OBSTETRICS

Birth hospital and racial and ethnic differences in severe maternal morbidity in the state of California

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BACKGROUND: Birth hospital has recently emerged as a potential key contributor to disparities in severe maternal morbidity, but investigations on its contribution to racial and ethnic differences remain limited.

OBJECTIVE: We leveraged statewide data from California to examine whether birth hospital explained racial and ethnic differences in severe maternal morbidity.

STUDY DESIGN: This cohort study used data on all births at ≥20 weeks gestation in California (2007—2012). Severe maternal morbidity during birth hospitalization was measured using the Centers for Disease Control and Prevention index of having at least 1 of the 21 diagnoses and procedures (eg, eclampsia, blood transfusion, hysterectomy). Mixed-effects logistic regression models (ie, women nested within hospitals) were used to compare racial and ethnic differences in severe maternal morbidity before and after adjustment for maternal sociodemographic and pregnancy-related factors, comorbidities, and hospital characteristics. We also estimated the risk-standardized severe maternal morbidity rates for each hospital (N=245) and the percentage reduction in severe maternal morbidity if each group of racially and ethnically minoritized women gave birth at the same distribution of hospitals as non-Hispanic white women.

RESULTS: Of the 3,020,525 women who gave birth, 39,192 (1.3%) had severe maternal morbidity (2.1% Black; 1.3% US-born Hispanic; 1.3% foreign-born Hispanic; 1.3% Asian and Pacific Islander; 1.1% white; 1.6% American Indian and Alaska Native, and Mixed-race referred to as Other). Risk-standardized rates of severe maternal morbidity ranged from 0.3 to 4.0 per 100 births across hospitals. After adjusting for covariates, the odds of severe maternal morbidity were greater among nonwhite women than white women in a given hospital (Black: odds ratio, 1.25; 95% confidence interval, 1.19—1.31); US-born Hispanic: odds ratio, 1.25; 95% confidence interval, 1.20—1.29; foreign-born Hispanic: odds ratio, 1.17; 95% confidence interval, 1.11—1.24; Asian and Pacific Islander: odds ratio, 1.26; 95% confidence interval, 1.21—1.32; Other: odds ratio, 1.31; 95% confidence interval, 1.15—1.50). Among the studied hospital factors, only teaching status was associated with severe maternal morbidity in fully adjusted models. Although 33% of white women delivered in hospitals with the highest tertile of severe maternal morbidity rates compared with 53% of Black women, birth hospital only accounted for 7.8% of the differences in severe maternal morbidity comparing Black and white women and accounted for 16.1% to 24.2% of the differences for all other racial and ethnic groups.

CONCLUSION: In California, excess odds of severe maternal morbidity among racially and ethnically minoritized women were not fully explained by birth hospital. Structural causes of racial and ethnic disparities in severe maternal morbidity may vary by region, which warrants further examination to inform effective policies.

Key words: health equity, hospital-level factors, racial and ethnic disparities, severe maternal morbidity

Introduction

Severe maternal morbidity (SMM) has emerged as a major public health crisis given its potential short- and long-term consequences on maternal and infant health.[1,2] In the United States, the rate of SMM was 144 per 10,000 delivery hospitalizations in 2014, representing a 200% increase from 1993 when the rate was 49.5 per 10,000.[1] Even more alarming are the persistent and pervasive racial and ethnic differences in SMM.[3–5] Black women have a 2- to 3-fold higher occurrence of SMM than white women, and although less pronounced, SMM is also higher in other racially minoritized women than white women, including Hispanic or Latino, Asian and Pacific Islander, and Native American women.[6,7]

Factors underlying racial and ethnic disparities in SMM remain poorly understood, with most studies documenting that differences persist after adjustment for sociodemographic and clinical characteristics.[4,6–9] Owing to a broader recognition of the importance of context (eg, neighborhoods, hospitals) in shaping racial and ethnic disparities in health more generally,[10–12] hospital quality of care has recently emerged as a potential driver of racial and ethnic disparities in SMM.[13] There is also compelling evidence to support that hospital factors may play a role in influencing SMM risk specifically, because delivery volume and provider practices have been related to maternal and infant outcomes, including SMM and maternal mortality.[14–16]

A parallel line of research has revealed that comparable to the patterns of residential segregation, Black and other racially minoritized women deliver at different hospitals from white women and that these hospitals have a lower quality of care.[14,17–19] Using a nationwide inpatient sample, Howell et al[18] documented a concentration of deliveries among Black women with only one-fourth of all hospitals providing care for three-fourth of all Black women in the United States. Moreover, hospitals with a higher proportion of births among Black women had higher rates of SMM independent of sociodemographic and clinical factors. Similarly, Creanga

Cite this article as: Mujahid MS, Kan P, Leonard SA, et al. Birth hospital and racial and ethnic differences in severe maternal morbidity in the state of California. Am J Obstet Gynecol 2021;224:219.e1-15.

0002-9378/$36.00

https://doi.org/10.1016/j.ajog.2020.08.017

AJOG at a Glance

Why was this study conducted?

Recent findings in New York City revealed a substantial contribution of birth hospital to racial and ethnic differences in severe maternal morbidity (SMM). This study attempted to replicate these findings in the state of California and enhance the understanding of regional differences in the role of hospitals in racial and ethnic disparities in SMM.

Key findings

We found that, after adjustment, the only hospital characteristic associated with SMM was teaching status; in addition, we found that SMM rates among Black, American Indian and Alaska Native, and Mixed-race women might be modestly reduced, had they given birth in the same hospitals as white women.

What does this add to what is known?

This study helps elucidate factors that may contribute to the alarming racial and ethnic disparities in SMM and provides evidence for future investigations of structural factors that may contribute to SMM risk differences across racial and ethnic groups.

et al[19] found that hospitals serving a higher proportion of racially and ethnically minoritized women performed worse on 12 of 15 quality of care indicators. These studies underscore the critical importance of investigating hospital-related factors as contributors to racial and ethnic differences in SMM. However, previous studies have been few and limited to either a small geographic area or the comparison of only 1 other racial and ethnic group with white women.[14,18,20]

Thus, the overall goal of this study was to determine whether hospital factors contribute to racial and ethnic differences in SMM in the state of California. We hypothesized that SMM would vary substantially across hospitals, that hospital-level factors would be associated with SMM, and that adjustment for hospital and hospital characteristics would reduce racial and ethnic differences in SMM.

Materials and Methods

Study population and data sources

This cohort study used data on all California births (live and stillbirths) delivered at ≥20 weeks gestation from 2007 to 2012 (N=3,117,856). Birth and fetal death certificates were linked to hospital discharge data by the California's Office of Statewide Health Planning and Development. We applied the following exclusion criteria: nonfirst birth for nonsingleton deliveries (to avoid duplicates), invalid hospital identifier, delivery at hospital with <100 deliveries per year, and implausible maternal age, leaving a final analytical sample of 3,010,525 infants delivered in 245 hospitals (Supplemental Figure). The study protocol was approved by the state of California's Committee for the Protection of Human Subjects and the institutional review boards of Stanford University and University of California, Berkeley.

Study outcome

SMM during birth hospitalization was assessed using the updated Severe Maternal Morbidity Index, a validated measure developed by the United States Centers for Disease Control and Prevention and its partners for use with administrative and population surveillance data.[1,21] SMM criteria included 21 potentially fatal conditions and lifesaving procedures that indicate severe and specific organ-system dysfunction using the diagnosis and procedure codes specified in the International Classification of Diseases, Ninth Revision. Women with 1 or more of these conditions were categorized as having SMM (Supplemental Table 1).

Race and ethnicity

Race and ethnicity data were ascertained from birth certificates (Table 1). Given the large number of Hispanic people in the state of California, we split this category into US- and foreign- born as a proxy for acculturation. In addition, owing to the limited sample size, American Indian and Alaska Native categories were combined with Mixed-race and Other categories, which we refer to as Other. American Indian and Alaska Native made up 84.8% of this category.

Other maternal characteristics

We selected potential confounders, a priori, from an extensive list of sociodemographic and pregnancy-related factors and clinical comorbidities. Sociodemographic characteristics included maternal age, education, and principal source of payment for delivery from vital records. Pregnancy-related factors included trimester of prenatal care initiation, plurality (singleton, multiple), obstetric history (combination of parity and previous cesarean delivery), prepregnancy body mass index category, smoking during pregnancy, and gestational age from vital records (Table 1). Based on previous studies, a list of 17 clinical comorbidities were also assessed using information from patient discharge records and vital records (Table 1).[8]

Hospital factors

We considered the following 4 hospital characteristics in our analyses: teaching affiliation, level of neonatal care (based on the American Academy of Pediatrics quality and standard of care guidelines), delivery volume, and ownership type (Table 1).[14,20]

Statistical analyses

All statistical analyses were performed using SAS version 9.4 (SAS Institute Inc, Cary, NC). In descriptive analyses, we used chi-square tests and *t* tests to compare the distribution of maternal and hospital factors by SMM and race and ethnicity. To determine whether maternal and hospital factors contribute to racial and ethnic differences in SMM, we ran a series of mixed-effects logistic

TABLE 1
Patient characteristics overall and by severe maternal morbidity in California (2007−2012) (N=3,010,525)

Characteristic	Overall		Severe maternal morbidity	
			Yes	No
	3,010,525 (100%)		39,132 (1.30%)	2,971,393 (98.70%)
	N	%	%	%
Maternal characteristics				
Sociodemographic factors				
Maternal age, y (mean, 28.3; SD, 6.3)				
<20	264,910	8.8	10.2	8.8
20—29	1,446,009	48	42.7	48.1
30—34	756,848	25.1	23.8	25.2
35—39	428,706	14.2	17	14.2
40—44	105,910	3.5	5.7	3.5
>45	8142	0.3	0.7	0.3
Maternal race and ethnicity				
White	813,211	27	22.1	27.1
US-born Hispanic	714,383	23.7	24.3	23.7
Foreign-born Hispanic	847,379	28.1	28.6	28.1
Black	172,912	5.7	9.3	5.7
Non-Hispanic Asian and Pacific Islander	395,591	13.1	13.3	13.1
Other	15,733	0.5	0.7	0.5
Unknown	51,316	1.7	1.8	1.7
Maternal education				
Less than HS	727,152	24.2	27.7	24.1
HS	767,400	25.5	25.5	25.5
Greater than HS	1,409,360	46.8	42.9	46.9
Unknown or missing	106,613	3.5	3.9	3.5
Principal source of payment for delivery				
Medi-Cal	1,452,579	48.3	52.3	48.2
Private	1,403,031	46.6	42.3	46.7
Uninsured	64,193	2.1	2.2	2.1
Other	84,955	2.8	2.8	2.8
Unknown or missing	5767	0.2	0.5	0.2
Pregnancy-related factors				
Trimester prenatal care begun				
No prenatal care	14,466	0.5	1.4	0.5
First trimester	2,444,875	81.2	76.4	81.3
Second trimester	399,280	13.3	14.1	13.3
Third trimester	79,355	2.6	3.2	2.6
Unknown or missing	72,549	2.4	4.9	2.4

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(continued)

TABLE 1
Patient characteristics overall and by severe maternal morbidity in California (2007−2012) (N=3,010,525) *(continued)*

	Overall		Severe maternal morbidity	
			Yes	No
	3,010,525 (100%)		39,132 (1.30%)	2,971,393 (98.70%)
Characteristic	N	%	%	%
Type of pregnancy				
Singleton	2,960,881	98.4	93.4	98.4
Multiple	49,644	1.6	6.6	1.6
Parity and previous cesarean delivery				
Nulliparous	1,192,491	39.6	43.2	39.6
Multiparous, no previous cesarean delivery	441,706	14.7	22.1	14.6
Multiparous, previous cesarean delivery	1,369,664	45.5	34	45.6
Unknown or missing	6664	0.2	0.7	0.2
Prepregnancy BMI				
Underweight	112,612	3.7	4	3.7
Normal weight	1,370,050	45.5	43.4	45.5
Overweight	714,073	23.7	23.4	23.7
Obesity class I	489,604	16.3	16.4	16.3
Obesity class II and III	82,920	2.8	3.3	2.7
Missing BMI	241,266	8	9.6	8
Cigarette smoking during pregnancy				
No	2,896,484	96.2	94.9	96.2
Yes	68,653	2.3	2.8	2.3
Unknown or missing	45,388	1.5	2.3	1.5
Gestational age				
<32 wk	41,149	1.4	7.5	1.3
32−36 wk	206,991	6.9	17.8	6.7
37−42 wk	2,753,445	91.5	74.3	91.7
Unknown or missing	8940	0.3	0.4	0.3
Clinical comorbidities				
Asthma or chronic pulmonary disease				
No	2,931,984	97.4	95.6	97.4
Yes	78,541	2.6	4.4	2.6
Blood disorder				
No	2,793,856	92.8	55.5	93.3
Yes	216,669	7.2	44.5	6.7
Cardiac disease				
No	3,003,223	99.8	98.2	99.8
Yes	7302	0.2	1.8	0.2
Central nervous system disorder				
No	2,987,567	99.2	98.1	99.3
Yes	22,958	0.8	1.9	0.7

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TABLE 1
Patient characteristics overall and by severe maternal morbidity in California (2007–2012) (N=3,010,525) *(continued)*

	Overall		Severe maternal morbidity	
			Yes	No
	3,010,525 (100%)		39,132 (1.30%)	2,971,393 (98.70%)
Characteristic	N	%	%	%
Collagen or vascular disorder				
No	3,009,808	100.0	99.9	99.98
Yes	717	0.0	0.1	0.02
Digestive				
No	3,009,584	100.0	99.9	100.0
Yes	941	0.0	0.1	0.0
Pregnancy diabetes mellitus				
No	2,983,980	99.1	97.8	99.1
Yes	26,545	0.9	2.2	0.9
Pregnancy hypertension				
No	2,907,873	96.6	84.8	96.7
Yes	102,652	3.4	15.2	3.3
Lupus				
No	3,007,518	99.9	99.5	99.9
Yes	3007	0.1	0.5	0.1
Mental disorder				
No	2,918,815	97	93.1	97
Yes	91,710	3	6.9	3
Musculoskeletal disorder				
No	3,004,642	99.8	99.3	99.8
Yes	5883	0.2	0.7	0.2
Disorder of placentation				
No	2,962,849	98.4	88.5	98.5
Yes	47,676	1.6	11.5	1.5
Prepregnancy diabetes mellitus				
No	2,985,840	99.2	98	99.2
Yes	24,685	0.8	2	0.8
Chronic hypertension				
No	2,978,884	98.9	97.6	99
Yes	31,641	1.1	2.4	1
Renal disease				
No	3,008,913	99.9	99.2	99.96
Yes	1612	0.1	0.8	0.04
Rheumatic heart disease				
No	3,009,915	100.0	99.7	100.0
Yes	610	0.0	0.3	0.0

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TABLE 1
Patient characteristics overall and by severe maternal morbidity in California (2007–2012) (N=3,010,525) *(continued)*

	Overall		Severe maternal morbidity	
			Yes	No
	3,010,525 (100%)		39,132 (1.30%)	2,971,393 (98.70%)
Characteristic	N	%	%	%
Rheumatoid arthritis				
No	3,008,249	99.9	99.9	99.9
Yes	2276	0.1	0.1	0.1
Hospital characteristics				
Teaching hospital				
No	2,653,883	88.2	82.4	88.2
Yes	356,642	11.8	17.6	11.8
AAP level				
Level I	401,999	13.4	11.7	13.4
Level II	616,829	20.5	18.6	20.5
Level III	1,600,604	53.2	52.6	53.2
Level IV	361,725	12	16.4	12
Unknown or missing	29,368	1	0.6	1
Nursery level				
CAH	16,944	0.6	0.6	0.6
Level I and not CAH	389,375	12.9	11.1	13
Level II	574,332	19.1	17	19.1
Levels III and IV	1,855,230	61.6	65.2	61.6
Unknown or missing	174,644	5.8	6.1	5.8
Delivery volume				
Low	187,315	6.2	5.8	6.2
Medium	484,136	16.1	15.2	16.1
High	829,508	27.6	31.2	27.5
Very high	1,509,566	50.1	47.7	50.2
Hospital ownership				
Public	478,456	15.9	21.7	15.8
Private	2,524,570	83.9	78	83.9
Unknown or missing	7499	0.2	0.3	0.2

Other refers to American Indian and Alaska Native, mixed-race, and Other women.

AAP, American Academy of Pediatrics; *BMI*, body mass index; *CAH*, critical access hospital; *HS*, high school; *SD*, standard deviation; *y*, years.

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regression models with women nested within hospitals. We report odds ratios (ORs) given that they are suitable approximations of relative risk, because SMM is a rare outcome and estimates using log-linear models produced identical results.[22] The unadjusted model included only race and ethnicity, and additional models sequentially included maternal sociodemographic characteristics (model 1), pregnancy-related factors (model 2), clinical comorbidities (model 3), and hospital-level factors (model 4).

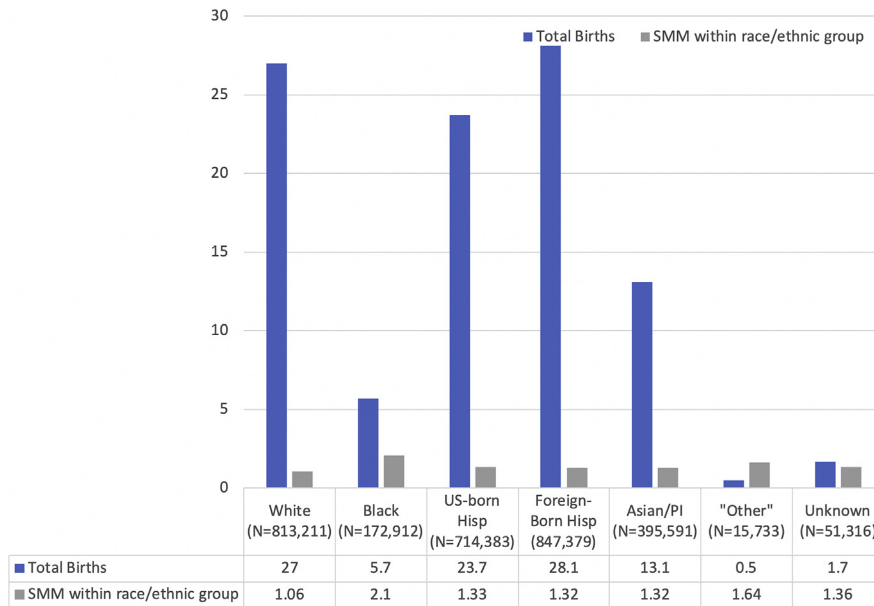
We calculated risk-standardized SMM rates for each hospital based on a multivariable model that included all covariates except for the hospital-level variables.[23,24] The rates were the ratio of predicted to expected SMM rates, multiplied by the California average

SMM rate, consistent with an indirect standardization approach. We calculated the cumulative distributions of births among hospitals ranked from lowest to highest using risk-standardized SMM rates, and a chi-square test was performed to compare the risk-standardized SMM rates across the racial and ethnic groups.

We then conducted a potential impact analysis to consider what the probability of SMM overall and by race and ethnicity would be in the hypothetical situation of all women giving birth at the same distribution of hospitals as white women. To evaluate this, we used a substitution estimator to estimate the unobserved counterfactual probability of SMM, if women were to deliver at the same distribution of hospitals as white women (Supplementary Table 2).[25] First, we estimated predicted probabilities of SMM for each mother at each hospital. We did this by using coefficients from our final mixed-effects logistic regression model (model 4) to estimate the predicted probabilities for each individual at each hospital using a standard formula.[26] The probabilities were then multiplied by hospital weights (the percentage of white mothers who went to each hospital) to get the weighted average probabilities of SMM. The sum of the differences between the probability of SMM at the original hospital in which the mother delivered and the weighted average probability is the decrease or increase in SMM events if the mother went to the same hospitals as white mothers. Second, we estimated the overall predicted probability of SMM among each racial and ethnic group and disparities relative to white women and the percentage change in the predicted probability and disparity, relative to those based on observed values, for each group.

In sensitivity analyses, we excluded women with blood transfusion as their only SMM indicator because it might not truly represent severe cases of SMM (given that the information on the volume of the transfusion was not available).[21] We also ran analyses restricting to only singleton births, given the etiology of SMM might be different for multiple births.

FIGURE 1
Proportion of total and SMM births by race and ethnicity in California (2007–2012) (N=3,010,525)



Summary of the distribution of total births and births with SMM in the state of California between the years 2007–2012. Black women had the highest proportion of births with SMM, whereas white women had the lowest prevalence of SMM births. All other racial groups also had a higher number of SMM births than white women. Other refers to American Indian and Alaska Native, Mixed-race, and Other women.

PI, Pacific Islander; *SMM*, severe maternal morbidity.

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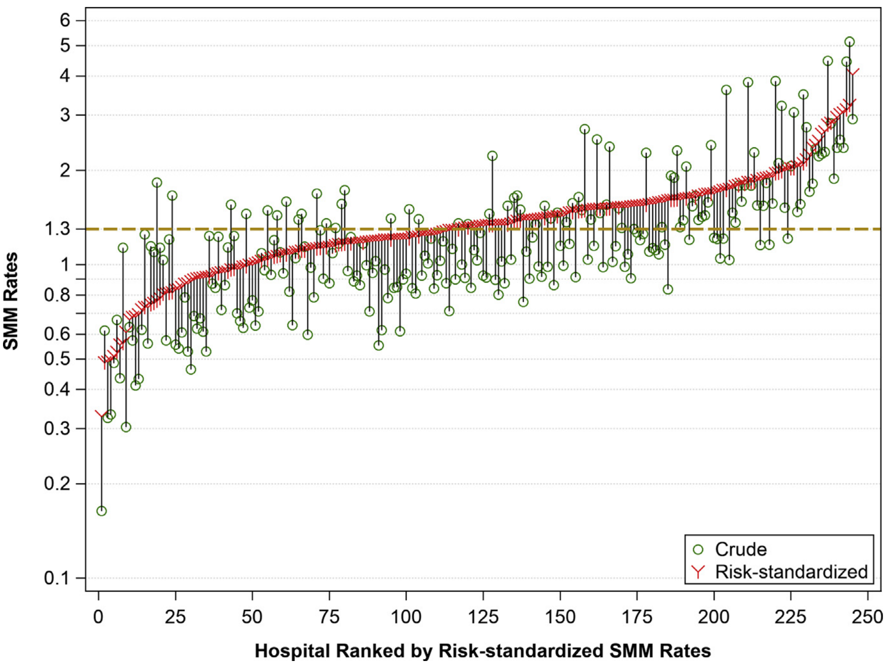
Results

Of the 3,010,525 births in California between the years 2007 and 2012, the mean maternal age was 28.3 years (standard deviation, 6.3) and most women were Hispanic (51.8%) (28.1% foreign-born; 23.7% US-born), followed by non-Hispanic white (27.0%), Asian and Pacific Islander (13.1%), Black (5.7%), Other (2.2%), and Unknown (2.2%). A total of 39,132 births (1.3%) were SMM births and the prevalence of SMM births was highest in Black or African American women (2.1%) and lowest in white women (1.1%) (Figure 1).

Births occurred at 245 hospitals. The majority (83.9%) occurred at private hospitals and only 11.8% occurred at teaching hospitals (Table 1). Across the hospitals, the median percentage of births was 27.4% for non-Hispanic white births, 20.9% for US-born Hispanic births, 23.9% for foreign-born Hispanic births, 2.6% for Black births, and 7% for Asian and Pacific Islander births (data not indicated). The median number of births across the hospitals was 10,682 (minimum, 933; maximum, 50,166). Hospital-level unadjusted SMM rates ranged from 0.16% to 5.14%, and risk-adjusted SMM rates ranged from 0.33% to 4.03% (Figure 2).

The adjusted risk ratios of SMM by race and ethnicity and hospital characteristics are presented in Table 2. In unadjusted models, in a given hospital, Black women had double the risk of SMM compared with white women (OR, 1.99; 95% confidence interval [CI], 1.92–2.07). US-born Hispanics (OR, 1.25; 95% CI, 1.21–1.29), foreign-born Hispanics (OR, 1.24; 95% CI, 1.21–1.28), Asian and Pacific Islanders (OR, 1.24; 95% CI, 1.20–1.28), and those categorized as Other (OR, 1.55; 95% CI, 1.37–1.75) also had a higher risk of SMM than white women.

FIGURE 2
Crude and risk-standardized SMM rates ranked by hospital SMM rate in California (2007–2012) (N=245)



The distribution of risk-standardized SMM rates across ranked hospital-level unadjusted SMM rates in the state of California between the years 2007 and 2012. The range of unadjusted hospital-level SMM rates was between 0.16% and 5.15%, whereas the range of risk adjusted SMM rates was between 0.19% and 4.18%.

SMM, severe maternal morbidity.

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Adjustment for sociodemographic factors, pregnancy-related factors, and clinical comorbidities significantly reduced the excess risk for Black women (OR, 1.25; 95% CI, 1.19–1.31), foreign-born Hispanic women (OR, 1.17; 95% CI, 1.11–1.24), and Other women (OR, 1.31; 95% CI, 1.15–1.50), but not for US-born Hispanic women (OR, 1.25; 95% CI, 1.20–1.29) or Asian and Pacific Islander women (OR, 1.26; 95% CI, 1.21–1.32). Although birth at a teaching hospital was associated with an increased risk of SMM (OR, 1.18; 95% CI, 1.10–1.27), adjustment for hospital factors did not reduce racial and ethnic differences in SMM beyond the sociodemographic and pregnancy-related factors and comorbidities (Table 2, model 3). Overall, 6% of the variability in SMM was between hospitals and 94% within hospitals.

The crude and risk-standardized cumulative distribution of SMM by race and ethnicity and ranked by hospital SMM rates in California is presented in Figure 3. In the unadjusted distribution, 33% of white women gave birth at hospitals in the highest tertile of SMM compared with 52.5% of Black women, 36% of US–born Hispanic women, 39.1% of foreign-born Hispanic women, 31.3% of Asian and Pacific Islander women, and 40.4% of women categorized as Other race and ethnicity. Risk-standardized rates that were adjusted for sociodemographic and clinical characteristics reduced SMM differences between racially and ethnically minoritized groups and white women giving birth in hospitals with the highest tertile of SMM (white, 32.9%; Black, 38.3%; US-born Hispanic, 30.7%; foreign-born Hispanic, 32%; Asian and Pacific Islander, 25.3%; Other 39.4%). Finally, the results of our simulation model to estimate the number of SMM cases that would have occurred if each racially and ethnically minoritized group gave birth at the same hospitals as white women revealed that there would be 156 fewer SMM cases among Black women had they given birth at the same hospitals as white women, which corresponds to a 7.8% reduction in the disparity in SMM between Black and white women (Table 3). The simulation also produced a 12.1% reduction in disparities between the Other racial and ethnic group and white women, which would have resulted in 10 fewer SMM cases in this group. Alternatively, there were increases in racial and ethnic disparities for US–born and foreign-born Hispanic women (16.1% and 19.4%, respectively) and Asian/Pacific Islander women (24.2%) in the simulation. These increases would have resulted in 272, 412, and 274 additional SMM cases for US-born Hispanic, foreign-born Hispanic, and Asian and Pacific Islander women, respectively.

The results of our sensitivity analyses revealed that racial and ethnic differences in SMM were comparable for our secondary outcome of nontransfusion SMM and among only singleton births (data not indicated).

Comments

Using data on 3,020,525 births at 245 hospitals in the state of California from 2007 to 2012, we found that the prevalence of SMM was 1.3% overall and varied considerably by race and ethnicity, with the highest rate of SMM observed in Black women (2.1%) and lowest in white women (1.1%). All racially and ethnically minoritized groups (Black, Hispanic, Asian and Pacific Islander, and Other) had significantly higher levels of SMM than white women, after adjustment for an extensive set of maternal sociodemographic factors, pregnancy-related factors, and comorbidities. Additional adjustment for birth hospital and specific hospital characteristics did not further attenuate racial and ethnic differences in SMM, and only teaching affiliation was

TABLE 2

Adjusted risk ratios of severe maternal morbidity by race or ethnicity and hospital characteristics in California (2007–2012) (N=3,010,525)

	Unadjusted OR	Model 1	Model 2	Model 3	Model 4
Characteristic	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Race and ethnicity					
White	Ref	Ref	Ref	Ref	Ref
Black	1.99 (1.92–2.07)	1.76 (1.69–1.84)	1.68 (1.61–1.75)	1.25 (1.19–1.31)	1.25 (1.19–1.31)
US-born Hispanic	1.25 (1.21–1.29)	1.29 (1.24–1.33)	1.32 (1.28–1.37)	1.25 (1.20–1.29)	1.25 (1.20–1.29)
Foreign-born Hispanic	1.24 (1.21–1.28)	1.12 (1.07–1.18)	1.18 (1.12–1.24)	1.17 (1.11–1.24)	1.17 (1.11–1.24)
Asian and Pacific Islander	1.24 (1.20–1.28)	1.27 (1.21–1.32)	1.29 (1.23–1.34)	1.26 (1.21–1.32)	1.26 (1.21–1.32)
Other	1.55 (1.37–1.75)	1.45 (1.28–1.65)	1.44 (1.27–1.63)	1.31 (1.15–1.49)	1.31 (1.15–1.50)
Unknown	1.28 (1.19–1.39)	1.08 (0.97–1.19)	1.03 (0.93–1.13)	1.00 (0.90–1.10)	0.99 (0.89–1.10)
Hospital characteristics					
Teaching hospital					
Yes vs no					1.18 (1.10–1.27)
AAP nursery level					
I					0.91 (0.71–1.18)
II					0.87 (0.69–1.09)
III					0.92 (0.74–1.13)
IV					Ref
Delivery volume					
Low					1.20 (0.97–1.48)
Medium					1.10 (0.93–1.30)
High					1.15 (0.99–1.32)
Very high					
Ownership					
Public vs private					1.05 (0.94–1.17)

Model 1: adjusts for sociodemographic factors; model 2: plus pregnancy-related behaviors; model 3: plus clinical factors; model 4: plus hospital factors. Other refers to American Indian and Alaska Native, Mixed-race, and Other women.

CI, confidence interval; *OR*, odds ratio; *PI*, Pacific Islander; *Ref*, referent.

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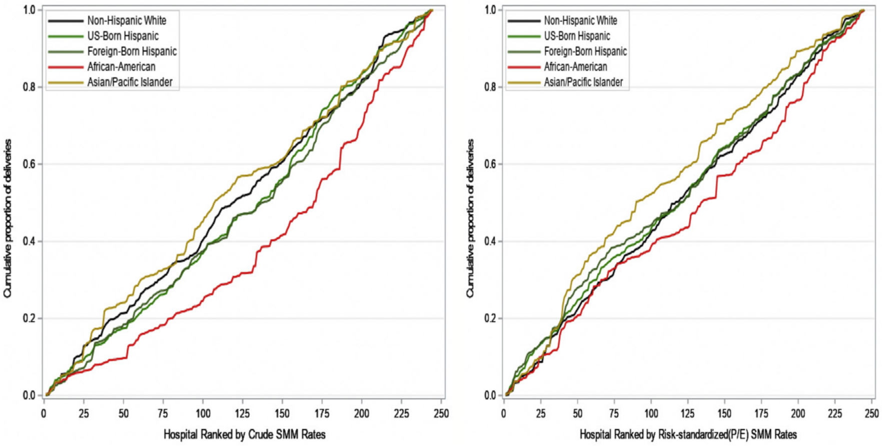
associated with SMM. However, in simulation analyses, we found that the rates of SMM would be reduced in Black and Other women, if they had given birth in the same hospitals as white women.

This study examined the contribution of birth hospital to racial and ethnic disparities in SMM in a comprehensive statewide database of women from diverse racial and ethnic backgrounds. The most comparable studies in this area come from a series of investigations by Howell et al[14,20] in New York City (NYC) from 2011 to 2013. They found that racial and ethnic differences in SMM were reduced but remained statistically significant after adjustment for sociodemographic, clinical, and hospital characteristics. They also found that simulation models designed to predict the rates of SMM for Black women, if they gave birth in similar hospitals as white women, would result in a 47.7% reduction in the disparities in SMM. Simulation models also estimated a 36.5% reduction in Hispanic-white disparities in SMM.[14,20] In our study, we also found that racial and ethnic differences in SMM persisted after adjustment for covariates, and simulation models revealed that hospital factors accounted for only 7.8% of the Black-white disparity in SMM. For women in the Other racial and ethnic group, which comprised mostly Native American women, there was a 13% reduction in disparities based on birth hospital.

There are several potential explanations for why birth hospital was not as strongly predictive of racial and ethnic differences in SMM for the state of

FIGURE 3
Crude and risk-standardized cumulative distribution of deliveries by race and ethnicity and ranked by hospital SMM rates in California (2007−2012) (N=245)



Distribution of crude and risk-standardized cumulative rate of severe SMM overall and within racial and ethnic groups, ranked by hospital SMM rates in the state of California between the years 2007 and 2012. Adjusting for sociodemographic and clinical characteristics (risk-standardized rates) decreased the difference in SMM differences between racial groups delivering in hospitals with the highest tertile of SMM. Crude cumulative distribution (left panel), risk-standardized cumulative distribution (right panel).

SMM, severe maternal morbidity.

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California compared with NYC. First, disparities in SMM between Black and white women were less pronounced in California than in NYC (3- vs 2-fold higher SMM rates, respectively), and Black women also made up a smaller proportion of our study sample (5.7% vs 21% in NYC) and a smaller proportion of births across hospitals (median percentage of Black deliveries was 2.6% vs 18.4% in NYC). Alternatively, California has a higher proportion of Hispanic deliveries than NYC (median percentage of Hispanic deliveries was 44.8% vs 28.7%, respectively), and the Hispanic subgroups vary significantly, with California having mostly Mexican women and NYC having more Puerto Rican and Cuban women. Second, there was less variability in SMM rates across hospitals in California than in NYC, with unadjusted SMM rates ranging from 0.16% to 5.15% in California but 0.6% to 11.5% in NYC. Third, when we investigated whether specific hospital factors were associated with SMM, we found that teaching hospitals had higher SMM rates than nonteaching hospitals but found no associations with the other hospital factors. The higher risk among teaching hospitals could be caused by higher acuity patients and the fact that our risk set for comorbidities was insufficient given they captured the existence but not severity of comorbidities. Our null findings for the other hospital factors are supported by mixed findings in the literature. Howell et al[14,20] found that public hospitals and those with lower nursery level and delivery volume had higher SMM rates than private and high nursery level and delivery volume

TABLE 3
Reduction in SMM by race or ethnicity and birth hospital

Race and ethnicity	SMM deliveries	Observed SMM rate: SMM (%)	Observed SMM rate: Disparity[a] (%)	Simulation: SMM (%)	Simulation: Disparity[b] (%)	Percentage reduction in disparity[c]	SMM events avoided[d]
White	813,211	1.06	—	—	—	—	—
Black	172,912	2.10	1.03	2.01	0.95	7.8	156
US-born Hispanic	714,383	1.33	0.26	1.37	0.31	16.1[e]	272[e]
Foreign-born Hispanic	847,379	1.32	0.25	1.37	0.31	19.4[e]	412[e]
Asian and Pacific Islander	395,591	1.32	0.25	1.39	0.33	24.2[e]	274[e]
Other	15,733	1.64	0.58	1.57	0.51	12.1	10

Other refers to American Indian and Alaska Native, mixed-race, and Other women.

SMM, severe maternal morbidity.

[a] Disparity is the difference in observed SMM (percentage) between each racial and ethnic group and white women; [b] Disparity is the difference in simulation SMM (percentage) between each racial and ethnic group and white women; [c] Percentage reduction=([Column A−Column B]/Column A)×100; [d] Details on calculation provided in Supplemental Table 2; [e] Indicates an increase instead of a reduction in disparity.

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hospitals, respectively. Other studies have yielded mixed findings, with 1 assessment in the state of New York in 2013−2014 finding that there were no associations between these factors and SMM, and a national study of hospital-level factors in the US indicating that only delivery volume was associated with SMM.[15,27]

The results of our simulation model also provided some counterintuitive findings. We found that for US- and foreign-born Hispanic and Asian and Pacific Islander women, there was actually an increase in SMM disparities when assigning them to hospitals in which white women gave birth. Our simulation models are based on the assumption that white women give birth at better quality hospitals. This assumption is supported by research documenting that hospitals serving predominately Black and other women from minoritized racial and ethnic groups have worse SMM rates and poorer performance on quality of care metrics.[18,19] However, whether this is true for the state of California remains understudied. Moreover, there is also significant within-hospital variability in SMM outcomes. As an example, Creanga et al[19] found that even within hospitals that served predominately racially and ethnically minoritized women, Black women received worse quality of care on 11 of 15 metrics. Given the substantial research documenting experiences of racial discrimination both within and out of the healthcare settings and the racial and ethnic differences in outcomes within hospitals,[28,29] future research should examine the factors that may account for both within-hospital variation in SMM and racial and ethnic disparities in SMM.

Limitations

This study has several limitations. First, although we used a validated measure of SMM, there is still a possibility of misclassification owing to the underreporting of the rare SMM conditions in hospital discharge data.[30] There may have also been misclassification owing to the inclusion of some women who required a blood transfusion for less severe complications, which we were unable to exclude from our definition of SMM.[21] We ran sensitivity analyses and found that the pattern of racial and ethnic differences was consistent for our secondary outcome of nontransfusion SMM cases, although less pronounced given that this excluded about 50% of our SMM cases. Second, our data ended in 2012, because the linked birth cohort files were only available until 2012. In California, SMM nearly tripled from 1997 to 2014,[4] but maternal mortality declined from 2008 to 2012; we are uncertain of more recent trends, although it is hoped that SMM has not continued to increase, especially in light of the quality improvement initiatives implemented by the California Maternal Quality Care Collaborative in more recent years. As such, we are uncertain of the applicability of our results to more recent years but hope to explore this in the future as the linked data become available. Third, the 4 hospital factors that we included in our analyses were crude proxies for hospital quality and do not reflect the disparities in individual-level clinical care that affect SMM and have been indicated to vary by race or ethnicity. Moreover, our simulation models were based on the assumption that hospital SMM rates were also a proxy for hospital quality, which may not be the case. Finally, we cannot rule out the potential for residual confounding owing to the unavailability of data on certain confounders, such as additional measures of socioeconomic status, which may have resulted in an overestimation of the racial and ethnic disparities in SMM.

Conclusions

This study documented that racial and ethnic differences in SMM are pervasive in California and that birth hospital likely contributes to but does not fully explain these differences, especially for black women and women categorized as Other race and ethnicity. Our work underscores the importance of continued efforts to address the disparities in SMM and the need for investigations of the multi-level contributors to these disparities.[31] The potential for regional differences in the role of hospital factors in shaping racial and ethnic disparities in SMM also warrants further examination to inform effective policies. Our population-level, hospital-focused approach is important; however, future studies are needed that delve more deeply into the systemic factors (such as racism) that lead to minoritized women giving birth at lower quality hospitals and into how this situation may be changed to ensure equitable, high-quality maternity care for all. ■

Acknowledgments

The authors would like to thank Audrey Lyndon and Alison El Ayadi for the feedback on the conceptualization of this work. The authors would also like to thank Lu Tian for the statistical support.

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Received Sept. 3, 2019; revised July 10, 2020; accepted Aug. 10, 2020.

This work was supported by grant number R01NR017020 from the National Institute of Nursing Research.

The authors report no conflict of interest.

This study was presented at the 32nd Annual Meeting of the Society for Pediatric and Perinatal Epidemiologic Research, Minneapolis, MN, June 17—18, 2019.

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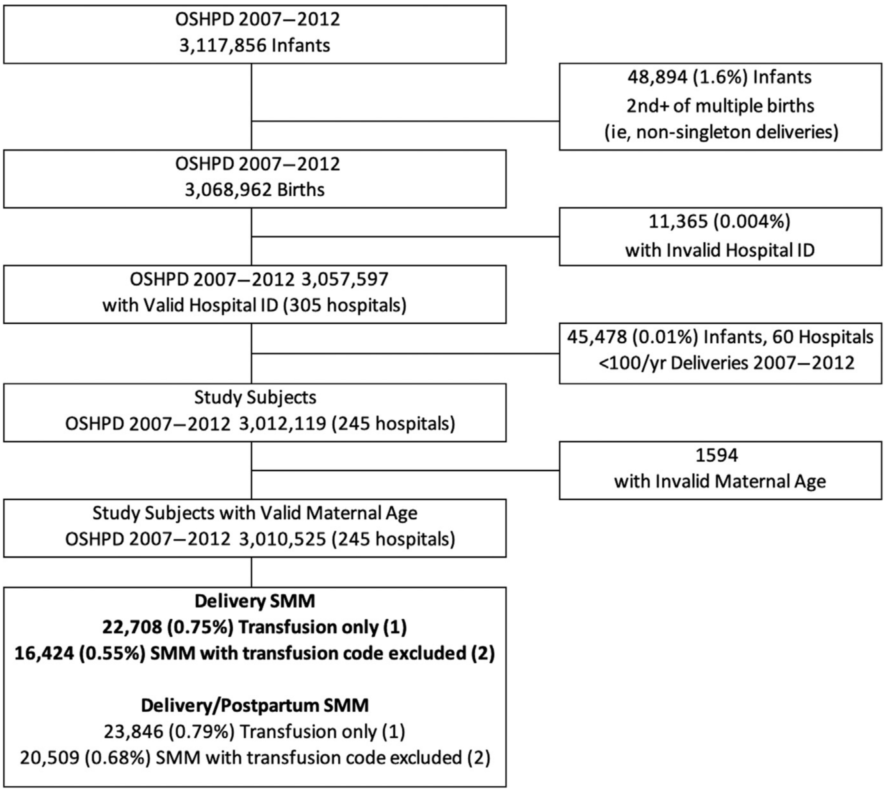
SUPPLEMENTAL FIGURE

Study flowchart for the state of California (2007−2012)



Summary of study exclusion criteria leading to the final analytical sample size. After removing samples because of missing and invalid data, 3,010,525 births that occurred in 245 hospitals were retained for analyses.

ID, identity; *OSHPD*, Office of Statewide Health Planning and Development; *SMM*, severe maternal morbidity.

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SUPPLEMENTAL TABLE 1

SMM indicators and the International Classification of Diseases, Ninth Revision, Clinical Modification codes

Severe maternal morbidity indicator	DX or PR	ICD-9
1. Acute myocardial infraction	DX	410.xx
2. Aneurysm	DX	441.xx
3. Acute renal failure	DX	584.5, 584.6, 584.7, 584.8, 584.9, 669.3x
4. Adult respiratory distress syndrome	DX	518.5x, 518.81 518.82 518.84, 799.1
5. Amniotic fluid embolism	DX	673.1x
6. Cardiac arrest and ventricular fibrillation	DX	427.41, 427.42[a], 427.5
7. Conversion of cardiac rhythm	PR	99.6x
8. Disseminated intravascular coagulation	DX	286.6, 286.9, 666.3x
9. Eclampsia	DX	642.6x
10. Heart failure and arrest during surgery or procedure	DX	997.1
11. Puerperal cerebrovascular disorders	DX	430.xx, 431.xx, 432.xx, 433.xx, 434.xx, 436xx, 437.xx, 671.5x, 674.0x, 997.02
12. Pulmonary edema and acute heart failure	DX	518.4, 428.1, 428.0, 428.21, 428.23, 428.31, 428.33, 428.41, 428.43
13. Severe anesthesia complications	DX	668.0x[a], 668.1x, 668.2x
14. Sepsis	DX	038.xx, 995.91, 995.92, 670.2x (after October 1, 2009)
15. Shock	DX	669.1x, 785.5x, 995.0, 995.4, 998.0x
16. Sickle cell disease with crisis	DX	282.42, 282.62, 282.64, 282.69
17. Air and thrombotic embolism	DX	415.1x, 673.0x, 673.2x, 673.3x, 673.8x
18. Blood products transfusion	PR	99.0x
19. Hysterectomy	PR	68.3x—68.9x
20. Temporary tracheostomy	PR	31.1
21. Ventilation	PR	93.90, 96.01, 96.02, 96.03, 96.05

DX, diagnostic code; *ICD-9*, International Classification of Diseases, Ninth Revision; *PR*, procedure code.

[a] ventricular flutter; [b] Due to rare prevalences, the following indicators may be combined for reporting purposes: 1) Acute myocardial infarction and aneurysm; 2) cardiac arrest/ventricular fibrillation and conversion of cardiac rhythm; and 3) temporary tracheostomy and ventilation.

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SUPPLEMENTAL TABLE 2

Steps of simulation model to calculate the number of SMM events avoided based on change in birth hospital

Step 1: Use model 3 in Table 2 to obtain the formula.
Step 2: Calculate the predicted probability of SMM for each mother at each hospital. This will result P1,P2, . . . , P245 (ie, predicted probability for each women [N=3,010,525] in each of 245 hospitals).
Step 3: Calculate the percentage of white mothers who went to each hospital. This will create 245 variables for each hospital (W1,W2, . . . , W245) and W1+W2+. . . +W245=1.
Step 4: Compute the weighted average of the probabilities of SMM for each woman (N=3,010,525) if delivered in the same distribution of hospitals as white mothers, using weights from step 3. MPW=W1P1+W2P2+. . .+W245×P245.
Step 5: Calculate the difference between the probability of original hospital and the probability if white hospital for each mother. DMPW=P(original hospital)−MPW; DMPW=0.090228228 for black women; 0.03801112 for US-born Hispanic; 0.04864774 for foreign-born Hispanic; −0.06929749 for Asian and Pacific Islander; and 0.064727675 for Other.
Step 6: Calculate the number SMM events avoided using the following formula: SMM avoided=number of deliveries for minoritized group×DMPW%.

Sample calculation: For black women, the number of SMM events avoided=172912×0.090228228%=156 events.

DMPW, Difference in Mother's Probability Weight or the difference of probabilities of SMM between mom goes to original hospital and mom goes to white mother's hospital; *SMM*, severe maternal morbidity; *MPW*, Mother's Probability Weight, or the weighted average(mean) of probabilities of SMM if mom goes to the white mother's hospital.

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