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Relationship Between Neighborhood Socioeconomic Disadvantage and Severe Maternal Morbidity and Maternal Mortality

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Background: Rates of severe maternal morbidity and maternal mortality (SMM/MM) in the United States are rising. Disparities in SMM/MM persist by race, ethnicity and geography, and could partially be attributed to social determinants of health.

Purpose: Utilizing data from the largest, statewide referral hospital in Alabama, we investigated the relationship between residence in disadvantaged neighborhoods and SMM/MM.

Methods: Data on all pregnancies between 2010 and 2020 were included; SMM/MM cases were identified using CDC definitions. Area deprivation index (ADI) available at the census-block group was geographically linked to individual records and categorized using quintile cutoffs; higher ADI score indicated higher socioeconomic disadvantage. Generalized estimating equation models were used to adjust for spatial autocorrelation and ORs were computed to evaluate the relationship between ADI and SMM/MM, adjusted for covariates including age, race, insurance, residence in medically underserved areas/population (MUAP), and urban/rural residence.

Results: Overall, 32,909 live-birth deliveries were identified, with a prevalence of 9.8% deliveries with SMM/MM with blood transfusion and 5.3% without blood transfusion, respectively. Increased levels of ADI were associated with increased odds of SMM/MM. Compared to women in the lowest quintile, the adjusted OR for SMM/MM among women in highest quintile was 1.78 (95%CI, 1.22-2.59, P=.0027); increasing age, non-Hispanic Black, government insurance and residence in MUAP were also significantly associated with increased odds of SMM/MM.

Conclusion: Our results suggest that residence within disadvantaged neighborhoods may contribute to SMM/MM even after adjusting for patient-level factors. Measures such as ADI can help identify the most vulnerable populations and provide points to intervene. *Ethn Dis.*2022;32(4):293-304; doi:10.18865/ed.32.4.293

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Introduction

Maternal morbidity and mortality have long been key markers for the progression of obstetrical care. Maternal mortality (MM) is defined by the World Health Organization (WHO) as "the annual number of female deaths from any cause related to or aggravated by pregnancy or its management (excluding accidental or incidental causes) during pregnancy and childbirth or within 42 days of termination of pregnancy, irrespective of the duration and site of the pregnancy."[1] Each year, there are approximately 358,000 maternal deaths globally, with 94% occurring in low and middle-income countries.[2] The maternal mortality ratio (MMR), which is the number of maternal deaths per 100,000 live births, has decreased globally over the last few decades, from 342 deaths to 211 deaths per 100,000 live births from 2000 to 2017.[3] However the United States is the only high-income country that is an exception to this trend.[3] The MMR in the United States increased from 12 to 23.8 deaths per 100,000 live births since 2000; 800 women die from complications of pregnancy and childbirth annually.[1]

Each maternal death is thought to represent between 50–100 cases of severe maternal morbidity (SMM).[4-7] SMM can be defined as "unintended outcomes of the process of labor and delivery that result in significant short-term or long-term consequences to a woman's health."[4-7] Annually, a projected 50,000 to 60,000 women experience severe complications during pregnancy and postpartum. The SMM rate in the United States has increased by 75%, from 73.8 cases in 1993 to 140 cases per 100,000 in 2014.[8]

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While both MMR and SMM have risen in the United States, significant disparities persist by race, ethnicity and geography. In 2020, non-Hispanic Black (NHB) women were nearly three times more likely to die from pregnancy complications than non-Hispanic White (NHW) and Hispanic women (NHB: 55.3 vs NHW: 19.1 vs Hispanic: 18.2 deaths per 100,000 live births, respectively). The rate has been increasing rapidly for NHB women since 2018[1,3] and is now comparable to the MMR of countries that WHO defines as a fragile state on the Fragile State Index for MMR, which ranges from 31 to 1150 deaths per 100,000 live births.[9]

Increase in obesity rates, prevalence of medical comorbidities, increased maternal age, and cesarean delivery rates are known risk factors of MM and SMM.[10] Studies have found a significant dose-response relationship between increasing obesity class and the risk of SMM at delivery hospitalizations. However, these proximal risk factors may not completely explain the disparity observed in maternal outcomes. Increasingly, researchers are investigating maternal health from the prism of social-ecological model framework[11] and the multidimensional framework of the health of women across life course,[12] to better understand the factors affecting women from preconception to pregnancy to postpartum period.[13] A large body of research has shown that social determinants of health (SDoH) such as structural racism, neighborhood environment, behavior, and policies interact with women's individual-level factors to significantly increase disease risk and susceptibility within clinical care and public health systems.[10,14] These factors may further interact with a patient's biological make-up to determine short- and long-term health, disease, and disability outcomes. SDoH including structural racism have been associated with negative impacts on Black women's reproductive health[15,16]; however, the measurement of these constructs has been fraught with limitations. Individual-level measurement of SDoH is most predictive of health outcomes but is inconsistently collected and rarely included in electronic health records (EHR). Alternatively, area-level measurement is often collected from external sources (eg, Census) making it more readily available, but is not as robust in risk prediction models.[17] In absence of individual-level deprivation data, area-level measures of social deprivation may serve as proxies for individual risk factors.[18]

We conducted this retrospective cohort study to assess the impact of residence in socio-economically deprived neighborhoods on SMM/MM. We hypothesized that women residing in neighborhoods with high area-level deprivation, measured by area deprivation index (ADI), have a higher risk of experiencing SMM/MM.

Methods

Data Sources

Data for all live births between January 1, 2010, to December 31, 2020, within the University of Alabama at Birmingham hospital system were retrieved for this study. This system has the largest hospital in Alabama and serves as the referral hospital for the state and adjourning areas of surrounding states accounting for approximately 7%-8% of births in Alabama. EHRs were obtained from the hospital system's Informatics for Integrating Biology and the Bedside (i2b2), a scalable informatics framework system designed for translational research. Ethical approval to conduct the study was provided by the University of Alabama at Birmingham Institutional Review Board.

Outcome Measures

Delivery Hospitalization Identification

We used an enhanced-method developed by Kulkina et al in 2008[19] to identify obstetric deliveries at the University of Alabama at Birmingham Hospital during the 11-year study period. Cases were identified using a combination of International Classification of Diseases, 10th Division, Clinical Modification (ICD-10-CM) codes, Diagnosis-related group (DRG) codes, and ICD-10-CM procedure codes for selected delivery-related procedures reported on the discharge summary. The enhanced-method uses a four-step hierarchical approach to identify delivery hospitalizations. In step 1, we queried i2b2 for EHRs delivery outcomes (ICD-10-CM, Z37.0); in step 2, we queried for EHRs with ICD10-CM disease code=O80, that were not included in step 1; in step 3, we queried i2b2 for EHRs with diagnosis-related group (DRG) delivery codes that were not included in step 1 and 2; and in step 4, we queried i2b2 for EHRs with ICD-10-CM procedure codes for selected delivery-related procedures to abstract records that were not included in steps 1-3. Figure 1 displays the re-

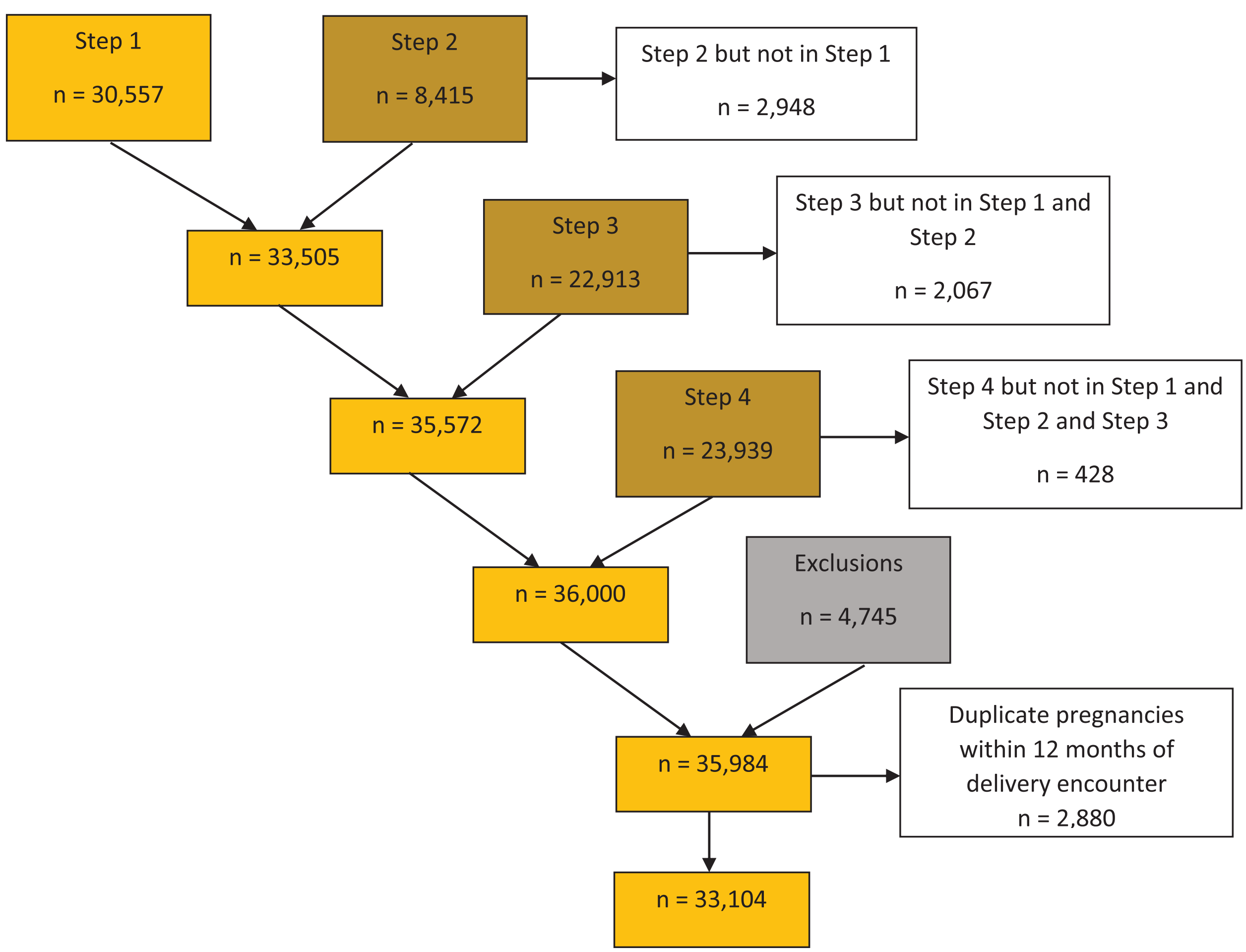

Figure 1. Enhanced delivery hospitalization method

sults for steps and the cumulative records retained after excluding EHRs with discharge diagnoses containing ICD-10-CM codes for abnormal or abortive pregnancy outcomes. We excluded patients (n=195) who resided outside the state of Alabama.

Identification of SMM and MM Cases

The CDC defines SMM as "unexpected outcomes of labor and delivery that result in significant short- or long-term consequences to a woman's health."[20] The CDC developed a comprehensive list of 21 adverse maternal health events indicative of SMM and their corresponding ICD-10 diagnostic and procedural codes.[21] The CDC categorizes maternal death into two main categories: pregnancy-related or pregnancy-associated. Broadly speaking, pregnancy-related deaths are maternal deaths due to physiologic effects of pregnancy or from pregnancy complications, and pregnancy-associated deaths occurred during the time period but were unrelated to the decedent's pregnancy status. For the purpose of this study, we defined SMM case as delivery hospitalization with one or more diagnostic codes or procedure codes from the 21 indicator codes within 1-year from delivery encounter, and MM cases as pregnant or postpartum patients who were deceased within 365 days of the delivery encounter.

Individual-Level Factors

Once the cases were identified, we obtained data on demographic factors including age in years, self-reported race/ethnicity (NHW, NHB, Hispanic, and Others), insurance type, and residential census block group (CBG) location. Age was categorized into seven groups (15-17, 18-25, 26-30, 31-35, 36-40, 41-45, 46+). Insurance status was categorized into private or commercial, and government which included Medicaid and Medicare. Due to very small numbers, we grouped self-pay within the government group.

Neighborhood-Level Factors

The ADI is a measure created by the Health Resources and Services Administration (HRSA) more than 30 years ago and has been since refined and validated to census block group (CBG) neighborhood level by Kind et al.[22] The ADI is a composite SDoH measure constructed from data on 17 measures on education, employment, housing quality, and poverty, from the American Community Survey data. The ADI values range from 1 to 100; a CBG with ADI ranking of 1 indicates lowest level of disadvantage within the United States and a CBG with ADI ranking of 100 indicates highest level of disadvantage. We linked the patient's data to their respective ADI, using the CBG level information. We also determined if the patient lived in metro or non-metro counties based on the 2013 rural-urban continuum code definitions.[23] Similarly, we determined if the patient lived in a medically underserved area or populations (MUAP). MUAPs are areas designated by the HRSA as having too few primary care providers, high infant mortality rates, high poverty or high elderly population. In Alabama, most of the MUAs are rural while areas with MUP are typically non-rural areas.[24]

Statistical Analyses

Descriptive statistics were used to summarize categorical variables by frequencies and proportions. Since MM counts were few (n=24), we created a composite variable combining SMM and MM cases as a single outcome measure. Distributions differences by SMM/MM status were compared using the X^2 test for categorical variables. We fitted a generalized estimating equation (GEE) model with an exchangeable matrix, to examine the association between ADI and prevalence of SMM/MM (yes vs no [referent]), accounting for similarities among women from the same CBG neighborhood. All delivery hospitalizations with residences in Alabama were included in the analyses. The main independent variable was ADI, which was categorized into 5-level categories using quintiles. The lowest quintile (ref: ADI score: 1-47) indicated least deprived neighborhood. Each subsequent quintile (Quintile 2: 48-66.9; Quintile 3: 67- 83.9; Quintile 4: 84-94.9; Quintile 5: 95-100) indicated increasing levels of neighborhood deprivation with Quintile 5 being most deprived neighborhood category.

We computed unadjusted and adjusted odds ratio (OR) and 95% confidence intervals (CI) for each quintile of ADI, comparing them to the lowest quintile (referent). Other variables including age (ref: 18-25 years); race (ref: NHW); insurance status (ref: private/military); residence in medically underserved area/population (ref: no); and residence (ref: urban) were in-

Table 1. Demographic characteristics of mothers with delivery hospitalizations

Characteristics	Total		Normal		SMM/MM		
	N	%	N	%	N	%	P
Total	32909		29679	90.2	3230	9.8	
Age categories							.0453
15-<18 years	842	2.57	763	2.6	79	2.4	
18-25	12432	38.0	11114	37.4	1318	40.8	
26-30	9307	28.4	8482	28.6	825	25.5	
31-35	6820	20.8	6201	20.9	619	19.2	
36-40	2784	8.5	2498	8.4	286	8.9	
41-45	494	1.5	437	1.5	57	1.8	
46+	80	.2	61	.2	19	.6	
Missing	150		123	.4	27	.8	
Race							<.0001
Non-Hispanic White	10686	32.8	9802	33.0	884	27.4	
Non-Hispanic Black	15941	49.0	13958	47.0	1983	61.4	
Hispanic/Latino	4885	15.0	4614	15.5	271	8.4	
Other[a]	1035	3.18	967	3.3	68	2.1	
Missing	362		338	1.1	24	.7	
Insurance							<.0001
Private/military	10995	33.4	10156	34.2	839	26	
Medicare/Medicaid/government	21914	66.6	19523	65.8	2391	74	
Area deprivation index (quintile)							<.0001
1st Quintile (1-47)	6489	19.7	6029	20.3	460	14.2	
2nd Quintile (48-66.9)	6491	19.7	5923	20.0	568	17.6	
3rd Quintile (67- 83.9)	6242	19.0	5614	18.9	628	19.4	
4th Quintile (84-94.9)	7016	21.3	6266	21.1	750	23.2	
5th Quintile (95-100)	6671	20.3	5847	19.7	824	25.5	
Residence in medically underserved areas							<.0001
No	12731	38.7	11631	39.2	1100	34.1	
Yes	20178	61.3	18048	60.8	2130	65.9	
Rural/urban							.0165
Metro counties	30247	91.9	27304	92.0	2943	91.1	
Non-metro counties	2278	6.9	2021	6.8	257	8.0	
Missing	384	1.2	354	1.2	30	.9	

a. Asian, Pacific Islander, American Indian or Alaskan Native, Multiracial
SMM/MM, Severe maternal morbidity and maternal mortality

cluded as covariates in the adjusted model. In additional analyses, we ran models limiting the dependent variable to patients with SMM/MM without blood transfusion (BT). Although BT has been classified as indicator for SMM, some patients are likely to receive blood even without experiencing other morbid conditions. BT of ≥4 units of blood has been found to be a significant predictor of SMM.[25] All analyses were performed with SAS software (Version 9.4, The SAS Institute Inc., Cary, NC, 2013).

Results

A total of 32,909 live births were identified and included in the study. Of the 32,909 deliveries, 29,679 (90.2%) were deliveries with live births without SMM/MM while 3,230 (9.8%) were cases of SMM/MM. Of the 3,230, 26 deliveries resulted in maternal deaths. Table 1 provides the patient characteristics. The average maternal age was 27.4 (±6.1) years with the majority being NHB (49.0%) or NHW (32.8%). Almost 93% of women lived in metro or urban counties and about 61% lived in MUAP. Results of bivariate comparison showed significant differences by age, race, insurance, ur-

Table 2. Severe morbidity indicators during delivery hospitalizations

Indicators	N	% of total hospitalizations	% of Total SMM/MM, n=3230 cases
Acute myocardial infarction	212	.64	6.6
Aneurysm	36	.11	1.1
Acute renal failure	626	1.90	19.4
Adult respiratory distress syndrome	364	1.11	11.3
Amniotic fluid embolism	3	.01	0.1
Cardiac arrest	39	.12	1.2
Disseminated intravascular coagulation	137	.42	4.2
Eclampsia	150	.46	4.6
Heart failure or arrest during surgery	5	.02	0.2
Puerperal cerebrovascular disorders	280	.85	8.7
Pulmonary edema or acute heart failure	376	1.14	11.6
Severe anesthesia complications	6	.02	.2
Sepsis	1026	3.12	31.8
Shock	165	.50	5.1
Hysterectomy	138	.42	2.4
Conversion of cardiac rhythm	42	.13	7.3
Air and thrombotic embolism			1.3
Blood transfusion	1235	3.75	38.2
Sickle cell disease with crisis	79	.24	4.3
Temporary tracheostomy	26	.08	.8
Ventilation	181	.55	5.6
Total deliveries with SMM/MM including blood transfusion	3230	9.88	
Total deliveries with SMM/MM without blood transfusion	1995	6.11	

ban/rural status, and MUAP status between deliveries with or without SMM/MM cases. Table 2 provides frequency and the percentages of individual indicators of SMM/MM across all deliveries. The most frequent indicator was BT (n=1,235, 38.2%) among all SMM/MM cases followed by sepsis (n=1,026, 31.8%).

Results of GEE models are presented in Table 3. Each increased level of ADI was associated with increased odds of SMM/MM. Compared to women in the least deprived neighborhood, women in most deprived neighborhood had an increased odds of SMM/MM in unadjusted (OR, 1.84; 95%CI, 1.60-2.12, P<.0001) and fully adjusted analyses (OR, 1.78; 95%CI, 1.22-2.59, P<.01). Increasing age, particularly age categories ≥35 years were significantly associated with increased odds of SMM/MM compared to the younger age group (18-25 years). Similarly, the odds for SMM/MM were nearly two times higher for NHB women compared to NHW (OR, 1.81; 95%CI 1.42-2.30, P<.0001) women. Compared to NHW women, the odds of SMM/MM for women who identified as Hispanic and 'Other' race were lower but statistically non-significant. The odds for SMM/MM for women with government insurance were about 37% higher compared to those with private or employer-based insurance (OR, 1.37; 95%CI, 1.23-1.52; P<.0001). Likewise, the odds of SMM/MM were slightly higher for those residing in MUAP (OR, 1.11; 95%CI, 1.01-1.22; P=.0307). However, no notable difference was observed between women living in metro areas vs non-metro areas (OR, 1.08; 95%CI, .92-1.26; P=.3335).

Discussion

The results of the study supported our hypothesis that residence in the highest deprivation neighborhoods was associated with increased odds for SMM/MM, compared to residence in least deprived neighborhoods. Consistent with previous studies, our study also found a strong association between NHB race, maternal age of 35 years or older, Medicare/ Medicaid insurance, residence in MUAP, and SMM/MM composite. No remarkable difference was found in SMM/MM rates among women

Table 3. Unadjusted and adjusted results for severe maternal morbidity and mortality

Variables	Crude OR[a] (95% CI)	P	Adjusted OR[a] (95% CI)	P
Area deprivation index (quintiles)				
1st Quintile (least deprived) (referent)	1.00		1.00	
2nd Quintile	1.28 (1.11-1.48)	.001	1.18 (.95-1.47)	.1429
3rd Quintile	1.43 (1.24-1.67)	<.0001	1.47 (1.18-1.84)	.0007
4th Quintile	1.58 (1.37-1.82)	<.0001	1.55 (1.18-2.04)	.0017
5th Quintile (most deprived)	1.84 (1.60-2.12)	<.0001	1.78 (1.22-2.59)	.0027
Race				
Non-Hispanic White (referent)			1.00	
Non-Hispanic Black	1.58 (1.44-1.74)	<.0001	1.81 (1.42-2.30)	<.0001
Hispanic/Latino	.66 (.57-.77)	<.0001	.84 (.58-1.23)	.3691
Other	.76 (.58-1.01)	.0614	.6 (.35-1.03)	.065
Age categories				
15-18 years	.87 (.67-1.12)	.7671	.83 (.65-1.07)	.1572
18-25 (referent)	1.00		1.00	
26-30	.84 (.77-.92)	.0003	.97 (.88-1.07)	.5344
31-35	.88 (.78-.98)	.0217	1.12 (1.00-1.26)	.0604
36-40	1 (.86-1.15)	.9782	1.3 (1.12-1.51)	.0007
41-45	1.16 (.87-1.53)	.3099	1.59 (1.19-2.12)	.0017
46+	2.56 (1.53-4.26)	.0003	3.56 (2.10-6.02)	<.0001
Insurance				
Private/military (referent)	1.00		1.00	
Medicare/Medicaid/Government	1.44 (1.32-1.57)	<.0001	1.37 (1.23-1.52)	<.0001
Residence in medically underserved areas				
No (referent)	1.00		1.00	
Yes	1.21 (1.10-1.32)	<.0001	1.11 (1.01-1.22)	.0307
Rural/urban				
Metro counties (referent)	1.00		1.00	
Non-metro counties	1.17 (1.01-1.36)	.0353	1.08 (.92-1.26)	.3335

a. Odds ratio and 95%CI computed using Genmod procedure with repeated subject = census block group geoid to adjust for within subject correlation

aged <35 years or Hispanic women (vs NHW) or by urban/rural status.

The MMR in our cohort was 72.9 per 100,000 which is approximately 3 times higher compared to the US ratio, which is 23.8 maternal deaths for every 100,000 live births,[26] and twice as high as the Alabama rate, which is 36.4 deaths per 100,000. Alabama has the third highest MMR in the United States, just behind Arkansas and Kentucky. According to the estimates reported by the Commonwealth Fund, about 1.4%, or 1,400 of 100,000 women giving birth in 2016-2017 had at least one of 21 CDC indicator conditions or procedures.[8] In comparison, the rates in our cohort were almost 9 times higher (9.3% or 9,334 of 100,000 live births). The most frequent SMM indicator was BT, lending credence to similar findings in other investigations.[8,27] Although BT is a well-known marker of SMM, it occurs together with more than 50% of other comorbid conditions including shock, amniotic fluid embolism, sickle cell disease with crisis and disseminated intravascular coagulation.[8,28] The higher rates observed in our cohort are most likely since the University of Alabama at Birmingham Hospital is a tertiary care teaching hospital which draws more complicated cases from all over the state, and consequently more severe outcomes. This hospital system is connected to the entire state through the longstanding Medical Information Service via Technology (MIST), which allows primary obstetric providers to access maternal-fetal-medicine and neonatology providers within minutes to receive advice and initiate transfer of complicated cases. The higher rates could additionally be attributed to higher percentage of patients who identified as NHB (49%). In comparison, only about 15.2% of all births in the United States are to a woman/person who identified as NHB.

Comparative data evaluating the relationship between neighborhood factors and SMM/MM composite are few and equivocal. The effect of neighborhood factors on SMM and MM have been studied in different ways using census tract and other proxies. A study conducted by Meeker and colleagues indicated that SMM rate increased by 2.4% for every 10% rise in proportion of individuals who identified as Black in a census tract after adjusting for other factors.[29] A cross-sectional study conducted in New York on neighborhood-level characteristics reported no association with SMM.[27] Another study found significantly lower odds of SMM among higher quartile (richer) compared to lowest quartile (poorest) neighborhoods using state level household income quartile for patient ZIP codes.[30] While the evidence with maternal outcomes is mixed, there is strong evidence linking ADI with morbidity including chronic disease management,[31] cardiac readmissions[32] and multimorbidity.[33] The results of our study showed a significant linear relationship between increasing levels of area deprivation and increased risk of SMM/MM; the effect statistically significant in the top three (most deprived) quintiles which associated with ADI score ≥67. The relationship persisted even after adjusting for known risk factors including race, age and insurance status.

The results of the study supported our hypothesis that residence in the highest deprivation neighborhoods was associated with increased odds for SMM/MM, compared to residence in least deprived neighborhoods.

The measurement of area-level SDoH is not without its challenges.[17] ADI is a validated measure for a community or neighborhood's socioeconomic status, and has been widely used as one of the metrics to measure SDoH at the community level. Other metrics or indices could be comparable to ADI (eg, social vulnerability index)[34] or in combination with ADI could better explain the impact of neighborhood factors on adverse health outcomes.[35] A new conceptual model–driven SDoH index has included additional dimensions of health-related social needs, such as food accessibility; however, this index has not yet been validated against actualized health outcomes.[35] Similarly, others have incorporated a wide-range of indicators as surrogates for SDoH, such as: crime statistics; physical environments including walkability index, access to parks[36]; environmental exposures etc.; and social indices such as racial segregation index – a proxy often used to measure structural racism.[37] However, there is little standardization and large variability in the way the proxy measures are used. Future studies focusing on SDoH need to address these gaps within the context of public data availability at the smallest spatial units.

With regard to race, our findings support racial disparities in SMM/MM that are well-documented in previous investigations.[1,27,29,30,38-41] Consistent with results from our study, studies have reported similar associations between NHB and SMM/MM composite.[40] We found no association between Hispanic ethnicity and SMM/MM composite when compared with NHW women. These findings are consistent with reports of a "Hispanic paradox,"[42] yet inconsistent with other studies on SMM/MM.[30,40,43] We speculate that a high proportion of NHW women seen in our hospital are from underserved areas leading to an attenuation of potential differences with both the NHB and Hispanic populations.

Regarding maternal age, this study found higher odds of SMM/MM with increasing maternal age above 35 years. While the finding is consistent with several studies,[30,41] some studies have reported increased SMM among young women aged 15-19 years.[30]

Consistent with previous investigations, women with government (Medicaid and Medicare) payor status were more likely to experience SMM during childbirth or pregnancy.[40, 41] Medicaid is the country's largest payor of perinatal care, particularly in rural and MUA. While women under Medicaid coverage receive care during the delivery and immediate postpartum, they often lose coverage after 60 days. Typically, women with Medicaid insurance are more likely to receive no or inadequate health services during prenatal, pregnancy and postpartum periods, increasing the chance of SMM/MM due to lack of support for conditions that emerge after the 60-day period. Of the top 10 high-income countries (HIC), the United States is the only country that does not guarantee paid maternity leave. The other HICs also offer universal and comprehensive maternal care coverage before, during and after pregnancy supported by seamless transfers across, out of, and into maternity care systems.

Study Strengths and Limitations

Our study has several strengths. We used a validated approach to identify delivery hospitalizations. Also, we used a broad definition for identifying SMM cases beyond the 60-day period to 365 days; thus, including patients who developed morbidity or died in our hospital system following initial discharge from the hospital. Our sample size is large and representative of the population who are most high-risk for SMM/MM. We expect our results to be generalizable to other similar urban and semi-urban populations in the Deep South.

There are a few limitations attributable to EHR use. The sample size underrepresents the deliveries occurring during the study period, given our average of about 4000 per year. Additional studies linking to our perinatal database are needed to understand this potential difference and any impact on our SMM/MM rates. While we adjusted for urban/rural status of the patient, the majority of our cases came from urban areas. Thus, results may not be generalizable to rural populations in the state. Also, we were unable to adjust for patient-level factors such as existing comorbidities due to lack of precise data. For example, pre-pregnancy obesity has been linked with SMM in earlier investigations; however, we did not adjust for obesity in our study given the inconsistency of reporting of this data in the EHRs. Thus, it is possible that the strong association between ADI and SMM/MM observed in our study could be confounded by presence of one or more co-morbid conditions. We may have overestimated SMM rates by including cases with BT alone in our analyses. However, the association between ADI and SMM/MM persisted even after excluding SMM cases with BT alone. Also, MM cases were too few for comprehensive analyses. However, earlier investigations have indicated that SMM is closely linked with MM, describing MM as "the tip and SMM, the base of the iceberg".[5]

Within the Global Context

Despite medical advancements throughout the 20th century, maternal health remains a major global public health concern. While MM rates in most HICs, barring the United States, have decreased or are decreasing, low middle-income countries particularly in Sub-Saharan Africa still carry a heavy burden with MM rates as high as 211 deaths per 100,000 women.[9] Consistent with MM rates, the SMM rates in these countries are also higher compared to those of HICs.[44] The impact of SDoH on women's health is especially pronounced in LMICs that carry a heavy burden of gender inequalities due to cultural norms, high poverty rates, low literacy rates, malnutrition, and structural barriers such as limited access to primary care and specialized care.[45,46] Of particular concern is that SMM rates appear to be trending upward. Such increases in maternal morbidity not only have impact on women's health but have long-term implications on infant health.[44] Therefore, it is incumbent upon all countries to implement surveillance initiatives to better understand the burden of SMM beyond individual biological and behavioral factors. Advancing strategies to address structural issues (eg, improved access to sufficient food and water, decreased exposure to environmental toxins, increased access to healthcare providers) can prevent or reduce this burden. Indirect measures such as ADI are not perfect, but can aid in surveillance to identify high-risk populations to plan a more targeted intervention approach.

Conclusion

Our study examined the association between ADI and SMM/MM and found that residence in the most deprived neighborhoods had the highest odds for SMM/MM as compared to residence in least deprived neighborhoods. Associations did not change even after adjusting for urban/rural status and residence in MAUP status, suggesting that neighborhood deprivation is independently associated with maternal morbidity and may play an important role in manifestation of adverse health outcomes in addition to individual-level risk factors. Our findings indicate that ADI quintiles could potentially be used as a tool to screen and treat high-risk patients and provide tailored interventions early-on to prevent antenatal complications. Future studies should explore the underlying factors and the causal pathways in which area deprivation plays a role in increasing maternal risk. Also, interaction between neighborhood deprivation indices and other metrics of SDoH such as area-level crime statistics, environmental exposure indices, and food accessibility, and their relative effect on health, warrant more attention. Finally, standardization of metrics of individual- and area-level SDoH are needed and would allow for comparative studies across countries and regions.

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Conflict of Interest

No conflicts of interest to report.

Author Contributions

Research concept and design: Tipre, Sinkey, Tita, Baskin; Acquisition of data: Tipre, Blanchard, Tita, Baskin; Data analysis and interpretation: Tipre, Bolaji, Harrelson, Szychowski, Sinkey, Tita, Baskin; Manuscript draft: Tipre, Bolaji, Blanchard, Harrelson, Szychowski, Sinkey, Tita; Statistical expertise: Tipre, Blanchard, Szychowski, Tita; Acquisition of funding: Sinkey, Baskin; Administrative: Bolaji, Blanchard, Harrelson, Sinkey, Tita, Baskin; Supervision: Tipre, Tita, Baskin

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