample, those who were excluded were more likely to have had higher education, private insurance and lived in less deprived neighbourhoods, but were comparable in terms of pregnancy factors.

2.2 | Outcome

The study outcome was defined using the SMM Index developed by the Centers for Disease Control and Prevention. This index has been validated using California data and for use with administrative and population surveillance data.[9,44,45] The index included 21 potentially fatal conditions and life-saving procedures related to pregnancy, labour, or delivery, identified using ICD diagnosis and procedure codes (Table S1). Hospital discharge records containing one or more of these 21 indicators were classified as cases.

2.3 | Exposure

Redlining was assessed using digitised HOLC maps from the Mapping Inequality Project.[21] We geospatially overlaid HOLC grades with birth census tracts and assigned HOLC grades based on overlapping regions between census tracts and HOLC areas.[46] Births between 1997

and 2009 were linked to HOLC maps using 2000 census tract identifiers, and births between 2010 and 2017 used 2010 census tract identifiers.

We spatially calculated each census tract's total land area that was contained within or overlapped with the HOLC map coverage areas. Based on the census tract's percentage of land in each type of HOLC grade, we weighted the grade by the percentage of land area. This continuous score was then rounded to four categories that corresponded to historical HOLC grades (HOLC grade: A = 1, B = 2, C = 3 and D = 4). For example, if 20% of a census tract's land is within a C area, and 70% is within a D area, then that tract would be scored 3.78, which rounded to 4, or a D score. We assigned the historical HOLC grades to census tracts, which were linked to participants via the address at the time of delivery. Due to the small number of births in "A: Best" HOLC areas, we combined those in tracts in "A: Best" and "B: Still Desirable" areas to be the referent group.

$$\text{Census Tract HOLC Score} = \frac{\sum_{n=1}^{4}(\%\ \text{of census tract in Grade}_n \times \text{Grade}_n)}{\%\ \text{of census tract in any HOLC area}}$$

2.4 | Race and ethnicity

We used self-reported information on birth certificates to determine the birthing person's race and ethnicity. The categories were non-Hispanic Black (Black/African American), non-Hispanic Asian/Pacific Islander (Asian Indian, Chinese, Filipino, Japanese, Korean, Vietnamese, Native Hawaiian, Guamanian or Chamorro, Samoan, other Asian or other Pacific Islander), non-Hispanic American Indian/Alaska Native and Hispanic (Hispanic/Latinx). To "actively investigate factors contributing to race-associated differences," or the elevated rates of SMM among racialised people, we stratified analyses by race and ethnicity to explore the role redlining plays in producing the elevated SMM risk observed in Black, Indigenous, Hispanic and API people.[42] In other words, we compared participants who lived in neighbourhoods that have been exposed to historical redlining, to their counterparts of the same race and ethnicity who lived in neighbourhood that did not experience this exposure.

2.5 | Covariates

The following set of sociodemographic and pregnancy-related factors were included in analytic models: parental age (years), parental education (less than high school, high school, some college, college graduate and postgraduate degree) and principal source of payment at delivery (private, Medicaid, uninsured or other), nativity (U.S. born vs. non-U.S. born), parity (any or no prior live births), type of birth (singleton or multiple). Participants were classified as having comorbidities if they had any of the following conditions: gestational hypertension or diabetes, pre-eclampsia, pre-conceptional diabetes or hypertension, or asthma.[47,48]

To measure neighbourhood deprivation, we constructed a standardised neighbourhood deprivation index (NDI), which combined socioeconomic variables at the census tract level.[49,50] Higher NDI scores indicate more deprivation, and lower values indicate less deprivation. For births between 1997 and 2004, the census-level variables were extracted

from the 2000 decennial census data. Births between 2005 and 2010 were linked to information from American Community Survey 2005–2010 5-year estimates, births between 2011 and 2015 were linked to ACS 2011–2015 estimates and births between 2016 and 2017 were linked to ACS 2015–2019 estimates.

2.6 | Statistical analysis

We examined the distribution of the participants' characteristics and their neighbourhood HOLC grades by whether they experienced SMM. To assess associations between redlining and SMM, we used race and ethnicity-stratified mixed-effect logistic regression models, with a random intercept to account for participants clustering within neighbourhoods. Due to the rarity of the outcome, estimated odds ratios approximated risk ratios. We sequentially adjusted for covariates. Model 1 adjusted for parental age, education, insurance type and nativity to assess the impact of redlining on SMM independent of individual sociodemographic factors; We further adjusted for pregnancy-related factors including parity and birth type (Model 2), as well as comorbidities (Model 3), which may be risk factors for SMM and associated with factors that can influence participant's residential location; Model 4 additionally adjusted for NDI to investigate whether historical redlining may matter for SMM above and beyond the influence of current neighbourhood conditions.

2.6.1 | Sensitivity analysis—In sensitivity analyses, we examined SMM excluding blood transfusion as the only indicator. Since administrative data do not have information on the volume of transfusion, including transfusion-only cases may include cases with only low-volume transfusion, which can result in an overestimation of cases.[7,44,51]

2.6.2 | Missing data—The variables race and ethnicity, age, education, insurance status, being born in the U.S. and parity had less than 2.0% missing information. In the overall sample, 3.0% of the observations had any missing covariate.

2.6.3 | Ethics approval—Study protocols were approved by the California Committee for the Protection of Human Subjects and the Institutional Review Boards of Stanford University and the University of California, Berkeley.

3 | RESULTS

The final analytic sample included 2,020,194 births, with 24,579 (1.2%) cases of SMM. The distribution of race and ethnicity was majority Hispanic (71.7%), 11.4% non-Hispanic Black, 16.7% API and 0.3% AIAN (Table 1). The mean age was 27.6 years (SD 6.4). Participants lived in 2652 census tracts, with an average of 762 participants per census tract (range: 1-3483). The proportion of birthing people living in neighbourhoods previously graded D ranged from 25% among API to 35% among Hispanic group (Figure 1). Table 1 displays the distribution of participant characteristics by SMM status within each racial and ethnic group. Those who experienced SMM were more likely to have had comorbidities and non-singleton births. Compared to those without SMM, Black, Hispanic and API participants with SMM were more likely to be older and have had Medi-Cal (public) insurance at delivery, and Black participants who experienced SMM were more likely to not have completed high school.

Residency in Grade D neighbourhoods, compared to better-graded neighbourhoods (Grade A or B), was associated with greater risk of SMM among Black (RR 1.15, 95% CI 1.03, 1.29) and Hispanic (RR 1.17, 95% CI 1.09, 1.25) birthing people, adjusting for individual-level factors (Table 2, Model 1). These associations were slightly attenuated but persisted after adjusting for parity, birth type and having any comorbidity. Adjusting for neighbourhood deprivation index did not substantively change these associations. Black and Hispanic participants who lived in neighbourhoods historically categorised “D: Hazardous” had higher risk of experiencing SMM, respectively, compared to their counterparts who did not live in previously redlined neighbourhoods. Similarly, living in neighbourhoods graded C was associated with higher risk of SMM among Hispanic participants. Redlining was not statistically associated with SMM in API and AIAN groups.

Sensitivity analysis assessing SMM after excluding transfusion-only SMM had similar results for Black and Hispanic participants. The magnitude of the associations for D areas was larger in Model 1 and Model 2 (Table 3) among Black participants. Additionally, API people in Grade C neighbourhoods also had greater risk of experiencing SMM, adjusting for individual SES and pregnancy-related factors (Table 3). These associations were attenuated after adjusting for neighbourhood deprivation.

4 | COMMENT

4.1 | Principal findings

This study examined associations between historical redlining and SMM, an adverse pregnancy-related health outcome that disproportionately affects racialised birthing people. Leveraging data from a population-based cohort of births in California between 1997 and 2017, we found that residency in a previously redlined neighbourhood was associated with greater risk of SMM among Black and Hispanic participants, after adjusting for sociodemographic characteristics, pregnancy-related factors and present-day neighbourhood deprivation.

4.2 | Strengths of the study

This study’s strengths came from leveraging a population-based study sample representative of California that had residential address information to enable linkage to place-based indicators, sufficient racial and ethnic diversity, validated assessment of SMM and measurement of covariate information to account for confounding.

4.3 | Limitations of the data

Limitations include potential misclassification of outcome due to the use of administrative hospital discharge data or the inclusion of people who received blood transfusions for non-severe complications.[44,52] However, sensitivity analyses excluding transfusion as the only SMM indicator found comparable results for Black and Hispanic birthing people. Second, HOLC maps were only available for eight California cities and the resulting exclusion of births in other parts of California, which may differ from births in these cities, may have limited the generalisability of findings. The practice of mortgage discrimination was institutionalised but did not originate from HOLC maps and may have occurred in

other neighbourhoods in California, which our study did not capture and may have biased estimates towards the null. Lastly, although we were able to adjust for individual-level education and insurance payment type at delivery, other socioeconomic factors, such as occupation and income, can influence selection into neighbourhoods and SMM risk, resulting in residual confounding. There may be unmeasured confounding due to other individual variables that we were not able to include in our analysis, such as residential mobility during pregnancy. To address unmeasured confounding due to area-level factors, future studies can leverage other data sources to incorporate other historical programs and policies, which may be a common cause of redlining and present-day SMM risk, to inform a fuller understanding of the role redlining plays in producing health inequities.

4.4 | Interpretation

Our results demonstrate the enduring influence of redlining, a form of structural racism, on pregnancy-related severe morbidity among birthing people of colour, almost a century after the HOLC maps were created. These results align with a prior study that reported positive associations between SMM and contemporary neighbourhood racial and economic spatial polarisation, measured by extreme concentrations of residents from marginalised racial or economic groups.[36] Our results are consistent with studies documenting associations between historical redlining and other adverse perinatal outcomes, such as low birth weight and preterm birth, as well as other risk factors of SMM, such as cardiovascular conditions.[25–27] Although redlining was outlawed by the 1968 Fair Housing Act, racial residential segregation and mortgage lending discrimination remain associated with birth outcomes.[53,54] This evidence and the modest but consistent associations in this study demonstrate that redlining may matter for SMM and other outcomes related to perinatal and reproductive health.

Investigations of the role neighbourhood environment plays in shaping SMM risks have been limited. Two studies documented associations between ZIP code level median household income and county-level poverty and SMM, and one study found that community district poverty modified racial differences in SMM.[55–57] We found that present-day neighbourhood deprivation did not fully attenuate the associations between redlining and SMM. This finding supports evidence showing that neighbourhood poverty and community education attainment did not attenuate the association between redlining and preterm births.[27] Taken together, these findings suggest that while neighbourhood condition can account for some of redlining's influence on SMM, redlining, as a government-sanctioned discriminatory policy, may be capturing forces beyond the neighbourhood level such as institutional racism. Future studies can conduct formal mediation analyses, using data that more robustly characterise neighbourhood conditions beyond neighbourhood deprivation, to evaluate neighbourhood context as a potential mediator between redlining and SMM. Indicators of the physical environment, such as access to green spaces or exposure to environmental hazards, and indicators of investment and wealth accumulation, such as availability of financial services, foreclosure risk and housing quality, may play a role in buffering or exacerbating the influence of redlining.

Another novel aspect of this study is the examination of whether the influence of redlining varied across racialised groups affected by structural racism. Although Black birthing people only delivered about 11% of the births in our study sample and 6% of all births in California over this period, our study documented consistent association between redlining and SMM in this group despite lower power due to sampling size, demonstrating structural racism's disproportionate impact on Black people. Redlining was associated with SMM among Hispanic birthing people. Other studies on place-based manifestations of structural racism, such as segregation, have also found larger associations with adverse perinatal outcomes among Black and Latinx people.[36,54,58,59] The within-group ethnic heterogeneity in our API sample may be affecting estimated associations in the main analysis, and sensitivity analyses documented associations between living in "C" neighbourhood and SMM without transfusion among API people. SMM rates vary substantially across Asian ethnic groups, and future studies should investigate factors that account for these inequities.[5,7,11] The sample size of AIAN birthing people in our study was small, resulting in unstable estimates and CIs. Given the high SMM rate among AIAN people, studies are needed to investigate policies of segregation, displacement and marginalisation that affect this population in both urban and rural regions.[6] Redlining, which solidified patterns of racial residential segregation, may be an important driver of contemporary adverse pregnancy-related health outcomes in racialised groups, particularly Black and Hispanic birthing people.

5 | CONCLUSIONS

This study demonstrates that historical redlining, a federally institutionalised discriminatory practice that influenced the trajectories of neighbourhoods, is associated with contemporary risk of SMM in California, particularly among Black and Hispanic birthing people, independent of sociodemographic, pregnancy-related and contemporary neighbourhood deprivation. These findings highlight the importance of understanding the overarching influence of structural racism on pregnancy-related health outcomes among racialised people and informing place-based approaches to address pregnancy-related health inequities. Lastly, redlining was only one of the many mechanisms that upheld the complex system in which structural racism operates.[60] Understanding and addressing other mechanisms of structural racism, both historical and contemporary, that contribute to the cumulative burden of adverse reproductive and perinatal outcomes among Black and other racialised birthing people is imperative to achieving health equity.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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DATA AVAILABILITY STATEMENT

The data that support the findings of this study can be requested from the California Department of Health Care Access and Information.

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Synopsis

Study question

How is historical redlining, a racially discriminatory policy designed to uphold structural racism, associated with severe maternal morbidity (SMM) among racially and ethnically marginalised populations in California?

What's already known

Individual- and hospital-level factors have not fully accounted for racial and ethnic inequities in SMM, highlighting the need to examine upstream factors. Studies have documented associations between redlining and increased risk of adverse birth outcomes, but there has been no study investigating associations between historical redlining and SMM.

What this study adds

Historical redlining is associated with an increased risk of SMM among Black and Hispanic birthing people today, demonstrating that addressing structural racism in policy-making is a vital step towards achieving racial equity in the health of pregnant people.

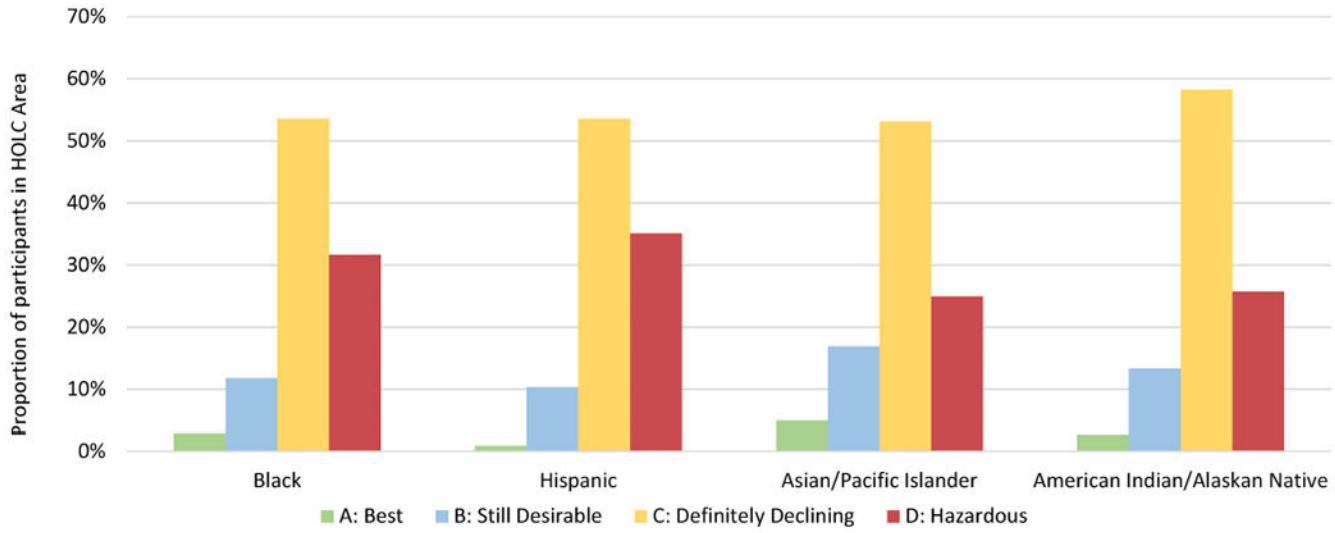

FIGURE 1.

Distribution of participants across Home Owner Loan Corporation (HOLC) grade, by race and ethnicity. Categories displayed are historical redlining grades assigned to the participant's current neighbourhood census tract.

TABLE 1

Participant characteristics by severe maternal morbidity (SMM) Status, California, 1997–2017 (n = 2,020,194)

	Non-Hispanic Black			Hispanic			Non-Hispanic Asian/Pacific Islander			Non-Hispanic American Indian/ Alaskan Native		
	Overall	**No SMM**	**SMM**	**Overall**	**No SMM**	**SMM**	**Overall**	**No SMM**	**SMM**	**Overall**	**No SMM**	**SMM**
Total births	229,606	98.3	1.7	1,447,676	98.9	1.1	337,167	98.8	1.2	5745	98.4	1.6
Age (year)												
<20	29,906 (13.0)	13.1	10.6	179,777 (12.4)	12.4	12.9	8166 (2.4)	2.4	2.0	684 (11.9)	11.9	11.1
20–34	167,321 (72.9)	73.0	67.6	1,075,787 (74.3)	74.4	68.5	233,884 (69.4)	69.5	58.7	4175 (72.7)	72.7	72.2
≥35	32,379 (14.1)	14.0	21.9	192,112 (13.3)	13.2	18.6	95,117 (28.2)	28.1	39.2	886 (15.4)	15.4	16.7
Education												
Less than High school	42,479 (18.5)	18.5	20.0	698,182 (48.2)	48.2	48.6	29,069 (8.6)	8.6	8.1	1442 (25.1)	25.1	26.7
High School	85,336 (37.2)	37.2	35.9	417,896 (28.9)	28.9	28.0	61,311 (18.2)	18.2	18.1	1843 (32.1)	32.2	25.6
Some College	69,528 (30.3)	30.3	30.0	231,190 (16.0)	16.0	16.4	73,663 (21.8)	21.9	20.9	1533 (26.7)	26.7	26.7
College/Graduate School	32,263 (14.1)	14.0	14.1	100,408 (6.9)	6.9	7.1	173,124 (51.3)	51.3	52.9	927 (16.1)	16.1	21.1
Payment type at delivery												
Private	89,201 (38.8)	38.9	34.8	381,259 (26.3)	26.4	24.2	212,544 (63.0)	63.0	63.1	2240 (39.0)	39.0	40.0
Medi-Cal	133,696 (58.2)	58.2	62.2	1,030,603 (71.2)	71.2	73.6	98,561 (29.2)	29.2	30.3	3297 (57.4)	57.4	55.6
Uninsured or Other	6709 (2.9)	2.9	3.0	35,814 (2.5)	2.5	2.2	26,062 (7.7)	7.7	6.7	208 (3.6)	<10.0	<10.0
US Born	208,424 (90.8)	90.8	90.1	557,216 (38.5)	38.5	40.6	67,332 (20.0)	20.0	20.4	5532 (96.3)	96.3	94.4
Multiple Birth	4543 (2.0)	1.9	6.0	15,323 (1.1)	1.0	4.2	4857 (1.4)	1.4	6.6	75 (1.3)	<15.0	<15.0
Primiparous	90,403 (39.4)	39.4	38.6	500,527 (34.6)	34.5	40.1	166,382 (49.3)	49.3	54.4	2090 (36.4)	36.3	43.3
Comorbidities	45,359 (19.8)	19.4	40.0	213,826 (14.8)	14.5	34.5	53,826 (16.0)	15.7	33.8	1179 (20.5)	20.0	53.3

	Non-Hispanic Black			Hispanic			Non-Hispanic Asian/Pacific Islander			Non-Hispanic American Indian/ Alaskan Native		
	Overall	**No SMM**	**SMM**	**Overall**	**No SMM**	**SMM**	**Overall**	**No SMM**	**SMM**	**Overall**	**No SMM**	**SMM**
Neighbourhood Deprivation Index	2.38 (2.53)	2.38 (2.53)	2.40 (2.51)	2.71 (2.27)	2.71 (2.27)	2.73 (2.30)	0.16 (2.30)	0.16 (2.30)	0.07 (2.27)	1.35 (2.67)	1.35 (2.67)	1.64 (2.77)

Note: Categorical variables: overall distribution is displayed by count and percentage in parentheses; distribution by SMM status is displayed by percentage. Exact percentages are not reported for some cells due to having fewer than 12 observations per data use agreement with the state of California. Continuous variables are displayed by mean value and standard deviation.

TABLE 2

Prevalence and adjusted risk ratios of severe maternal morbidity (SMM) by HOLC score and maternal race and ethnicity; California, 1997–2017 (n = 2,020,194)

	Deliveries	SMM Cases	SMM Prevalence per 10,000 Deliveries	Model 1, RR (95% CI)	Model 2, RR (95% CI)	Model 3, RR (95% CI)	Model 4, RR (95% CI)
Non-Hispanic Black (n = 229,606)							
HOLC Grade A + B	33,714	554	164	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
HOLC Grade C	123,126	2105	171	1.06 (0.95, 1.18)	1.07 (0.96, 1.20)	1.05 (0.94, 1.17)	1.05 (0.94, 1.17)
HOLC Grade D	72,766	1345	185	1.15 (1.03, 1.29)	1.17 (1.04, 1.31)	1.13 (1.00, 1.26)	1.12 (1.00, 1.26)
Hispanic (n = 1,447,676)							
HOLC Grade A + B	163,269	1700	104	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
HOLC Grade C	775,681	8600	111	1.07 (1.00, 1.14)	1.09 (1.02, 1.16)	1.06 (1.00, 1.13)	1.07 (1.00, 1.14)
HOLC Grade D	508,726	6156	121	1.17 (1.09, 1.25)	1.19 (1.11, 1.28)	1.15 (1.08, 1.23)	1.15 (1.08, 1.24)
Non-Hispanic Asian/Pacific Islander (n = 337,167)							
HOLC Grade A + B	74,017	886	120	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
HOLC Grade C	179,103	2146	120	1.07 (0.98, 1.16)	1.08 (0.99, 1.17)	1.05 (0.97, 1.15)	1.04 (0.95, 1.14)
HOLC Grade D	84,047	997	119	1.05 (0.95, 1.16)	1.06 (0.96, 1.17)	1.02 (0.93, 1.13)	1.00 (0.90, 1.11)
Non-Hispanic American Indian/Alaskan Native (n = 5745)							
HOLC Grade A + B	NR	NR	130	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
HOLC Grade C	NR	NR	176	1.70 (0.87, 3.35)	1.80 (0.91, 3.57)	1.71 (0.86, 3.40)	1.51 (0.75, 3.07)
HOLC Grade D	NR	NR	135	1.27 (0.59, 2.73)	1.32 (0.61, 2.85)	1.25 (0.57, 2.74)	1.12 (0.50, 2.47)

Note: Model 1: adjusted for maternal age, education, insurance type and nativity. Model 2: adjusted for covariates in Model 1 and parity, birth type. Model 3: adjusted for covariates in Model 2 and having any comorbidities. Model 4: adjusted for covariates in Models 1–3, as well as Neighbourhood Deprivation Index. Home Owner Loan Corporation (HOLC) Grade: A = best, B = still desirable, C = definitely declining, D = hazardous. NR, not reported; Sample sizes are not reported for some cells due to having fewer than 12 observations per data use in agreement with the state of California.

TABLE 3

Prevalence and adjusted risk ratios of SMM (no transfusion) by HOLC Score and maternal race and ethnicity; California, 1997–2017 (n = 2,007,297)

	Deliveries	SMM Cases	SMM Prevalence per 10,000 Deliveries	Model 1, RR (95% CI)	Model 2, RR (95% CI)	Model 3, RR (95% CI)	Model 4, RR (95% CI)
Non-Hispanic black (n = 227,685)							
HOLC Grade A + B	33,439	279	83	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
HOLC Grade C	122,129	1108	91	1.12 (0.97, 1.29)	1.14 (0.99, 1.31)	1.12 (0.97, 1.28)	1.08 (0.93, 1.24)
HOLC Grade D	72,117	696	97	1.20 (1.03, 1.39)	1.23 (1.06, 1.43)	1.18 (1.02, 1.37)	1.13 (0.97, 1.32)
Hispanic (n = 1,438,932)							
HOLC Grade A + B	162,369	800	49	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
HOLC Grade C	771,152	4071	53	1.09 (1.00, 1.18)	1.10 (1.01, 1.20)	1.07 (0.99, 1.17)	1.04 (0.96, 1.14)
HOLC Grade D	505,411	2841	56	1.16 (1.06, 1.27)	1.18 (1.08, 1.29)	1.13 (1.04, 1.24)	1.09 (1.00, 1.20)
Non-Hispanic Asian/Pacific Islander (n = 334,982)							
HOLC Grade A + B	73,522	391	53	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
HOLC Grade C	177,958	1001	56	1.14 (1.01, 1.28)	1.15 (1.02, 1.29)	1.12 (0.99, 1.26)	1.07 (0.95, 1.22)
HOLC Grade D	83,502	452	54	1.08 (0.94, 1.24)	1.09 (0.94, 1.25)	1.04 (0.90, 1.19)	0.99 (0.85, 1.14)
Non-Hispanic American Indian/Alaskan Native (n = 5698)							
HOLC Grade A + B	NR	NR	87	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)	1.00 (Reference)
HOLC Grade C	NR	NR	75	0.98 (0.43, 2.22)	1.03 (0.45, 2.34)	0.93 (0.40, 2.13)	0.87 (0.37, 2.06)
HOLC Grade D	NR	NR	68	0.86 (0.33, 2.24)	0.89 (0.34, 2.31)	0.81 (0.31, 2.13)	0.77 (0.28, 2.06)

Note: Model 1: adjusted for maternal age, education, insurance type and nativity. Model 2: adjusted for covariates in Model 1 and parity, birth type. Model 3: adjusted for covariates in Model 2 and having any comorbidities. Model 4: adjusted for covariates in Models 1–3, as well as Neighbourhood Deprivation Index. Home Owner Loan Corporation (HOLC) Grade: A = Best, B = Still Desirable, C = Definitely Declining, D = Hazardous. NR, not reported; Sample sizes are not reported for some cells due to having fewer than 12 observations per data use agreement with the state of California.