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Geographic Variation in Hypertensive Disorders of Pregnancy

By

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Doctor of Philosophy

Epidemiology

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Geographic Variation in Hypertensive Disorders of Pregnancy

By

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MPH, University of Maryland, Baltimore, 2016
BS, University of Maryland, 2014

Advisor: Michael R. Kramer, PhD, MS

An abstract of
A dissertation submitted to the Faculty of the
James T. Laney School of Graduate Studies of Emory University
in partial fulfillment of the requirements for the degree of
Doctor of Philosophy in Epidemiology
2024

Abstract

Geographic Variation in Hypertensive Disorders of Pregnancy

By Katherine Campbell

The overarching goal for this dissertation is to explore variation in the distribution of types of hypertensive disorders of pregnancy (HDPs) across geography, race, and measures of access to healthcare in the United States and Georgia.

Aim 1: We described county-level patterns of hypertensive disorder of pregnancy types and identified characteristics of counties with high burden using Bayesian spatial analysis to address challenges in small-area estimation. We found that place-based sociodemographic covariates differed in counties with high-burden chronic hypertension compared to those without, whereas high-burden gestational hypertension was only weakly associated with racial density of counties and did not exhibit a clear correlation with the identified place-based markers of risk.

Aim 2: We examined whether area-based indicators of access to health care during pregnancy is associated with increased rates of chronic and gestational hypertension at the county-level in the US. These findings suggest that living in low access (i.e. living in a rural area, having fewer providers per capita, and living in an area with a larger proportion of uninsured persons) is associated with higher rates of chronic hypertension. Measures of geographic access were more strongly associated with chronic compared to gestational hypertension when we examined this relationship at the national level.

Aim 3: We estimated the association of small-area (census tract and county) geographic access to care and HDP types in Georgia to explore how other spatial scales of access to care may be associated with higher rates of hypertension during pregnancy. We also compare reporting of linked hospital discharge records to birth certificate records with respect to chronic and gestational hypertension for validity and data quality concerns. We found relative discordance between reporting of hospital discharge records and birth certificate data between both chronic and gestational hypertension. These discrepancies resulted in differing statistical conclusions in the association between access to health care and each hypertensive type when we used different outcome measures (i.e. birth certificate versus hospital discharge), although the direction of the association was similar. Additionally, spatial scale did not change the conclusions when we changed from county level measures to census tract.

This dissertation underscores the questionability of combining hypertensive disorder of pregnancy types for surveillance and research, given their distinct geographic distributions and the variation in their relation to place-based characteristics. Accurate reporting of these types is important for research given there are unknowns about the etiology of gestational hypertension and being able to discern the types from chronic onset hypertension is valuable to disentangle potential markers of risk and drivers of pregnancy onset hypertension.

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Overview of hypertensive disorders of pregnancy

Hypertensive disorders of pregnancy (HDPs) are a group of conditions that contribute to maternal morbidity and mortality. HDPs are classified as chronic hypertension, gestational hypertension, preeclampsia, and chronic hypertension superimposed with preeclampsia, and they are differentiated based on timing of hypertension onset and the presence or absence of end-organ disfunction (**Figure 1.1**).[1] Chronic and gestational hypertension are characterized by a systolic blood pressure of 140 or higher and/or diastolic of 90 or higher, and the two disorders are differentiated by timing of elevated blood pressure, prior to or after 20 weeks gestation.[2] Chronic hypertension occurs prior to 20 weeks gestation or persists after the post-partum period, while gestational hypertension occurs at least 20 weeks gestation and resolves in the post-partum period.[2] Preeclampsia can develop with either of these disorders and it is characterized by proteinuria and/or end-organ dysfunction, in addition to high blood pressure.[2] Complications from these HDPs may result in poor outcomes for mother and child during pregnancy, such as progress to more severe conditions such as eclampsia and HELLP syndrome and placental abruption, and preterm birth or small for gestational age for the child.[3–5] The complications from disease

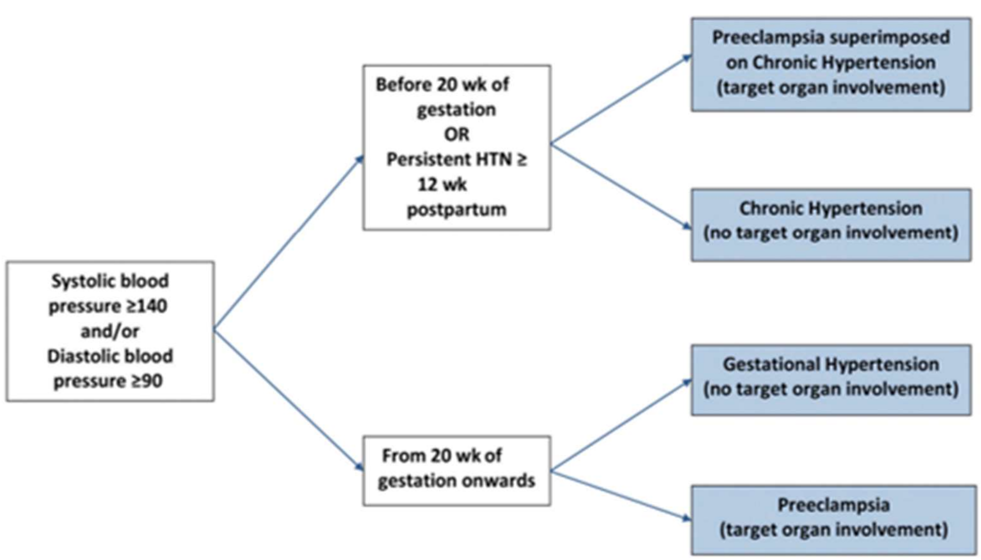


Figure 1.1. Identification of hypertension during pregnancy

onset may also arise post-pregnancy and result in long-term complications.[6] Previous studies established an association between HDPs and lifetime risk of cardiovascular disease, which is the leading cause of death in the US.[7,8] Each of these disorders are characterized by high blood pressure but they differ in underlying pathophysiology and severity, in addition to the timing of hypertension presentation.[9]

Chronic hypertension can be identified as "essential" or "secondary" depending on if high blood pressure is the primary diagnosis or if the onset is due to another condition.[6] Essential hypertension occurs where there are multi-factorial causes for the onset of high blood pressure and it cannot be defined by one single cause.[10] The onset of hypertension prior to pregnancy can put the individual at risk for blood vessel damage and other long-term complications such as heart attack and heart failure during the period of high blood pressure.[10] Additionally, essential hypertension can cause issues during the pregnancy such as fetal growth restriction and superimposed preeclampsia.[6] Secondary hypertension occurs as a result of a medical condition or the body's response to a medication.[10] For example, hypertension may be a result of renal disease and this puts individuals at higher risk for poor maternal and fetal outcomes due to the complexity of care needed.[6] In either of case of hypertension, elevated blood pressure is a danger to mother and child during gestation and requires management of symptoms from a provider to prevent further complications, considering 17% to 25% of cases develop superimposed preeclampsia.[11]

Gestational hypertension is diagnosed as high blood pressure (systolic 140mm Hg or greater and diastolic 90 mm Hg or greater) occurring de novo after 20 weeks gestation.[5] In order to avoid misdiagnosis and occurrence of high blood pressure due to whitecoat hypertension, blood pressure readings must meet the criteria at least twice, greater than four hours apart.[12] Although gestational hypertension does not include proteinuria or end-organ disfunction, there are still risks associated with a high blood pressure system during pregnancy that can be addressed with anti-hypertensive therapies.[5] Treatment and care for high or severe hypertension during pregnancy should be accompanied by frequent evaluation by a provider for management and progression of the associated risk, which can present a challenge for mothers that are unable to receive timely care.[5] According to the literature, up to 50% of the cases of gestational hypertension will have diagnostic criteria that fits preeclampsia later in the pregnancy.[13] Although there are proposed mechanisms in the literature, the cause of the hypertension onset during pregnancy is largely unknown. The onset is thought to be caused by reduced blood flow to from the uterus to the placenta such that when the placenta attaches to the uterus, the spiral arteries do not invade as deeply and creates challenges for passage of blood from mother to fetus.[6] This can result in system wide issues such as increased blood pressure in an attempt to improve the blood flow from mother to fetus (**Figure 1.2**).[6]

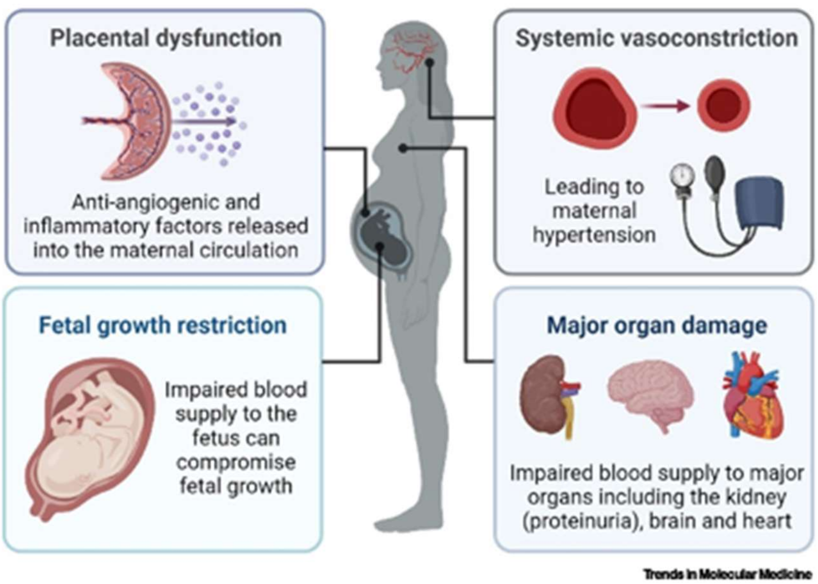


Figure 1.2. Mechanism of gestational hypertension

Preeclampsia can occur after either type of hypertension onset, either gestational or chronic.[14] Similar to the other HDPs, preeclampsia is diagnosed with maternal hypertension (140 mmHg/90mmHg) but is also co-occurring with signs of end-organ disfunction. Most commonly reported is proteinuria, or protein in the urine, which is diagnosed as 300mg or more in a 24-hour period.[5] Other signs may include: low platelet count (thrombocytopenia), elevated liver enzymes, epigastric pain, renal insufficiency, excess fluid in the lungs (pulmonary edema), and headaches that are not relieved by medications.[5] These additional diagnostic criteria are considered “severe features”, in addition to very high blood pressure (160 mmHg/110 mmHg).[5] Preeclampsia can progress to more severe conditions such as eclampsia and

HELLP syndrome. In eclampsia, maternal seizures can occur and result in high blood flow that can push the placenta from the wall of the uterus. Preeclampsia can develop into HELLP during or post pregnancy and affect liver functioning, liver bleeding, and issues with blood clotting.[6] To manage pre-eclampsia and prevent progression to eclampsia, early delivery may be the best solution for the mother and child and often the only "cure".

Some of the more severe manifestations of these HDPs include eclampsia and Hemolysis, Elevated Liver Enzyme, and Low Platelet count (HELLP) syndrome. Both of these diagnoses are associated with higher risks for maternal morbidity and mortality due to the danger that they present to the birthing person and child.[15] Access to clinical care is of the utmost importance for these conditions because resolution can require early delivery to reduce maternal and fetal mortality.[15] In addition to the more acute complications, birthing people who experience pregnancy onset hypertension have a two-fold increased risk of developing cardiovascular disease compared to women who have a normotensive pregnancy.[16] Additionally, birthing people who have blood pressure that resolves in the postpartum period are at higher risk for future development of chronic hypertension, and at a younger age of on-set.[17,18] Other long-term complications may include: stroke, coronary artery disease, heart failure, and chronic kidney disease.[19] Hypertension during pregnancy is also a leading cause of maternal morbidity and mortality, accounting for one third of deaths during delivery hospitalization, and the majority are related to pregnancy onset hypertension (**Figure 1.3**).[20]

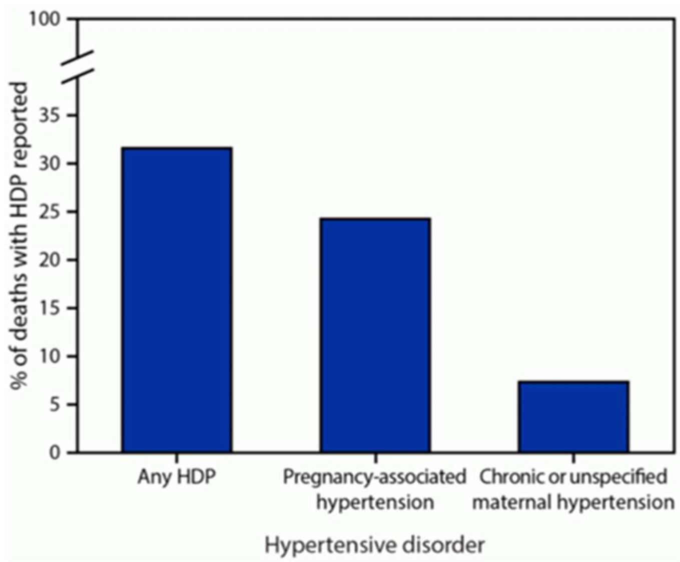


Figure 1.3. Hypertensive disorders of pregnancy mortality in 2009

Motivation for disentangling types

There is debate to whether gestational hypertension is a precursor for preeclampsia or if they are separate mechanisms, largely because the causes of these disorders are unknown despite acknowledgement of associated risk factors in the literature.[21] Due to the uncertainties in etiology, there is value in examining these types separately. Beyond etiologic differences, American College of Obstetrics and Gynecology have differences in treatment course depending on the hypertension type. For instance, the Task Force recommends antihypertensives to those with persistent high chronic hypertension or with a history of preeclampsia and there is low evidence that moderate chronic hypertension should not be treated with anti-hypertensives.[22] This can be compared to the recommendations for gestational hypertension, where there is stronger evidence to suggest not initiating antihypertensives unless the sustained blood pressure becomes severe, or the patient develops preeclampsia. Similarly, the recommendations for time to delivery change based on the hypertension type such that delivery at 37 weeks is suggested to resolve the condition.[22]

National and local surveillance of HDPs

Although the four types of hypertensive disorders of pregnancy are recognized with ICD-10 classification, national reporting has different specification such that a pregnancy is reported as "Prepregnancy hypertension", "Gestational hypertension" and "Eclampsia" if the women experience hypertension during the prenatal period. Prepregnancy hypertension is referring to chronic hypertension and gestational hypertension is an umbrella term for pregnancy onset hypertension and type of preeclampsia. To further complicate reporting, often in the literature chronic hypertension is excluded from the categorization of "hypertensive disorders of pregnancy" and the binary of "chronic" and "hypertensive disorders of pregnancy" is used to report prevalence statistics and for evaluation in research studies. The various definitions and categorizations create a challenge for disaggregation of types and summarizing literature.

An additional consideration for surveillance is that the diagnostic thresholds for hypertensive classification in pregnancy are currently different than the updated criteria from the American Heart Association (AHA) for non-pregnant persons. In 2017, the AHA determined that a systolic blood pressure of 130 mmHg and greater or a diastolic blood pressure of 80 mmHg and greater is considered "hypertensive" according to the updated criteria. Although the ACOG criteria still stands for pre-pregnancy and gestational hypertension, there would be a large difference in prevalence if the AHA 2017 criteria were to be adopted. Bello et al identified that the rate of hypertension in pregnancy overall would increase, in addition to changes in diagnosis from those previously considered de novo (gestational) during pregnancy would now be considered chronic hypertensive.[23]

Classification of HDPs vary depending on the reporting structure of the records, where birth certificate records often report gestational hypertension and preeclampsia in aggregate (separated into pre-pregnancy hypertension versus gestational hypertension) and hospital discharge records use the more discrete categories based on ICD-10 codes (four types). According to a recent Morbidity and Mortality Weekly Report (MMWR) from the Centers for Disease Control and Prevention (CDC), the rate of hypertension during pregnancy (chronic and gestational) was approximately 16% in 2019.[20] Hypertension occurring during pregnancy was more prevalent than chronic hypertension among pregnant women, such that chronic hypertension occurred in 2.3% of pregnancies and gestational in 13% of pregnancies.[20,24] Preeclampsia is less common than gestational hypertension and occurs in 5% to 7% of pregnancies.[25] There are concerning epidemiologic patterns in the distribution of HDPs over time and place. Trends data shows an increasing burden of HDPs in the US, which may be associated with advanced maternal age and increased burden of obesity.[26–29]

Markers of risk for hypertension in pregnancy

The risk factors for hypertension prior to pregnancy and onset during pregnancy tend to overlap because the presentation of high blood pressure exists in all four disorders, and they can be both clinical and demographic markers of risk. Even though the mechanisms of action are likely different, there are fewer documented differences in risk factors that what may be expected. For pre-pregnancy hypertension, risk factors include genetic or familial history, pre-gestational diabetes, kidney disease, systemic lupus erythematosus (SLE), having a high body mass index, smoking and alcohol use, stress, and older age. Pregnancy onset hypertension shares these risk factors and other examples include: advanced maternal age, multiple gestation, and experiencing an HDPs during prior pregnancy.[19]

Disparities in cardiovascular disease are well-documented in the literature, particularly for racial/ethnic minority populations in studies such as CARDIA, Multi-Ethnic Study of Atherosclerosis (MESA), and the Jackson Heart Study. The burden of cardiovascular disease is high among racial/ethnic minority populations across age groups, with hypertension being highly prevalent among Black individuals.[30] Findings from the CARDIA study suggest that among individuals younger than 35 years of age, the odds of hypertension onset were 5.08 (3.17-8.14) times greater for Black participants compared to White participants.[31] In the MESA study, the odds of treated but uncontrolled hypertension was 1.49 (1.19-1.84) times among Black participants compared to White participants.[32]

Disparities also exist in HDPs, such that minority individuals have higher rates of preeclampsia and pregnancy-related mortality compared to non-Hispanic White women.[33–36] A 10-year longitudinal study in New York identified that Black women and Hispanic women had higher rates of preeclampsia (3.2 per 100 hospitalizations; 2.9) compared to White women (1.8).[33] Previous studies suggest that the prevalence of both gestational and chronic hypertension is highest among non-Hispanic Black women, followed by non-Hispanic White and Hispanic women, with greater disparities existing among those with chronic hypertension.[36] The risk of HDPs among pregnancies in Florida found to be 1.42 times higher among African American women compared to non-African American women.[35] On a national scale, the prevalence of HDPs is the highest among Black women (20.9%) compared to other racial/ethnic groups.[20] Represented in the figure below (**Figure 1.4**), the graph depicts variation in the rates of gestational hypertension and chronic hypertension among racial/ethnic subgroups in 2018.[36] Studies have also examined the intersection of race and socioeconomic status (SES), finding that that Black women of lower SES are at higher risk for preeclampsia compared to White women and those of higher SES.[37] Describing and distinguishing social and geographic epidemiologic patterns among these disorders may provide more clues to disentangle drivers to better understand the HDPs.

The underlying structures (political, social, economic) that reinforce inequalities can be drivers of disparities in health outcomes. These disparities may be experienced through inequitable access to goods,

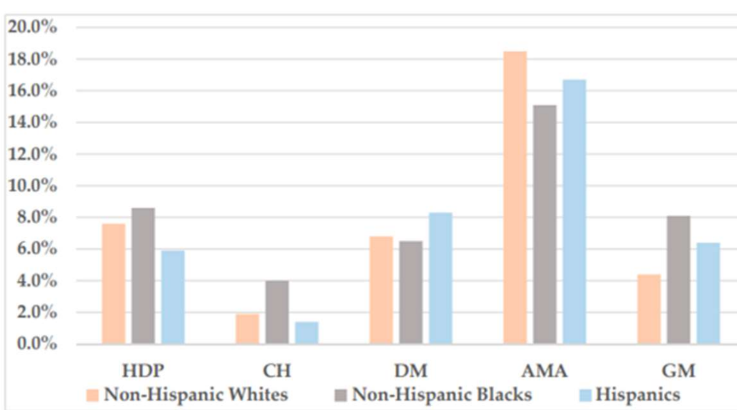


Figure 1. The prevalence of the pregnancy risk factors/complications in 2018, by racial/ethnic group. All of the differences between the racial/ethnic groups are statistically significant ($p < 0.001$).

Figure 1.4. Prevalence of pregnancy related risk factors and complications, 2018

services, housing opportunities, and other mechanisms of oppression.[38] The lack of resources, whether it be material goods or socioeconomic status , contributes to negative health outcomes for racialized and minoritized groups.[39] Race as a proxy for racism is considered to be a process of social stratification that results in inequities for the racialized and marginalized groups, often through poor resource allocation to individuals or areas that have high populations of marginalized individuals.[39] The production of racialized spaces means that the same place is not always experienced equally across race groups, here in reference to accessing and experiences with health care and resources.[39,40] Although focused on a slightly older population than women of child-bearing age, results from the MESA and Jackson Heart study suggest that lifetime perceived discrimination is associated with incident hypertension among Black individuals.[41,42] Differences in risk for pregnancy outcomes between White women and Black women were previously attributed to biology but the growing body of literature supports that the increase in risk is associated with access to health care, social inequities, and persistent stressors.[43] Using a framework for health equity, we can describe how social stratification can result in disparate outcomes through embodiment of constraints from the community environment (**Figure 1.5**).[44]

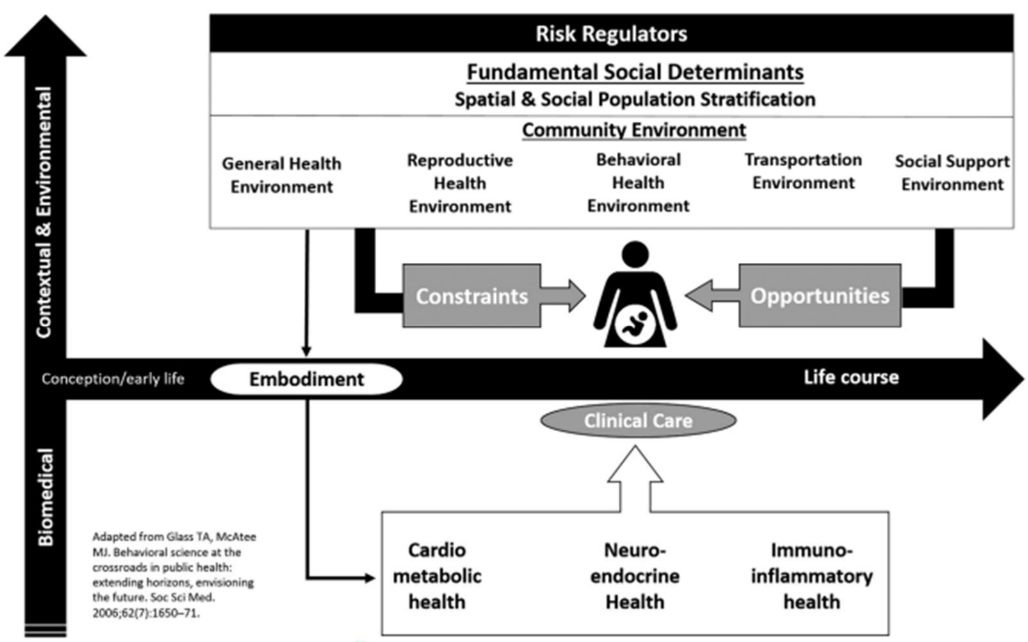


Figure 1.5. Health equity framework by Kramer et. al.

The role of "place" and health care access

Access to health care plays a large role in the prevention, diagnosis, and treatment of HDPs. The first point being that showing up to a healthcare provider only at delivery does not allow for adequate hypertension diagnosis because there is no previous blood pressure readings or diagnostic tests to reference to make a confident diagnosis. Additionally, more notes are important for continuity of care because a previous HDP increases the likelihood of another occurrence during the next pregnancy.[22] Access to prenatal care specifically can improve health outcomes through the relaying of pertinent health information such as nutritional recommendations, frequency of care, and social services.[45] We hypothesis that geographic access to care may play a role in how these disease manifest spatially because having enough providers, in a nearby location, and providing affordable healthcare can enable prenatal care visits.

Geographic disparities exist at both the state and regional level, such that states in the southern US had the highest prevalence of preeclampsia and gestational hypertension compared to other regions.[46,47] Additionally, there is state-level variability in the distribution of HDPs, after controlling for factors such as race/ethnicity.[46] Rural urbanicity is associated with higher maternal morbidity and mortality, where lack of access to health care contributes to rural-urban gaps in burden and not seeking healthcare prior to conception or early in the pregnancy may result in worst maternal-fetal outcomes.[48,49] Cameron et al identified the incidence of new-onset HDPs were higher in rural compared to urban areas in 2019 (rate ratio: 1.09; rural vs. urban), although the ratio is decreasing over time compared to estimates from 2007 (rate ratio: 1.31; rural vs. urban).[50] Lack of geographic access to hospitals and clinics, reduction in retail pharmacies, and sparse distribution of other place-based health facilities are documented in low resource areas.[51] Reduction in health access and opportunity for health is a culmination of place-based risk factors, such as neighborhood poverty, lower income/wealth, lower educational attainment, food deserts and elements of social cohesion.[52] Social and health resources are unevenly distributed geographically and identification of spatial patterns in HDPs both nationally and in Georgia may provide meaningful insight to decompose the epidemiology of the types of HDP.

Access to care is a critical component for providing and engaging in preventative care and disease management care. Health care capacity, population demand for care, and geographic impedance to care facilities play a role in the receipt of care for an individual or population.[53] An additional component to consider in the US is insurance status, due to the structure of public, private, and uninsured persons. Lack of coverage to seek providers and care can be a barrier if costs are too high out of pocket. Health care capacity encompasses the number of providers and infrastructure available to provide care in a region.[54] Population demand for care may be related to the age distribution of individuals because older persons may require more care than younger populations, or population density of the health care shortage area.[54]

Table 1.1. Five domains of access to care

Domain of Access to Care	Definition
Affordability	Determined by how the provider's charges relate to the client's ability and willingness to pay for services.
Availability	Measures the extent to which the provider has the requisite resources, such as personnel and technology, to meet the needs of the client
Accessibility	Refers to geographic accessibility, which is determined by how easily the client can physically reach the provider's location
Accommodation	Reflects the extent to which the provider's operation is organized in ways that meet the constraints and preferences of the client. Of greatest concern are hours of operation, how telephone communications are handled, and the client's ability to receive care without prior appointments.
Acceptability	Captures the extent to which the client is comfortable with the more immutable characteristics of the provider, and vice versa. These characteristics include the age, sex, social class, and ethnicity of the provider (and of the client), as well as the diagnosis and type of coverage of the client.

Geographic access is a function of social, economic, and political decisions about where resources should be located, and that low access places tend to also be places experiencing neighborhood poverty, lower income, lower educational attainment, food deserts and lack of social cohesion. Considering geographic impedance, access to care may not be limited to proximity, but also methods of transportation and resources to obtain care (monetary, childcare, insurance).

Despite the recognition that access to care has a role to play with cardiovascular outcomes, there are challenges in measuring "access" and capturing what component of access is related to HDPs. One way to conceptualize access to care is through Penchansky and Thomas' five A's of access to care (**Table 1.1**).[45] Each of the A's or domain refer to an aspect of "access to care", separating out geography, personnel, expense, and other components to define different constructs. Access to care can vary for both primary and specialist services. In the case of HDPs, primary care is necessary to monitor and diagnose high blood pressure pre-pregnancy to start with symptom management and ensure proper diagnosis. Aspirin use and 24-hour BP monitoring may be required to create a more stable condition for the mother when she is pregnant and to meet the diagnostic criteria to be considered hypertensive. Secondary care is essential to monitor disease progression, to allow for quick action to be taken if signs of end-organ disfunction arise or more severe manifestation such as new on-set headaches. We can consider timely secondary care as being important for diagnosis of preeclampsia if there are other signs than hypertension to avoid misclassification as gestational hypertension. Researchers take a variety of approaches to quantify individual and population health care access through the use of proxy measures.

Extending the knowledge base of geographic variation in HDPs

Previous studies have laid the groundwork for this dissertation by identifying geographic difference in disease burden at the state-level between types. Butwick et al showed states that are high prevalence in chronic hypertension are not always the same in gestational.[46] Walker et al provided insight that there is variation at the county level for sociodemographic characteristics hypothesize to be related to early-onset gestational hypertension and Hu et al proposed county level relative risk for gestational hypertension in Black birthing people were spatially structured in Florida.[35,55] These studies and other work highlighted the gaps in knowledge that this dissertation aims to fill, starting with the knowledge that variation in racial disparities at the county-level are not always highest for Black birthing people despite great disparities for other pregnancy outcomes like severe maternal morbidity.[35]

The goal of this dissertation is to use the study of geographic differences to enhance understanding in population patterns chronic and gestational hypertension separately and explore how various metrics for access to care may relate to burden of HDPs in the US and state of Georgia. In this dissertation we explore how geographic access to care may impact race/ethnic groups differently when considering the association with structural racism and socio-economic inequities. We highlight the Black-White disparity in burdens of HDPs through unequal resource allocation and forgone healthcare. Previous literature describes racial disparities in hypertension in large studies such as CARDIA, MESA, and the Jackson Heart study, and we can take an epidemiologic approach to determine how exploring the relationship among different race groups separately may indicate differing relationships with HDPs.

Using multiple data sources to assess the burden of HDPs allows for data quality assessment of birth certificate records compared to hospital discharge records in their identification of HDP cases. Additionally, using multiple spatial scales provide clues for differentiation of disorders based on place-based risk factors, such as access to care, and allow for modification of this association by race as a proxy for structural racism. We hypothesize that place-based exposures may be related to levels of HDP burdens, and this relationship may differ by race/ethnicity as a consequence of structural racism and by type of HDP. Disentangling types by contextual factors (place-based) and individual risk factors can guide future research to inform potential mechanisms for gestational hypertension through an exploratory and descriptive approach of geographic variation. This research is motivated by how chronic hypertension risk factors are often applied to the other instances of pregnancy onset hypertension, whereas we provide evidence to suggest there are differences in the risk factor distribution between hypertension types that would help explain the variability in burden of HDPs. This research adds to the existing literature by highlighting how geographic disparities in prenatal outcomes may differ depending on types of HDP and how the absence of care facilities may lead to higher rates of hypertensive disorders in these counties. We also highlight how HDPs are combined for surveillance and research studies, but they may ultimately be separate mechanisms and manifestations.

Specific aims

The overarching goal for this dissertation is to explore variation in the distribution of types of hypertensive disorders of pregnancy (HDPs) across geography, race, and measures of access to healthcare in the United States and Georgia.

Aim 1: Explore geographic distribution of counties with excess risk of HDP types to describe variation in disease burden in the US at the county level. We described county-level patterns of hypertensive disorder of pregnancy types and identified characteristics of counties with high burden using Bayesian spatial analysis to address challenges in small-area estimation.

Aim 2: Estimate the association between access to care and HDP types in the US, modified by maternal race/ethnicity. We examined whether area-based indicators of access to health care during pregnancy is associated with increased rates of chronic and gestational hypertension at the county-level. We explore whether living in low access (i.e. living in a rural area, having fewer providers per capita, and living in an area with a larger proportion of uninsured persons) is associated with higher rates of chronic and gestational hypertension and that measures of geographic access were more strongly associated with chronic compared to gestational hypertension.

Aim 3. **Estimate the association of small-area geographic access to care with varying data sources and spatial scales in Georgia.** We estimated the association of small-area (census tract and county) geographic access to care and HDP types in Georgia to explore how other spatial scales of access to care may be associated with higher rates of hypertension during pregnancy. We also compare reporting of linked hospital discharge records to birth certificate records with respect to chronic and gestational hypertension for validity and data quality concerns.

This dissertation underscores the questionability of combining hypertensive disorder of pregnancy types for surveillance and research, given their distinct geographic distributions and the variation in their relation to place-based characteristics. Accurate reporting of these types is important for research given there are unknowns about the etiology of gestational hypertension and being able to discern the types from chronic onset hypertension is valuable to disentangle potential markers of risk and drivers of pregnancy onset hypertension.

Data Sources

National Vital Statistics System (NVSS) Live Birth Records

For Aim 1, we use National Vital Statistics System (NVSS) Live Birth data from the National Center for Health Statistics to identify individuals ages 15 to 44 years who experience a live birth in the US between 2009 and 2019. These data compile birth certificate records at the state-level for the eleven-year period. The birth certificates provide socio-demographics and hypertension diagnosis for these pregnancies. To collect data on individual-level covariates (e.g. race, insurance status, county of residence, hypertension status, education, prenatal care), data were made available by request. NVSS records collapse hypertensive status into three categories: pre-pregnancy or chronic hypertension, gestational hypertension (gestational and preeclampsia), and eclampsia, instead of the four types previously described. For Aim 2, we use the same data and restrict the sample to non-Hispanic Black and non-Hispanic Women identify individuals ages 15 to 44 years who experience a live birth in the US between 2014 and 2019.

Georgia Birth Certificate Records and Hospital Discharge Records

For Aim 3, we link Georgia Birth Certificate Records and Georgia Hospital Discharge Records to create a cohort of women ages 15 to 44 who gave birth during 2014 to 2019. These data include information on socio-demographics and residential census tract for live births such as gestational age, age of the birthing person, race and ethnicity, and risk factors (i.e. chronic kidney disease, diabetes, multiparity). ICD-10 codes for HDPs will be extracted from Georgia hospital discharge records and linked to birth records to identify hypertension type and discharge diagnoses.[56] These codes classify the specific HDPs (chronic, gestational, preeclampsia, and chronic superimposed with preeclampsia) and catalog hypertensive status during and prior to pregnancy. We will be using the ICD-10 codes to identify chronic and gestational hypertension, defining gestational hypertension to include preeclampsia to be consistent with Aim 1 and Aim 2. Using birth records data from the Georgia Department of Public Health and hospital discharge records, we compiled linked hospital discharge data in Georgia to create a cohort for the study population with a smaller area unit for analysis (census tract) compared to the national data sample (county).

Health Resources and Services Administration (HRSA)

For Aims 2 and 3, we use the Health Resources and Services Administration (HRSA) data on physicians per capita and health care shortage areas. HRSA provides data which categorize geographic access to care with the Area Health Resource Files (AHRF) rate of physicians per 100,000 population. These data are released by the Bureau of Health Workforce annually. The data capture the number of active health care providers (MD or DO) at the county level. AHRF data from 2010 and 2017 at the county level will represent the active healthcare professionals during 2009 to 2019. We also extract the number of obstetric providers in each county to provide a measure of access to maternity care.[54] Similarly, HRSA provides data on Health Provider Shortage Areas (HPSA). The criteria for HPSAs are population-to-provider ratio, percent of population below 100% of the Federal Poverty Level, and travel time to the nearest source of care outside the HPSA designation area. Each area or facility is given a score from 0-25 based on the scoring criteria, and counties HPSAs are estimated based on the number of facilities qualifying as an HPSA. The classification can be determined as a “not an HPSA”, “partial HPSA”, or “full HPSA”.

American Community Survey (ACS)

For all the specific aims, area-level sociodemographic data (e.g. median household income, % insured, % racial/ethnic minority, urbanicity) were extracted from the 2015-2019 American Community Survey (ACS) 5-year estimates. The ACS is a yearly survey administered by the United States Census Bureau.[57] This publicly available survey data provides sociodemographic estimates at the county-level for Aim 1 to 3 and census tract-level for Aim 3.

2. Geographic Variation and Racial Disparities in Hypertensive Disorders of Pregnancy

Abstract

Introduction: Small area estimates of hypertensive disorders of pregnancy (HDP) and its component types (chronic hypertension, gestational hypertension, preeclampsia and eclampsia, and chronic hypertension with superimposed preeclampsia) are not readily available for county and local areas. Documenting local rates of these disorders are of interest for planning population health and clinical interventions, but generating statistically robust small area estimates can be difficult when local populations and event counts are small. We use Bayesian spatial analysis to address challenges in describing county-level patterns of HDP types and in identifying characteristics of counties with high burden.

Methods: We abstracted birth certificate data for births to individuals ages 15 to 44 years in the US between 2009 and 2019. We model counts of HDP types (chronic hypertension, gestational hypertension and preeclampsia) at the county-level via Poisson-Gamma Bayesian spatial model to estimate stable local rates of HDPs, account for spatial dependency, and identify counties exceeding the expectation of disease rates. We describe demographic and socioeconomic context based on county-specific measures to characterize counties identified as "high burden" (posterior probability of exceeding the third quartile of the national average) for each HDP.

Results: Among 42 million live births in 3,135 counties, gestational hypertension (inclusive of preeclampsia) rates were higher than expected in 519 counties. Chronic hypertension rates were higher than expected in 575 counties which were more commonly located in the southeastern US. The results revealed 202 counties exhibiting co-occurrence of high burden for both chronic and gestational hypertension, but more than 600 counties showed component type discordance. Contextual factors differed in counties with high-burden chronic hypertension compared to those without, whereas high-burden gestational hypertension was only weakly associated with racial density of counties and did not exhibit a clear correlation with rural-urban designation.

Conclusion: This study underscores the questionability of combining HDPs for surveillance and research, given their distinct geographic distributions and the variation in their relation to place-based characteristics.

Background

Hypertensive disorders of pregnancy (HDPs), which include chronic hypertension, gestational hypertension, preeclampsia, and chronic hypertension superimposed with preeclampsia, are a group of conditions that are important contributors to maternal and feto-infant morbidity and mortality.[6] In the US, they are a leading cause of maternal mortality, with almost one-third of maternal deaths during delivery hospitalization including a HDP diagnosis.[20] The component types of HDP are differentiated based on timing of hypertension onset and the presence or absence of end-organ disfunction, although there is opportunity for misclassification if healthcare is not accessible prior to or early in pregnancy.[56] This continues to be a contemporary issue and trends data show an increasing burden of HDPs nationally, which may be associated with more people having pregnancies later in life (advanced maternal age) and increased burden of obesity.[26–29] In 2017, there was an estimated 1.9% of pregnancies complicated by chronic hypertension and 6.5% for gestational hypertension in the US.[46]

Geographic disparities in the burden of HDPs exist at both the state and regional level, such that states in the southern US have the highest prevalence of preeclampsia and gestational hypertension compared to other regions.[46,47] The underlying structures (political, social, economic) that reinforce inequalities can be drivers of disparities in health outcomes. For instance, rurality is associated with higher maternal morbidity and mortality, where lack of access to health care likely contributes to rural-urban gaps in burden because not accessing healthcare prior to conception or early in the pregnancy may result in worse maternal-fetal outcomes, such as incident HDPs.[48–50] Lack of geographic access to hospitals and clinics, reduction in retail pharmacies, and sparse distribution of other place-based health facilities are documented in low resource areas.[51] Processes of social stratification result in inequities for minoritized groups, often through poor resource allocation to individuals or areas that have high populations of marginalized individuals.[39] This could have a downstream effect on the national scale causing inequalities in disease burden. This has been shown in other studies using hospital discharge records, where they determined the prevalence of HDPs is the highest among Black women (20.9%) compared to other racial/ethnic groups.[20] Social and health resources are unevenly distributed geographically and identification of spatial patterns in HDPs both nationally and in Georgia may identify which social and health resources are driving HDP inequities among chronic and gestational hypertension.

Aside from exploring HDPs overall, there is value in exploring the types separately instead of in aggregate. Despite acknowledgement of associated risk factors shared by chronic and gestational hypertension, the causes that distinguish these separate conditions are unknown. There is value in examining these types separately due to etiologic uncertainties and to plan population health and clinical interventions such that the types of intervention strategies for these at the population level and the clinical level would vary substantially. Primary chronic hypertension is often attributable to multi-factorial contributors such as genetics or lifestyle factors such as poor diet and sedentary behavior, while less is known about gestational hypertension and preeclampsia. Descriptive spatial analysis of HDP types may uncover distinct spatial patterns of each, which could generate hypotheses for additional causes of these disorders. Further, the distribution of local area rates of different HDP types could inform the development of place-based interventions.

Although there are state-level estimates of HDP burden, sub-state analysis of separate types of HDPs are not readily available. Local health data (e.g., data for census tracts or counties) are important for documenting geographic disparities and tailoring public health programs and policies to the needs of specific communities. Despite their utility, generating statistically robust small area estimates can be a difficult undertaking when population size and numbers of events are small. One solution is to employ Bayesian spatial methods to smooth rates for each geographic unit toward a weighted average of the observed rate of its adjacent neighbors based on the amount of data available in the neighboring regions. The goals of this study are 1) to describe sub-state and race-specific patterns of HDP types, 2) to identify convergent or divergent population patterns in relation to HDP types, and 3) to explore area-level characteristics of counties with excess risk compared to other counties with less disease burden. We examined spatial patterning between gestational and chronic hypertension with the goal of locating and describing these high-burden counties independently for each HDP. We identified statistically high rates of HDPs in the US at the county-level, stratified by race/ethnicity.

Methods

Study population

National Vital Statistics System (NVSS) Live Birth data from the National Center for Health Statistics (NCHS) was abstracted to identify individuals ages 15 to 44 years who experienced a live birth in the US between 2009 and 2019. These data are a compilation of individual birth certificate records from each state, which include socio-demographics and hypertension diagnosis for each pregnancy. The birth certificates data are used to calculate county-level hypertension rates with the number of births with a hypertension diagnosis contributing to the numerator, and the total number of births in the county contributing to the denominator. The NVSS provided individual-level covariate information (e.g. race, insurance status, county of residence, hypertension type, education) upon request. Birth records were excluded if the hypertension type was unknown or the individual experienced eclampsia without chronic or gestational diagnosis.

Outcome estimation

Birth certificate records collapse hypertensive disorders into three categories: chronic hypertension (i.e., diagnosis pre-pregnancy or before 20 weeks' gestation), gestational hypertension (inclusive of both gestational and preeclampsia), and eclampsia - this study focused on the first two types. Individuals who experienced eclampsia without a chronic or gestation hypertension diagnosis were excluded from the analysis. The counts of HDP type at the county-level during the 11-year period provided the observed outcome values for a Bayesian spatial model with a Queen contiguity neighbor matrix, which is used to estimate more stable rates of HDPs and to account for spatial dependency. Counties with less than 50 births are suppressed to account for instability in rate estimation.[58]

From the Bayesian spatial models, we abstracted the median rate from each county's posterior distribution and use the resulting credible intervals to draw conclusions about the estimates and their likelihood of being high by chance or if they are consistently high rates. To visualize the geographic distribution of estimates, we use the median (50^{th} percentile) of each county estimates to describe general trends. We use exceedance probabilities from the Bayesian posterior distribution to identify the highest burden counties. The exceedance probability is the likelihood that the credible interval lower bound from the posterior distribution exceeds the predefined value of the overall median county-level rate of the HDP type. We define exceedance as if we were to do 1,000 posterior draws from each estimated distribution, counties where there is 80% probability (at least 800 of the 1000 draws) that the posterior lower credible interval exceeds 73 per 1,000 live births for gestational hypertension and 24 per 1,000 for chronic hypertension was considered "high burden". HDP threshold determination for exceedance was made by selecting the 75th percentile of the counties with stable estimates to take a data-driven approach, in this case 7.3% and 2.4% of births. We identified whether there is concordance or discordance for each county's designation as "high burden" for each HDP type, to further explore how geographic burden may differ between chronic and gestational hypertension. HDP rates were estimated for all race/ethnic groups for the overall models.

In addition to the overall models, race-specific HDP rates were estimated for Non-Hispanic White and Non-Hispanic Black live births. We also explored the stratification of Black and White birthing people to investigate non-Hispanic Black-White differences in chronic and gestation hypertension burden. Given the population distribution of Black individuals, we focused on states in the Southeastern US to compare smoothed estimated rates of HDPs to Black and White birthing people. We chose these race groups to emphasize the legacy of racism and disproportionate disenfranchisement of Black people, and to address sample size concerns with less populous minoritized groups. While we recognize the importance of research among these subgroups, we were unable to calculate stable race-specific HDP rates for these populations among smaller racial and ethnic groups. Future research is needed to tailor the study designs to address their unique challenges.

Contextualization of high-burden counties

To characterize similarities or differences between counties identified as "high burden" for each HDP compared to the counties not identified as excess risk, we described their demographic and socioeconomic context based on county-specific covariates. The 2015-2019 American Community Survey (ACS) 5-year estimates were used for area-level sociodemographic data, (e.g. median household income, % insured, % racial/ethnic minority, urbanicity). The ACS is a yearly survey administered by the United States Census Bureau.[57] Once the counties were identified, county-level socio-demographic commonalities were assessed to explore possible place-based risk factors.

Statistical Analysis

Following a spatial Bayesian framework, we used integrated nested Laplace approximation (INLA) to estimate the county-level prevalence of each HDP. Using INLA with Besag-York-Mollie priors, Poisson-Gamma models estimate the county-level rates of chronic hypertension and gestational hypertension. Bayesian approximation methods smooth the data and account for unstable rates resulting from the low prevalence of the individual HDP types and small population sizes while addressing statistical dependence of neighboring counties. To provide more precise estimates, models are adjusted for age, account for fixed effects for state, include a temporal random effect for year, and include spatial random effects to account for spatial dependence between counties and to borrow statistical information from neighbors**.** We are using individual models to calculate county-level rate of gestational hypertension among all live births and chronic hypertension among all live births. These multi-level models were used to estimate geographic heterogeneity in HDP burden to describe counties that have meaningfully different burden from the national average rate for gestational and chronic hypertension burden. We classified counties with a lower bound of the estimated credible interval that was higher than the national average HDP rate (chronic: 2.4%; gestational: 7.3%), as having higher than expected rates of chronic or gestational hypertension.

For contextualization of the high-burden areas, we stratified counties as high-burden or not high-burden for each type and compare the differences in demographic and socioeconomic characteristics. We explore the association with the following covariates from ACS: urbanicity, percent unemployment, median household income, percent below the poverty-level, percent uninsured, percent without high school degree, percent of the population that identifies as Black, and percent of the population that identifies as White, report average percents for the counties in each stratum of risk (high vs. not-high).

Results

We identified 43,100,403 live births in the US between 2009 and 2019 for 3,135 counties. There are eight counties excluded from the smoothed analysis due to small number of births. Excluded counties were almost entirely non-metropolitan areas and had smaller populations of Black individuals (3.4%) compared to those that were included (9.4%) in the analysis. Characteristics of the census regions are included in **Table 2.1**. The South census region has the highest burden for most of the HDP markers of risk, including the greatest percentage of unemployment, poverty, percent uninsured, and educational attainment. Compared to the other census regions, the South also has the greatest percent of both chronic and gestational hypertension (2.3%; 6.5%). For individual level characteristics, many births were without a HDP diagnosis (93%), and there is a slight increase in prevalence of chronic and gestational hypertension in the oldest age category (35 to 44 years) (**Table 2.2**). The prevalence of gestational hypertension increased with multiple gestation (11% vs 5%). Among those included in the study sample, the trend in rate of hypertension type increased over time among both Black and White birthing people (**Figure 2.1**).

Table 2.1. Descriptive characteristics of US counties by Census Region

Table 1. Descriptive characteristics of US counties by Census Region

	Census Region			
Variables (N (%); % (SD); Mean (SD)	**Northeast**	**South**	**Midwest**	**West**
Number of counties	217	1419	1054	444
Excluded counties	*0*	*3*	*1*	*4*
Non-metropolitan counties	87 (40.1)	827 (58.3)	752 (71.3)	303 (68.0)
Percent Unemployment	3.3 (0.8)	3.6 (1.4)	2.7 (1.4)	3.4 (1.8)
Median Household Income (US dollars)	61,994 (15,393)	47,294 (13,801)	53,491 (9,960)	55,677 (15,122)
Percent below the poverty-level	12.2 (3.8)	18.4 (6.6)	13.1 (5.4)	14.6 (5.8)
Percent Uninsured	6.1 (2.5)	12.2 (4.7)	7.8 (4.5)	10.7 (5.2)
Percent without High School degree	9.9 (3.3)	16.9 (6.0)	10.2 (4.4)	11.2 (6.0)
Percent Black population	5.4 (6.8)	16.9 (18.2)	2.5 (4.6)	1.3 (1.9)
Gestational hypertension	5.2 (1.5)	6.5 (2.0)	6.1 (1.7)	5.8 (2.0)
Chronic hypertension	1.8 (0.51)	2.3 (1.1)	1.6 (0.7)	1.3 (0.8)

Footnotes: Counties are excluded if there are less than 50 births from 2009-2019 (N=8)

Figure 2.1. Trend analysis of hypertensive disorders of pregnancy for Black and White Birthing people

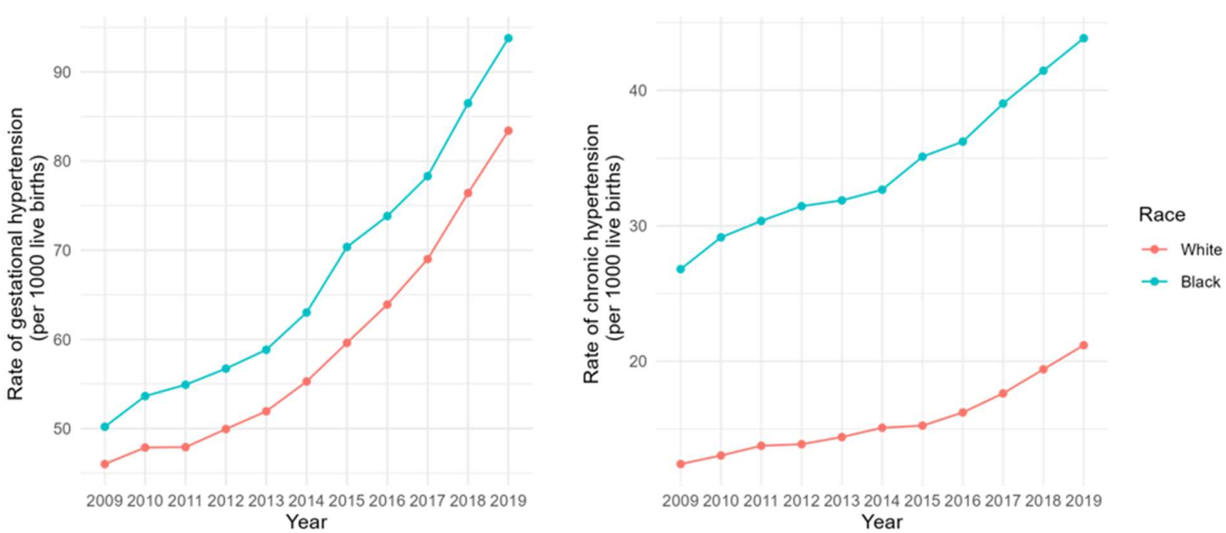


Figure Note: Figure 1a shows the race-stratified rate of gestational hypertension for non-Hispanic Black and Non-Hispanic White birthing people from 2009-2019. Figure 1b shows the race-stratified rate of chronic hypertension for non-Hispanic Black and Non-Hispanic White birthing people from 2009-2019.

Table 2.2. Sample Characteristics of Birthing People by Hypertension State during Pregnancy

Table 2. Sample Characteristics of Birthing People by Hypertension State during Pregnancy				
Variable	Total	No Hypertension diagnosis	Gestational	Chronic
	43,100,403	39,911,659 (93%)	2,348,058 (5%)	840,686 (2%)
Age (years)				
15-24	12,393,351	11,524,478 (93%)	657,925 (5%)	210,948 (2%)
25-34	23,870,339	22,180,206 (93%)	1,271,343 (5%)	418,790 (2%)
35-44	6,836,713	6,206,975 (91%)	418,790 (6%)	210,948 (3%)
Race/Ethnicity				
White	21,248,869	19,591,581 (92%)	1,272,687 (6%)	384,601 (2%)
Black	8,034,437	7,463,937 (93%)	424,602 (5%)	145,898 (2%)
Other	1,594,339	1,525,013 (96%)	52,779 (3%)	16,547 (1%)
Hispanic	11,048,351	10,352,313 (94%)	544,099 (5%)	151,939 (1%)
Unknown	335,573	320,567 (96%)	10,408 (3%)	4,598 (1%)
Education				
Less than High	5,391,719	5,079,823 (94%)	235,436 (4%)	76,460 (1%)
High School	9,787,792	9,066,106 (93%)	553,634 (6%)	168,052 (2%)
College/Associate degree	18,599,082	17,150,065 (92%)	1,117,095 65%)	331,922 (2%)
Advanced degree	4,276,423	3,995,263 (93%)	219,677 (5%)	61,483 (1%)
Unknown	4,206,553	3,962,154 (94%)	178,733 (4%)	65,666 (2%)
Insurance				
Medicaid	16,272,212	15,097,465 (93%)	884,639 (5%)	290,108 (2%)
Private	18,579,162	17,168,599 (92%)	1,105,284 (6%)	305,279 (2%)
Self-pay	1,595,753	1,527,796 (96%)	53,730 (3%)	14,227 (1%)
Other	1,670,266	1,553,638 (93%)	87,799 (5%)	28,829 (2%)
Unknown	4,144,176	3,905,913 (94%)	173,123 (4%)	65,140 (2%)
Plurality				
Singleton	40,810,582	38,003,351 (93%)	2,140,520 (5%)	666,711 (2%)
Twin	1,402,090	1,210,018 (86%)	156,838 (11%)	35,234 (3%)
Triplet or higher	2,948	2,447 (83%)	367 (12%)	134 (5%)
Unknown	45,949	37,595 (82%)	6,850 (15%)	1,504 (3%)
Marital Status				
Unmarried	16,094,864	14,878,005 (92%)	921,845 (6%)	295,014 (2%)
Married	24,814,358	23,105,400 (93%)	1,315,010 (5%)	393,948 (2%)
Missing/Unknown	1,352,347	1,270,006 (94%)	67,720 (5%)	14,621 (1%)
Rurality				
Micropolitan	36,534,733	33,989,741 (93%)	1,953,136 (5%)	591,856 (2%)
Metropolitan	5,726,836	5,263,670 (92%)	351,439 (6%)	111,727 (2%)

Adjusted county-level gestational hypertension ranged from 5 to 157 per 1000 live births (median 60 per 1000) compared to 1 to 73 per 1000 live births (median 17 per 1000) for chronic hypertension. Modeled rate-estimates of HDPs for the 11-year period are displayed in **Figure 2.2**. Gestational hypertension was estimated to be high in pockets of the southeastern US and in the Ohio valley region (**Figure 2.2a**), although generally did not follow the concentrated high-burden areas like chronic hypertension in the southern US (**Figure 2.2b**). Using the exceedance probabilities, gestational hypertension rates were higher than expectation in 519 counties, specifically in parts of Arizona, Louisiana, Alabama, and Kentucky, highlighted in **Figure 2.2c**. Chronic hypertension rates were higher than expectation in 575 counties and are more consistently located in the southeastern US (**Figure 2.2d**). Of these high-burden areas, 202 were co-located for both chronic and gestational hypertension although over 600 counties were discordant (**Figure 2.3**). Counties with high burden chronic hypertension rates (high burden group) were more likely be in non-metro areas (67%), have a higher proportion of residents below the poverty rate (21%) and have a higher percentage of Black residents (22%) compared to those without (**Table 2.3**).

Table 2.3. Context of high-burden counties for gestational and chronic hypertension

Table 3. Context of high-burden counties for gestational and chronic hypertension

	Gestational		Chronic	
Variable	**Not High-burden**	**High-burden**	**Not High-burden**	**High-burden**
N counties	2347	521	2355	512
Number of Non-metropolitan counties N (%)	1400 (59.7)	318 (61.0)	1372 (58.3)	345 (67.4)
Percent Unemployment (SD)	5.2 (2.1)	5.5 (2.5)	5.1 (2.0)	5.9 (2.7)
Median Household Income (IQR)	52668.4 (14188.2)	47895.5 (11414.2)	53759.4 (13721.7)	42799.9 (10466.3)
Percent below the poverty-level (SD)	15.4 (6.2)	17.5 (6.7)	14.7 (5.6)	20.6 (7.4)
Percent Uninsured (SD)	10.1 (5.1)	9.8 (5.0)	9.8 (5.1)	10.9 (4.1)
Percent without HS degree (SD)	13.2 (6.1)	14.8 (6.1)	12.7 (5.9)	16.9 (5.8)
Percent Black (SD)	9.3 (14.5)	10.8 (15.6)	6.8 (10.7)	22.4 (21.9)

Footnote: High-burden counties are defined by the exceedance probabilities calculated from a posterior probability distribution

Figure 2.2. Smoothed estimated rates for gestational and chronic hypertension with exceedance probabilities, 2009-2019

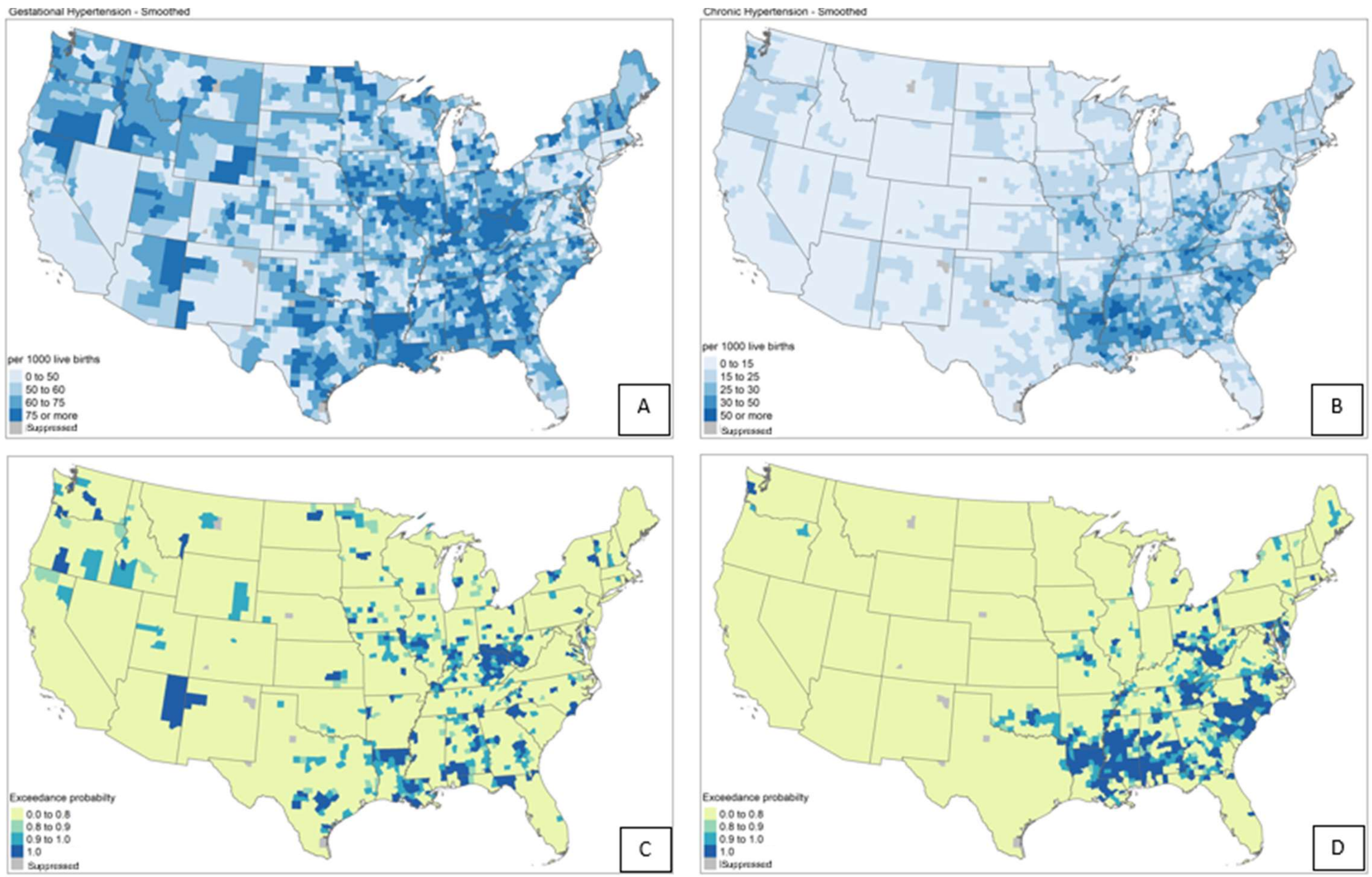


Figure Note: Figure 2a-b represent the estimated smoothed rates for gestational (2a) and chronic (2b). Figure 2c-d show the probability of a county's lower posterior credible exceeding the national average for each subtype (gestational: 2c; chronic: 2d). Maps includes the continental US for simplicity – Alaska and Hawaii available in the supplements.

Figure 2.3. Concordance of high-risk gestational and chronic hypertension at the county-level

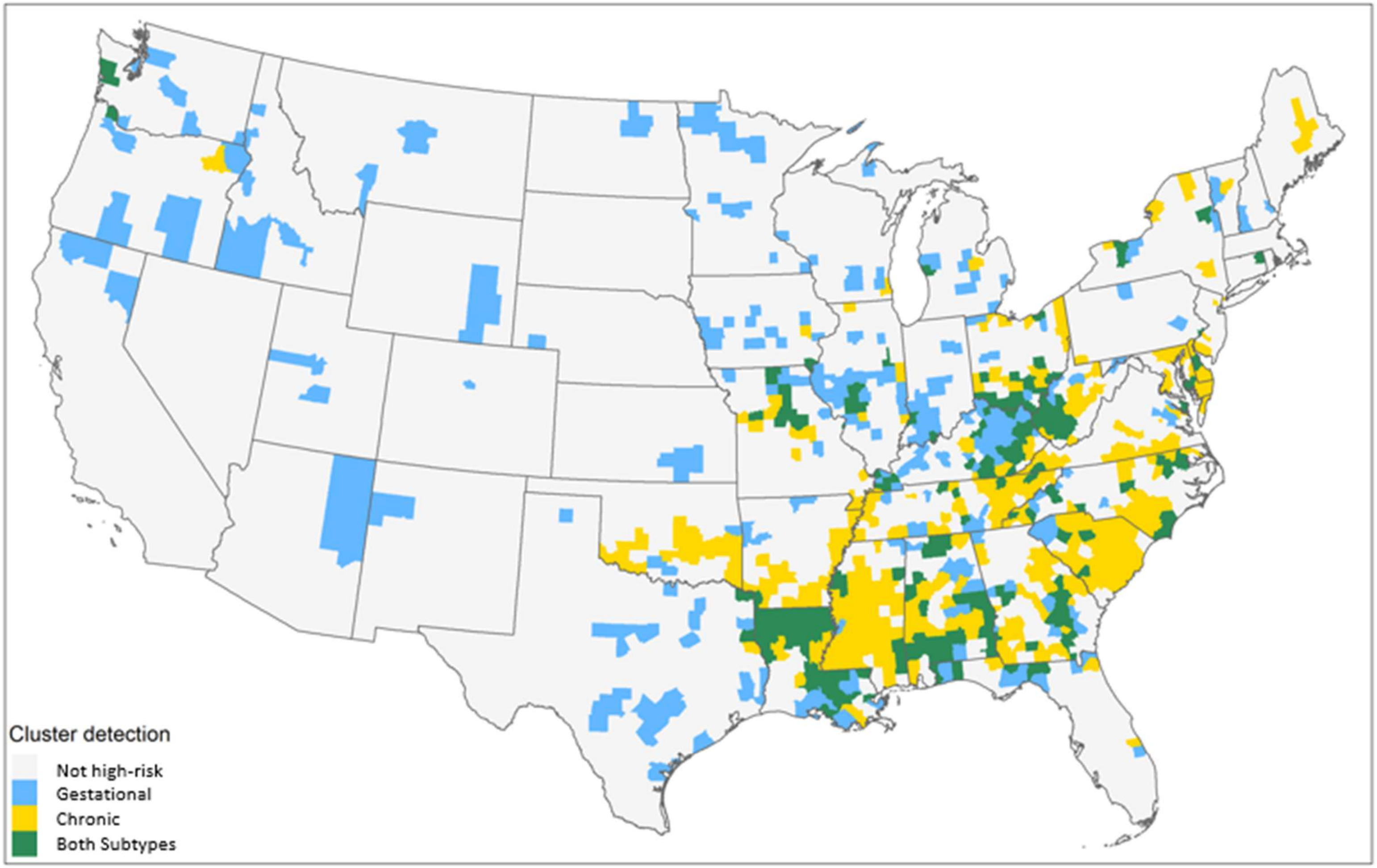


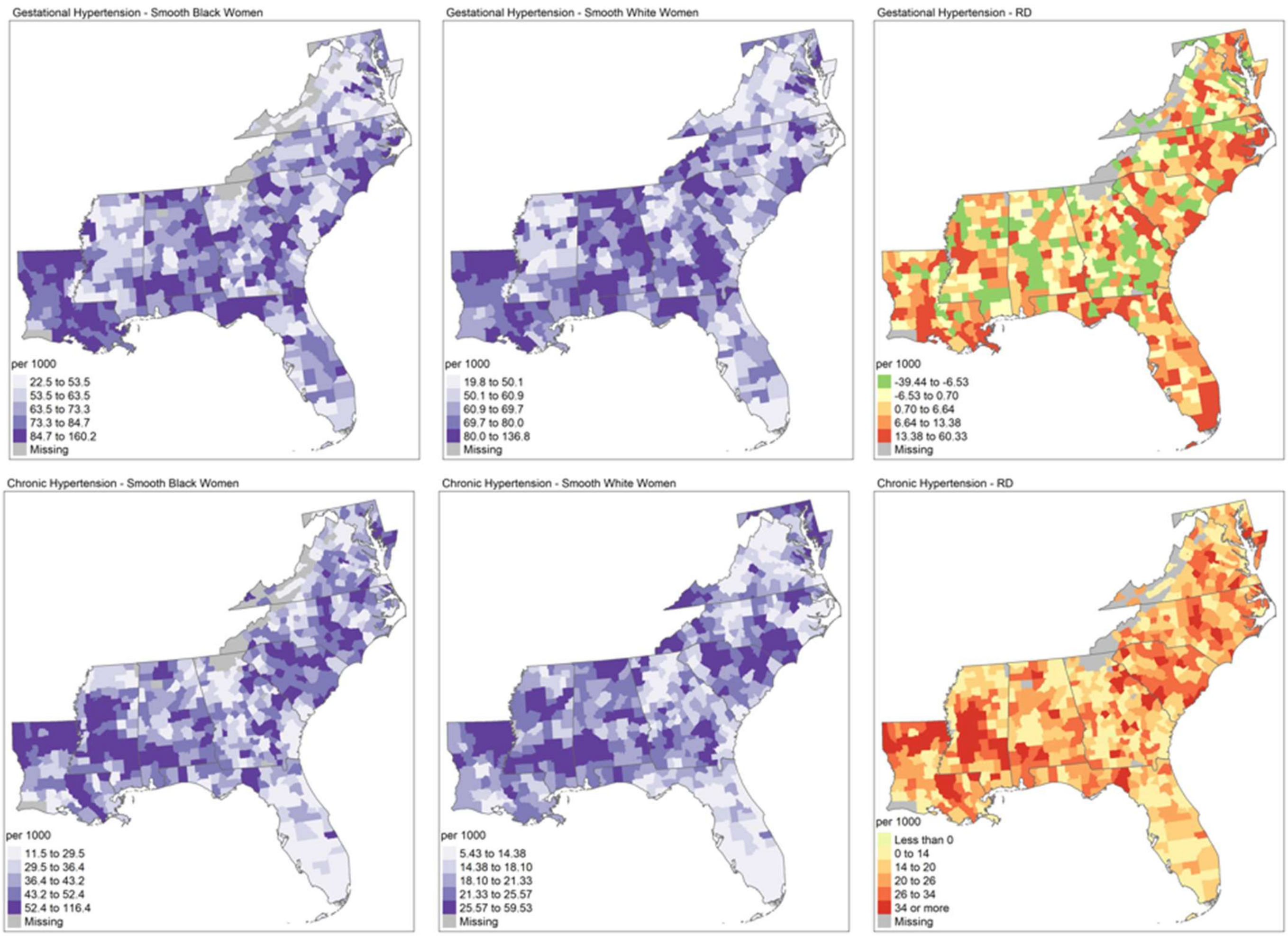
Figure Note: High-risk counties defined by posterior probabilities of exceedance

In contrast, counties with high burden gestational hypertension rates were only weakly associated with racial density of counties, based on the proportion of Black individuals, and did not exhibit a clear correlation with rural-urban designation. Race-stratified maps show the rates of gestational and chronic hypertension for Black and White birthing people in addition to the absolute rate difference between NHB and NHW (**Figure 1.4**). We focus on counties in the Southeast because of sparse data for Black populations in other regions of the US. Figure 1.4a and 1.4b show similar magnitude and geographic patterning for Black and White individuals who experience gestational hypertension. Similarly, Figure 1.4d and 1.4e show similar counties with higher rates of chronic hypertension, but the magnitude is higher for Black birthing people. For overall prevalence of hypertension types, Black birthing people had higher burden of chronic (34 per 1,000 births) and gestational hypertension (64 per 1,000) compared to White counterparts (17 per 1,000; 63 per 1,000). The largest disparities exist for chronic hypertension, where in almost every county there are excess cases for Black compared to White individuals, some in excess of 34 cases per 1,000. This is compared to gestational hypertension, where there is more variability in which race group presented as the having a higher rate of HDP such that counties with an excess of HDP for White compared to Black individuals are represented in every state.

Discussion

This research addresses county-level disparities in HDP, focusing on chronic and gestational hypertension (inclusive of preeclampsia) types. Using Bayesian spatial modeling techniques, we provide stable rates at the county level and identify areas that are higher than expected in disease burden when compared to the national average. The results show differences in high burden areas between hypertension types, showing evident discordance in geographic burden beyond what we previously hypothesized. This work demonstrated that chronic hypertension is more related to common place-based risk factors compared to gestational hypertension high burden areas. Racial density high burden counties also did not follow the same pattern between hypertension types, where disparities were more evident for

Figure 2.4. Race-specific rates of chronic and gestational hypertension in the Southeastern US.



chronic hypertension for Black birthing people. This may suggest that chronic and gestational hypertension are not spatially and contextually connected based on this national sample.

Previous literature on variation in HDPs have mostly covered larger geographic areas, such as states or regions, or explored state-specific county-level rates. Butwick et al investigated state-level variation of hypertensive disorders in 2017 using median odds ratios for each state and found notable clustering for eclampsia, but not other HDPs.[46] They reported prevalence of chronic hypertension as 1.9% and 6.5% for gestational hypertension, which were similar to the overall rates of this study. Our methods expand upon this research by employing spatial Bayesian methods to be able to explore county-level rates across10 years of data, which showed an increase in prevalence of both chronic and gestational hypertension over time among Black and White birthing people. Similar to Butwick et al, we found less clear patterns for gestational hypertension, but we did see strong clustering of chronic hypertension in the Southeast. Hu et al used data from 2005-2014 to conduct a Bayesian spatio-temporal analysis at the county-level for the state of Florida to examine racial disparities in HDP, using similar methodology to this study with relative risks and exceedance probabilities.[35] They saw disparities in rate of HDPs between Black and White birthing people at the county-level, particularly clusters in the "Big Bend" region of Florida. This region is also highlighted in our analysis as having a high rate of chronic and gestational hypertension, in addition to one of the larger rate differences between Black and White birthing people. One difference is Hu et al excluded pre-pregnancy (chronic) hypertension so our study can extend the knowledge base by expanding the analysis to include racial disparities in chronic hypertension. Tanaka et al used data from New York state (1993-2002) to look at specific HDP types and the relation with poverty among strata of race/ethnicity.[33] The relationship between race/ethnicity and HDPs held such that minoritized populations had greater prevalence of HDPs, even after stratifying by poverty level. In the southeastern US, we also found that chronic hypertension is more burdensome among non-Hispanic Black birthing people. However, the areas that have higher rates of chronic hypertension tend to be high for both Black and White birthing people, highlighted by the maps in Figure 1.4. We found gestational hypertension is more similar in magnitude for Black and White birthing people although the absolute difference varies across the counties in the Southeastern US. This is unlike chronic hypertension where it is universally higher for Black birthing people in almost all counties.

Gestational hypertension rates are more stable across counties and do not appear to be strongly associated with the county characteristics we identified that tend to be associated with other adverse health outcomes.[59,60] Alternatively, chronic hypertension is more spatially clustered and associated with the county characteristics we would expect based on other literature.[59] When utilizing exceedance probabilities, findings reveal that chronic and gestational hypertension high-burden areas are not co-located in the many of counites in the US, and they have a different risk profile such that chronic hypertension is more strongly related to measures of place-based sociodemographic characteristic. More spatial clustering of chronic hypertension than with gestational hypertension may indicate a stronger association with place-based markers of risk. Supported by the race-stratified models and rate differences, chronic hypertension is consistently higher among Black birthing persons, and this suggests an association that may be attributable to structural racism lending to worse health outcomes among Black birthing people. The overall and race-stratified spatial patterns of gestational hypertension are less clear, which is unexpected based on the shared risk factors for chronic and gestational hypertension. Major lifestyle factors for chronic hypertension (e.g., poor diet, inclusive of diets high in sodium and in saturated fat and processed foot; sedentary lifestyle) may be more related to place (e.g., food deserts, built environment). Gestational hypertension may be less related to place and more about the individual-level clinical risk factors (e.g., maternal age, parity, multi-fetal pregnancy, presence of other chronic conditions such as diabetes mellitus and kidney disease) but there is more to explore with sociodemographic characteristics and HDPs.

People with gestational hypertension are at greater risk for developing hypertension later on in their life course, but not everyone with gestational hypertension develops hypertension after pregnancy while chronic hypertension continues to persist.[46] This suggests there may be more complicated mechanisms separating the two types and there is benefit in parsing out incongruent markers of risk. Other potential drivers of HDPs to consider are air pollution, access to health care, individual markers of risk, structural racism and discrimination pathways, genetics[61,62], and SES[27]. We may also consider hypothesized markers of risk such as trauma[63], nutrition[64], and sleep disorders[65], which may be less influenced by "place". Additionally, this research emphasizes the importance of considering types and geographic nuances in understanding and addressing hypertensive disorders of pregnancy, such that chronic hypertension follows the expected patterns based on other cardiovascular health outcomes, but other factors might be driving gestational hypertension.

Strengths and limitations

One strength of this analysis is the use of spatial Bayesian methods to handle smaller area estimates. Bayesian analysis presented solutions for not only identifying counties, but also utilizing the posterior distributions for exceedance probabilities. There are various challenges to overcome with conducting spatial analyses, including defining appropriate areal units, determining the method for identifying clusters or areas with excess burden, and considerations of small area analysis when there are low case counts. This manuscript expands on previous studies by including Bayesian modeling techniques to estimate more precise rates on a set of outcomes to account for these challenges. The benefit of using the Bayesian smoothing methods addresses the concerns with unstable rate estimates, given the constraints of the data and allows for a reduction in random error introduced by sparse data and improvement in stability when compared to an unsmoothed estimate.[66] Additionally, we identified areas of excess burden at the more granular county level, where previous studies have focused on particular states or aggregated to a larger areal unit. Our study extends this research by including the entire US and estimating contextual factors associated with these "high-burden" counties. There is value in comparing the high burden areas of chronic and gestational hypertension separately to disentangle where place-based associations may differ between the types. We described patterns in context (i.e., county-level social determinants) for births that occur within versus outside of specific areas of excess burden using the specified models.

For this analysis, there are concerns of data quality for HDP specification on birth certificate records for the national data. We note that there are differences between reporting of national hospital discharge records and birth certificate data. According to Ford et al, the rate of hypertension during pregnancy was approximately 16% in 2019 and the rate of hypertension varied between component types such that chronic hypertension occurred in 2.3% of pregnancies and gestational hypertension occurred in 13% of pregnancies.[20,24] Although the rates for chronic hypertension appear to be similar, there is an under reporting of gestational hypertension in the vital statistics compared to hospital discharge records.[67] There is a potential for misclassification among types, particularly if the individual does not have frequent interactions with the healthcare systems prior to or early in pregnancy. Another limitation to address is the change in reporting of chronic hypertension over the study period. In 2017, the American Heart Association classifications for hypertension was revised to include a lower threshold for being considered hypertensive but this did not change the American College of Obstetrics and Gynecology reporting for gestational hypertension. Our paper does not address the consideration that the definitions of chronic hypertension are changing over time to include “less severe” blood pressure readings to be classified as hypertensive, but other studies have suggested that the new criteria is associated with an increased risk of developing an HDP.[68] An additional limitation is the NVSS data uses categories for HDPs (chronic, gestational, eclampsia) other than the four types that are detailed in clinical guidance. Although this distinction limits disentangling preeclampsia from gestational hypertension, there is still benefit in the examination of chronic and gestational hypertension for discordance due to the nature of surveilling these disorders. Our intention to explore Black-White disparities in HDPs suffers from small numbers issues in counties with low birth rate or small case load so we chose to focus on the southeastern US in lieu of using the full national sample. One alternative is to combine data from adjacent geographic units – e.g., combining counties into states as it will have a similar effect with respect to the reliability of the estimates, but it will also preclude users from conducting inference on geographic disparities at finer spatial resolutions. Lastly, fetal loss, a competing risk for hypertensive disorders, may introduce bias because women who are hypertensive have greater chances of maternal and fetal mortality and they would be excluded from the live births. We are not using a database that includes still births because hypertension readings may be difficult to obtain depending on time in gestation. If the still birth occurs early in the pregnancy, a diagnosis of gestational hypertension or worsening to preeclampsia or eclampsia will be missed. We expect that limiting to live births data will underestimate the true burden of HDPs because HDPs are a leading cause of stillbirths.

In summary, we found chronic hypertension is more related to “place” such that even among race-strata, there are counties in the US that remain “high” in disease burden. This work adds to the existing literature by highlighting how place-based disparities in prenatal outcomes may extend to chronic hypertension but not gestational hypertension, and how county characteristics may lead to higher rates of hypertensive disorders in these counties. This work has more granularity in terms of spatial resolution and case ascertainment compared to previous studies and suggests the value of considering spatial scale in estimating disease burden. We also highlight how chronic and gestational hypertension are often combined for surveillance and research studies, but they may ultimately be separate mechanisms and manifestations. Reporting is critical to estimate burdens of these disorders to be able to plan and provide appropriate population health and clinical resource before, during, and after pregnancy[69,70] Future directions of this work will include conducting a bias analysis using validation studies in ICD-10 codes and birth certificate records and examination of the high burden areas of eclampsia to learn more about which counties may have more complications with unmanaged preeclampsia.[56,71]

3. Measures of Geographic Access to Healthcare and Disparities in Hypertensive Disorders of Pregnancy

Abstract

Introduction: The underlying social structures that reinforce inequalities can be drivers of racial and geographic disparities in maternal and child health outcomes. Health disparities may be a consequence of inequitable access to care and other mechanisms of oppression. The lack of resources, whether it be material goods and services or socioeconomic status, contributes to negative health outcomes for racialized and minoritized groups. Despite the recognition that access to care has a role to play with cardiovascular outcomes, there are challenges in measuring “access” and capturing which components of access is related to hypertensive disorders of pregnancy. The study's objective is to examine whether access to health care is associated with increased rates of chronic and/or gestational hypertension at the county-level.

Methods: We abstracted birth certificate data for births to individuals ages 15 to 44 years in the US between 2014 and 2019. We estimate the association of four measures of access to healthcare and HDP types (chronic hypertension, gestational hypertension and preeclampsia) separately by maternal race at the county-level via Poisson-Gamma Bayesian spatial models. The measures of access include physicians per capita, rural-urban continuum codes, percent of the population uninsured and health provider shortage areas.

Results: Spatial models showed rates of chronic hypertension and access to health care measures were significantly higher in areas of low access compared to greater access. The county rate of gestational hypertension was not as related to place-based measures of access to care. Race-specific models showed that Black birthing people had higher rates of chronic hypertension Black birthing people presented with a stronger association between rates of chronic hypertension and all low access to care measures.

Conclusions: These findings suggest that living in low access (i.e. living in a rural area, having fewer providers per capita, and living in an area with a larger proportion of uninsured persons) is associated

with higher rates of chronic hypertension and these associations are stronger among Black birthing people.

Background

Hypertension during pregnancy is a leading cause of maternal morbidity and mortality in the United States.[6,20] The onset of hypertension may be prior to conception (chronic hypertension) or after 20 weeks gestation (gestational hypertension/pregnancy-induced hypertension).[6,72] The markers of risk for these hypertensive disorders of pregnancy (HDPs) are often shared between types, despite the differences in etiology of disease onset. Markers of risk may include individual factors, such as body mass index or advanced age of the birthing person, or more systemic factors such as accessibility of health care facilities or structural racism and discrimination.[19,73,74]

Access to healthcare is a critical component for providing and engaging in preventative care and disease management. Healthcare capacity, population demand for care, and geographic barriers to care facilities play a role in the receipt of care for an individual or population.[53] Individual and average insurance status may also shape service accessibility and availability. Individual lack of insurance coverage can be a barrier to care seeking if out of pocket costs are too high. Area-based health care capacity, including the number of providers and infrastructure available to provide care in a region, [54] may be related to the population payor status and age distribution of individuals, or population density of the health care shortage area.[54] Geographic access to healthcare services is a function of social, economic, and political decisions about where resources should be located. Low access places tend to also be places experiencing neighborhood poverty, lower income, lower educational attainment, food deserts and lack of social cohesion. Considering geographic impedance, access to care may not be limited to proximity, but also methods of transportation and resources to obtain care (monetary, childcare, insurance).[75] Access to care matters to be able to see a provider and have the proper treatment course before and after pregnancy, in addition to becoming diagnosed with any hypertensive state. Proper treatment can reduce preeclampsia risk, low birthweight, and other adverse outcomes with monitoring and use of low-dose aspirin to control blood pressure.[76]

The underlying structures (political, social, economic) that reinforce social inequalities can be drivers of racial, economic and geographic disparities in maternal and child health outcomes. These disparities may be experienced through inequitable access to goods, services, housing opportunities, and other mechanisms of oppression.[38] The lack of resources, whether it be material goods or socioeconomic status, contributes to negative health outcomes for racialized and minoritized groups.[39] Individual race may be conceived of in part as a proxy for the experience of racism, and a process of social stratification that results in inequities for the racialized and marginalized groups, often through differential resource allocation to individuals or areas that have high populations of marginalized individuals.[39] This social stratification can result in some areas (e.g. racially segregated) having different resources than others, or the same place may be experienced in distinct ways according to racial identity as a result of the racialization of experience in places, here in reference to access and experiences with health care and resources.[39,40] Differences in risk for pregnancy outcomes, including hypertensive disorders, between White and Black birthing were previously attributed to race-specific biologically essential traits, but most evidence links racial differences in outcomes to socially patterned differences in access to health care, other life course opportunities, perceived discrimination, and chronic stressors.[41–43]

Despite the recognition that access to care has a role to play with cardiovascular outcomes, there are challenges in measuring "access" and capturing what component of access is related to HDPs. One way to conceptualize access to care is through Penchansky and Thomas' five A's of access to care (*availability*, *affordability, accessibility, accommodation,* and *acceptability*).[45,77] Each of the A's or domains refers to an aspect of "access to care", separating out geography, number of health care personnel, expense, and other components to define different constructs. There are a variety of approaches to quantify individual and population health care access using proxy measures, and ultimately measuring access to care has many complexities that require evaluation.[78] The study's objective is to examine whether access to care during pregnancy is associated with increased rates of chronic and gestational hypertension at the county-level. We hypothesized that individuals living in counties with more physicians and in full access to care regions will have lower rates of chronic and gestational hypertension compared to individuals with reduced access to care.

Methods

Study population

We used National Vital Statistics System (NVSS) Live Birth data from the National Center for Health Statistics to identify individuals ages 15 to 44 years who experience a live birth in the US between 2014 and 2019. These birth certificate records are available at the county-level for the six-year period and provide socio-demographics and hypertension diagnosis for these pregnancies. Individual-level covariates (e.g., race, county of residence, hypertension type, plurality), data were made available by request. The cohort included women in the US who are (1) 15 to 44 years of age (2) identify as Non-Hispanic Black (NHB) or Non-Hispanic White (NHW) and (3) experience a live birth from 2014 to 2019. We chose to focus on differences between NHW and NHB birthing people because there are large and persistent disparities in maternal and child health outcomes and there is substantial geographic distribution of both NHW and NHB births. Describing HDP outcomes among other racial and ethnic groups is important, although beyond the scope of the current study.

Outcome

NVSS records collapse hypertensive disorders during pregnancy into the following categories: pre-pregnancy or chronic hypertension, gestational hypertension (including both gestational and preeclampsia), and eclampsia. This study focuses on the variation between chronic and gestational hypertension. Individuals who experienced eclampsia without indication of either chronic or gestation hypertension diagnosis were excluded from the cohort. The counts of HDP type at the county-level during the 6-year period provided the observed outcome values for a Bayesian spatial model with a Queen contiguity neighbor matrix, which is used to estimate more stable rates of chronic and gestational hypertension, accounting for spatial dependency. Counties with less than 25 births are suppressed to account for instability in rate estimation.

Exposure measurement

To understand the relationship between HDP types and having access to healthcare, we consider four different proxy measures of health care access at the county level, two continuous and two categorical measure: 1) primary care physicians per 100,000 population, and 2) Health Provider Shortage Areas, 3) Percent uninsured population, and 4) Rural-Urban continuum codes. The number of physicians per 100,000 population is extracted from 2017-18 HRSA Area Health Resource Files. Providers as classified as any physician (MD or DO) that provides primary or obstetric care. The Health Resources and Services Administration (HRSA) uses scoring criteria to identify geographic areas with healthcare shortage. The criteria are population-to-provider ratio, percent of population below 100% of the Federal Poverty Level, and travel time to the nearest source of care outside the HPSA designation area. Based on scoring, designated each county is designated as “not an health provider shortage area”, “partial shortage area”, or “full shortage area”. Data from the American Community Survey (ACS) 5-year estimates were extracted to capture the percent of individuals who were uninsured from (2014 to 2018). This dimension of access to care may be a fiscal approximation of affordability to receive care from a provider. An additional measure of access that is common in the literature is distinction between rural and urban regions.[50] Studies have shown that residents in rural communities have to commute further to receive care compared to urban residents, in addition to having more severe workforce shortages.[48,79] We will use metro and non-metro designations for each county using the 2013 Rural-Urban continuum codes.

Each of these four measures target a different combination of Penchansky and Thomas’s five A’s of access to care.[77] The providers per capita can be described as measure of *availability*, capturing the number of personnel in the county that are able to provide care. The HPSA measure touches on *availability*, *affordability,* and *accessibility* through the criteria of population-to-provider ratio, percent of population below 100% of the Federal Poverty Level, and travel time to the nearest source of care outside the HPSA designation area. Using Rural-Urban continuum codes, we describe *accessibility* and *availability* of health care access. ACS data of percent uninsured will explore the percent of individuals in the county that are without health insurance, capturing *affordability.*

Covariates

Individual-level covariates (e.g. race, age) were available from NVSS records by request and we chose to adjust models for age, year of birth, and state of residence. Analyses were stratified by race because we recognize that the social production of racialized spaces means that the same place is not always experienced equally across race groups, here in reference to access and experiences with health care and resources. Therefore, we will evaluate if the magnitude of the association between healthcare access proxies and HDP varies between race groups. This feature of the analysis may touch on the *acceptability* component of the five domains of access to care because in addition to racialized differences in opportunity and experience, there may also be differences in how acceptable given services are based on race due to history of discrimination in those places.[74]

Statistical Analysis

In this analysis, we were using four different exposure measures to estimate how each metric is associated with each HDP outcome. Using a spatial Bayesian framework, integrated nested Laplace approximation (INLA) estimates the county-level rate ratio for HDPs comparing across levels of health care access. Poisson-Gamma models with Besag-York-Mollie priors estimate the county-level rates of chronic hypertension and gestational hypertension. These models are adjusted for age, account for fixed effects for state, include a temporal random effect for year, and include a spatial random effect to account for spatial dependence between counties. Continuous exposures are modeled as changes in one standard deviation increments to aid interpretation. For analytic models, we used one standard deviation as an increment of change to better interpret the rate ratios for physician per capita and percent uninsured population.

For more descriptive results of the county-level distribution of exposure, we split exposure measures (% uninsured and PCP ratio) into tertiles and define rural-urban into three categories to compare with the three HPSA categories for descriptive analyses. Exposures are mapped to display geographic placement of "high", "mid", and "low" access for each county, conducted to describe the county level variation occurring between measures of health care access. We use tertile of the continuous measures and three categories of Rural-Urban (urban, suburban, rural) to emphasize potential colocation of low access. Counties were given a score from 0 to 4 depending on if they were considered "low access" on none of the measures or up to all four of the measures.

Results

There were 15,113,108 live births included in the cohort from 2014 to 2019, 7% of which were cases of gestational hypertension and 2% were chronic hypertension. Both chronic and gestational hypertension prevalence are higher among the older age category (35 to 44), Black birthing people, and higher plurality. Other notable differences include the increase in prevalence in gestational and chronic hypertension with multiple gestation (13%; 4%). Black birthing people comprised 21% of the births overall (**Table 3.1**).

Results of the Poisson models showed that these measures of healthcare access do not appear to be strongly associated with rate of gestational hypertension except for a few bordering estimates. For providers per capita, there is a marginal protective effect of increased providers resulting in reduction in county-level rate for gestational and chronic hypertension (aRR: 0.98, CI: 0.97, 0.99) (**Table 3.2**). For rurality, counties in non-metro areas tend to have higher rates of chronic hypertension compared to metro areas for the adjusted model, despite no effect in the unadjusted model (aRR:1.07, CI: 1.04, 1.11).

Table 3.1. Descriptive statistics for cohort, 2014-2019

Table 1. Descriptive Statistics				
Variable	Total	No Diagnosis	Gestational	Chronic
N	15,113,108	13,729,356 (91%)	1,054,282 (7%)	329,470 (2%)
Age (years)				
15-24	3,580,663	3,283,321 (92%)	252,560 (7%)	44,782 (1%)
25-34	9,004,999	8,205,694 (91%)	611,640 (7%)	187,665 (2%)
35-44	2,527,446	2,240,341 (89%)	190,082 (8%)	97,023 (4%)
Race/Ethnicity				
Black	3,231,391	2,857,946 (86%)	250,602 (8%)	122,843 (4%)
White	11881927	10,446,192 (88%)	803,696 (7%)	206,629 (2%)
Gestational Diabetes				
Yes	820069	662,697 (81%)	111,855 (14%)	45,517 (7%)
No	14,270,526	13,044,740 (91%)	941,950 (7%)	283,836 (2%)
Missing	22,513	21,919 (97%)	477 (2%)	117 (1%)
Insurance Payor				
Medicaid	5,658,074	5,119,383 (90%)	392,157 (7%)	146,534 (3%)
Private	8,354,677	7,586,665 (91%)	604,320 (7%)	163,692 (2%)
Self-pay	452,994	431,532 (95%)	16,629 (4%)	4,833 (1%)
Other	535,102	487,319 (91%)	35,358 (7%)	12,425 (3%)
Missing	112,261	104,457 (93%)	5,818 (5%)	1,986 (2%)
Plurality				
Singleton	14,548,122	13,257,836 (91%)	978,940 (7%)	311,346 (2%)
Twin or more	548,692	458,735 (84%)	72,518 (13%)	17,439 (4%)
Missing	16,294	12,785 (78%)	2,824 (17%)	685 (5%)
Parity				
1st	5,769,220	5,125,508 (89%)	530,519 (9%)	113,193 (2%)
2nd	4,935,085	4,554,601 (92%)	280,518 (6%)	99,966 (2%)
3rd or more	4,352,011	3,995,740 (92%)	240,885 (6%)	115,386 (3%)
Missing	56,792	53,507 (94%)	2,360 (4%)	925 (2%)
Marital Status				
Single	5,455,032	4,904,241 (90%)	408,748 (7%)	142,043 (2%)
Married	9,222,222	8,418,869 (91%)	621,648 (7%)	181,705 (2%)
Missing	435,854	406,246 (93%)	23,886 (5%)	5,722 (1%)
Body Mass Index				
Underweight	480,943	463,021 (96%)	15,461 (3%)	2,461 (1%)
Normal	6,497,473	6,167,960 (95%)	279,244 (4%)	50,269 (1%)
Overweight	3,717,510	3,389,519 (91%)	263,397 (7%)	64,594 (2%)
Obese	4,017,208	3,345,327 (83%)	470,178 (12%)	201,703 (6%)
Missing	399,974	363,529 (91%)	26,002 (7%)	10,443 (3%)

Table 3.2. Rate ratio estimates of county level measures of access to care and hypertensive disorders of pregnancy

Table 2. Rate ratio estimates of county level measures of access to care and hypertensive disorders of pregnancy				
Effect measure: Rate ratio with 95% CI	Gestational		Chronic	
Exposure	Rate ratio	Adjusted rate ratio	Rate ratio	Adjusted rate ratio
PCP Ratio Increase of one standard deviation in providers per capita	**0.98 (0.97, 0.99)**	**0.98 (0.97, 0.99)**	0.99 (0.98, 1.00)	**0.97 (0.95, 0.98)**
Rurality Non-Metro vs. Metro	0.98 (0.96, 1.00)	0.98 (0.96, 1.01)	1.02 (0.99, 1.05)	**1.07 (1.04, 1.11)**
% Uninsured Increase of one standard deviation of uninsured percent	0.97 (0.96, 1.00)	**0.97 (0.95, 0.98)**	1.00 (0.98, 1.02)	**1.04 (1.01, 1.06)**
HPSA No Shortage	ref	ref	ref	ref
HPSA Partial Shortage	1.00 (0.97, 1.03)	1.00 (0.97, 1.03)	1.04 (1.00, 1.08)	**1.05 (1.01, 1.10)**
HPSA Full Shortage	1.00 (0.97, 1.03)	1.00 (0.97, 1.03)	**1.07 (1.01, 1.12)**	**1.11 (1.06, 1.17)**
Footnotes. Models are adjusted for year, age, state. Effect measures are rate ratio with 95% CI.				

There are diverging patterns for increasing rates of percent uninsured population, where a one standard deviation increase in proportion of uninsured persons is associated with increased rates of chronic hypertension for the adjusted models (aRR: 1.04, CI: 1.01, 1.06), but a slight protective effect for gestational hypertension (aRR: 0.97, CI: 0.95, 0.98). Lastly, the HPSA shortage categories were associated with higher county level rates of chronic hypertension when comparing areas of no shortage to partial and full shortage areas with the greatest association for full shortage areas.

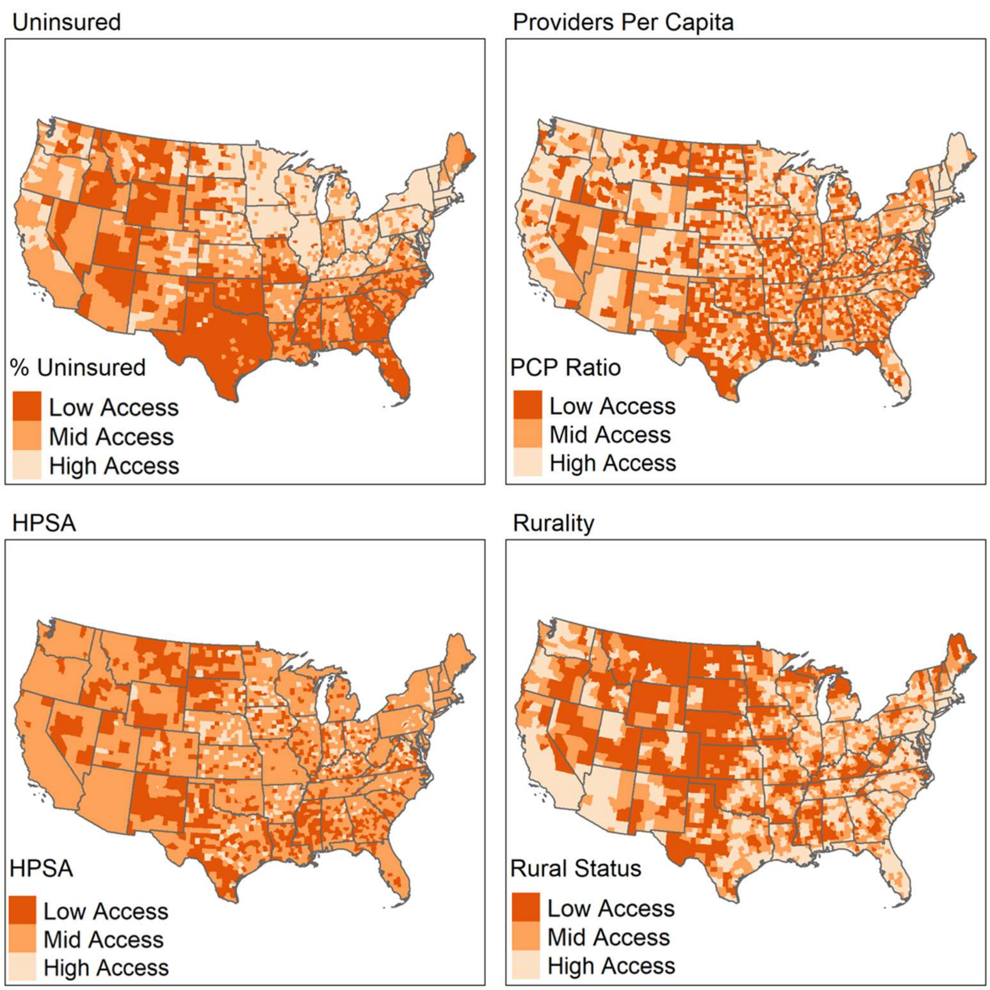
Results of the race-stratified models were similar to overall models. Across all strata and hypertension type, there is a marginal decrease in county rate of chronic and gestational hypertension compared to counties with fewer providers. There were not strong associations for county level rates of gestational hypertension among any of the other access to care measures regardless of race, other than a slight protective effect of living in a county with higher uninsured populations among White birthing people (aRR: 0.97, CI: 0.95, 0.98). Rurality, percent uninsured, and HSPA provided an assocation for Black birthing people and rates of chonic hypertension where rates among Black birthing people in non-metro counties were higher compared to births in metro counties (aRR: 1.17, CI: 1.12, 1.22), in counties with higher percent uninsured populations, and in full and partial HPSA shortage areas. Results among county level rates of chronic hypertension for White birthing people followed the same trends (Rurality RR: 1.07, CI: 1.04, 1.11). Among the overall models and for White birthing people, there was a slight protective effect for lower rates of gestational hypertension for counties with greater percent uninsured populations (overall adjusted RR: 0.97, CI: 0.95, 0.98) (**Table 3.3**).

Table 3.3. Rate ratio estimates of county level measures of access to care and hypertensive disorders of pregnancy

Table 3. Rate ratio estimates of county level measures of access to care and hypertensive disorders of pregnancy								
	Black Birthing People				White Birthing People			
Effect measure: Rate ratio with 95% CI	Gestational		Chronic		Gestational		Chronic	
Exposure	Unadjusted RR	Adjusted RR	Unadjusted RR	Adjusted RR	Unadjusted RR	Adjusted RR	Unadjusted RR	Adjusted RR
PCP Ratio Increase of one standard deviation in providers per capita	**0.97 (0.95, 0.98)**	**0.97 (0.95, 0.98)**	**0.93 (0.91, 0.95)**	**0.94 (0.92, 0.96)**	**0.98 (0.97, 0.99)**	**0.98 (0.97, 0.99)**	0.99 (0.98, 1.01)	**0.97 (0.95, 0.98)**
Rurality Non-Metro vs. Metro	1.01 (0.98, 1.04)	1.00 (0.97, 1.03)	**1.18 (1.13, 1.24)**	**1.17 (1.12, 1.22)**	0.98 (0.96, 1.00)	0.98 (0.96, 1.01)	1.01 (0.99, 1.05)	**1.07 (1.04, 1.11)**
% Uninsured Increase of one standard deviation of uninsured percent	1.00 (0.97, 1.02)	0.98 (0.96, 1.01)	**1.15 (1.11, 1.19)**	**1.14 (1.10, 1.19)**	**0.97 (0.96, 0.99)**	**0.97 (0.95, 0.98)**	1.00 (0.98, 1.02)	**1.04 (1.01, 1.06)**
HPSA No Shortage	*ref*	*ref*	*ref*	*ref*	*Ref*	*ref*	*Ref*	*ref*
HPSA Partial Shortage	0.97 (0.93, 1.01)	1.01 (0.97, 1.05)	1.06 (0.99, 1.14)	**1.10 (1.04, 1.16)**	1.00 (0.96, 1.03)	1.00 (0.97, 1.03)	1.04 (1.00, 1.08)	**1.05 (1.01, 1.10)**
HPSA Full Shortage	1.01 (0.96, 1.07)	1.05 (1.00, 1.10)	**1.34 (1.23, 1.45)**	**1.27 (1.18, 1.36)**	1.00 (0.97, 1.03)	1.00 (0.97, 1.03)	**1.07 (1.02, 1.12)**	**1.11 (1.06, 1.17)**

Using three category measures of exposure access (high, mid, low), we were able to highlight how similar constructs of low access to care do not necessarily equate to the same geographic areas. **Figure 3.1** shows there is heterogenity between counties and between proxy measures when we compared the “low access” to “high acess” areas. Each of these four measures serve as proxy measures for components of health care access. Texas and the southeastern US have pockets of low access on multiple metrics while the Northeast has sparse areas of low access among all measures of access to healthcare.

Figure 3.1. Exposure measures of access to care using tertile measures



Discussion

This study identified how measures of geographic access to care are differential in their relationship with hypertensive disorder of pregnancy types. We explored whether access to health care is associated with increased probability of chronic and gestational hypertension considering the heterogeneity of components to define the construct of "access to care", captured by selected components of the five A's (Affordability, Availability, Accessibility, Accommodation, Acceptability).[45] The takeaway from these metrics is that they are all measures either related to or used as a proxy to indicate place-based access to health care, but there is variablity in the characterization of place and showed discordance in places considered low access. In addition, we described how social stratification can result in disparate outcomes by exploring these relationships among Black and White birthing people separately. We found that measures of geographic access were more strongly associated with chronic hypertension compared to gestational hypertension. These findings suggest that living in low access (i.e. living in a rural area, having fewer providers per capita, and living in an area with a larger proportion of uninsured persons) is associated with higher rates of chronic hypertension.

We hypothesized that counties with more physicians per capita would be related to lower rates of chronic and gestational hypertension because of greater availability for appointments and more providers to serve a community. In the case of HDPs, primary care is necessary to monitor and diagnose high blood pressure pre-pregnancy to start with symptom management and ensure proper diagnosis. Aspirin use and 24-hour BP monitoring may be required to create a more stable condition for the mother when she is pregnant and to meet the diagnostic criteria to be considered hypertensive. Secondary care is essential to monitor disease progression, to allow for quick action to be taken if signs of end-organ disfunction arise or more severe manifestation such as new on-set headaches.[22] We can consider timely secondary care as being important for diagnosis of preeclampsia if there are other signs than hypertension to avoid misclassification as gestational hypertension. We acknowledge that this was a weak association and there may be additional factors at play. Both primary and specialist services are needed for caring for the complex conditions in pregnancy, so provider type may be more important and number of OBGYNs may be better measure or incorporating other disciplines such as nurse practitioners and midwifes could be more representative. Additionally, the presence of nearby providers means that geographically there are greater opportunities to see a physician, but having a physician in the area does not mean that it is equitable for every person that lives in the area.[51]

For the analytic models, the two dimensional measure of rurality shows the population distribution of residents in each state, where we could hypothesize that smaller populations of individuals may indicate fewer hospitals and care facilities, or longer distances to cover to receive care. Access to health care in rural areas was significantly associated increased burden in chronic hypertension but was not associated with gestational hypertension. The null findings for gestational model were surprising because pregnancy outcomes such as severe maternal morbidity have been shown to be associated with greater incidence in among rural populations.[48] This may suggest that gestational hypertension may be less associated with the constraints of "place" and may be more related to individual risk factors (Aim 1), or that the US is too heterogenous in areas considered metro versus non-metro.[80] Among Black birthing people, counties in rural settings had higher rates of chronic hypertension and this could be due to embodiment of constraints from the community environment and the intersectionality of racial discrimination and living in a non-metro county.[44,50]

Living in an area of high uninsured population often goes along with other aspects of resource deprivation. Individuals with public insurance or no insurance face the challenge of finding not only a place to receive care, but also a facility that takes the payment they are able to offer. Although the lack of findings or opposite of what we would expect occurred for gestational hypertension, it may be an issue of ecological fallacy where an individual's insurance payor may be more associated with the health outcome instead of the place, or it may simply not be a good predictor.[81] It is also possible that the national level association introduces too much heterogeneity for insured and uninsured populations, such that low insured places may also be unique communities such as reservations, remote locations, or even urban areas, all of which are facing their own health challenges. Therefore we may lose variation or see unexpected results by summarizing over national counties. Another consideration may be to focus solely on women of reproductive age instead of a population approach to include the whole county in the denominator of who can be uninsured.

Health provider shortage areas are a conglomerate of multiple measures of access used in this study, such as patient to provider ratio, but adds a component of poverty and geographic distance. It was surprising to see that HSPA designation did not appear to be related to burden of gestational hypertension, given factors such as socioeconomic status and neighborhood deprivation are contributors to disease prevalence.[82] Similar to rurality, we see strong effects of chronic hypertension and living in a full or partial HPSA designation. Areas with higher minority populations are more likely of losing health care facilities, which may contribute to this association being stronger among Black birthing people.[51]

Strengths and limitations

We take robust approach to considering access to care with multiple measures situated in a conceptual framework. Using the five domains of access to care, we identify measures of access to care that address differing aspects of the "access" framework such as accessibility, availability, and affordability. The examination of the signal and magnitude of the association between each access measure and HDP subtype can provide some insight into if the measures have similar or differing relationships and explore if certain domains have a larger association, therefore providing further evidence for where we can intervene. Additionally, we use a Bayesian spatiotemporal framework to stabilize rate estimates and allow for variability between counties. This allows for smaller area of analysis and uses surrounding counties to inform issues of small numerators and denominators. Also, we take a more ecologic approach identifying rates of HDPs as they relate to access may suggest a community-informed model versus physician centered may provide an approach to mitigate poor maternal and fetal health outcomes resulting from hypertension during pregnancy.[83] Although access to care has also been explored as an intermediate between other social determinant of health exposures and birth outcomes, such as preterm birth, we explored access to care as the exposure that may be modified across race groups.[84]

This study has a few limitations to note. There is the chance that those with greater access may be disproportionately represented or more accurately in the hypertension group because access to care may be associated with probability of diagnosis with a hypertensive disorder or misclassification of diagnosis. Individuals who do not have contact with the health care system prior to pregnancy may not be screened for hypertension before their prenatal visit and they may not return for care post-partum. This could make it challenging to make an accurate diagnosis and the concern is access to care could be associated with reporting bias. Although this is a limitation, gestational hypertension is recorded after 20 weeks of pregnancy, so there is a window of time for a pregnant person to have contact with the healthcare system in order to have a blood pressure reading. Misclassification may also be related to higher volume of healthcare and imbalanced coverage of documentation may also be related to access. Also, we consider the use of proxy variables to measure the exposure and modifier definitions, including access to care and race as a proxy for structural racism. In this work, we used insurance status and HPSA categories to represent having access to care, as well as using race/ethnicity as a proxy for racism and lived experience. Although they are not direct measures of the constructs, they are available in the data sources we were leveraging for the analyses, and they have been used in prior literature to examine similar relationships. For example, the presence of nearby providers means that geographically, there are greater opportunities to see a physician, but having a physician in the area does not mean that it is equitable for every mother that lives in the area. Additionally, the provider per capita measure includes MDs or DOs but excludes other primary or obstetric providers who could support patient care with more nurses, midwife, or others - or be limited in specialty providers that may be needed such as nephrologists or cardiologists. Another limitation to note is diagnostic criteria for these subtypes diverged in 2017 with the changes the American Heart Association (AHA) and the American College of Cardiology (ACC), where the definition of chronic hypertension was modified to fit a lower diagnostic thresholds of SBP ≥130 or DBP ≥80, compared to the previous definition of SBP ≥140 or DBP ≥90 that still holds for gestational hypertension.[23,68]Although the ACOG criteria still stands for pre-pregnancy and gestational hypertension, there would be a large difference in prevalence if the AHA 2017 criteria were to be adopted. Bello et al identified that the rate of hypertension in pregnancy overall would increase, in addition to changes in diagnosis from those previously considered de novo (gestational) during pregnancy would now be considered chronic hypertensive.[23] Using a live birth database may introduce bias because women who are hypertensive have greater chances of maternal and fetal mortality and they would be excluded from the live births. Limiting to live births data may underestimate the true burden of HDPs. Lastly, the analytic sample is limited to Black and White women and excludes other high-risk groups such as AI/AN and Hispanic women. This is due to data suppression and small numbers issues, as there are counties in the US that may not have large minority populations and HDPs can be a rare outcome. Additional sub-analyses can be considered for exploring peri-natal outcomes in Hispanic and AI/AN women.

Conclusion

Based on this work, geography continues to have a strong relationship with chronic hypertension but is variable for gestational hypertension. These results suggest that areas of care deprivation, such as locations of low provider count, rural areas, and under resourced area, are detrimental for chronically occurring hypertension among birthing people. Access to health care facilities and the means to afford health care have a stronger impact for Black birthing and prioritizing Black communities is essential for reducing inequities in chronic hypertension. This identifies opportunities to prevent chronic hypertension through improved resource allocation to the communities where health care may be sparse and improve quality of care for rural communities or the quality of care is not equitable across social groups for disease prevention and management and should be considered for future research.

4. Comparing data sources and spatial resolution in the association of access to healthcare and hypertensive disorders of pregnancy

Abstract

Background: Hypertensive disorders of pregnancy (HDPs) are a dangerous condition for birthing people and a contributor to morbidity and mortality. Despite the impact they have during gestation, they can be challenging to diagnose if the patient does not have regular interactions with the health care system. Also, there are notable differences in reporting between data sources that make estimating disease burden challenging to accomplish. The objective of this study is to estimate the association of small-area (census tract and county) geographic access to healthcare and HDP types in Georgia to explore how these domains and measures of access to care may be associated with higher rates of HDPs.

Methods: Georgia Birth Certificate Records and Georgia Hospital Discharge Records from the Georgia Department of Public Health were linked to create a cohort of birthing people who gave birth during 2014 to 2019. Using a Bayesian spatial model, we examined if exposures of health care access (provider ratio, rurality, percent uninsured, health provider shortage area) have similar associations with counts of HDP type (birth records and hospital discharge records, separately) and across strata of non-Hispanic White and non-Hispanic Black birthing people.

Results: Prevalence of chronic hypertension was similar across data sources (BC: 2.3%; HD: 2.6%) and has a specificity of 98%, compared to the hospital discharge records. The sensitivity and specificity of the birth certificate records for gestational hypertension (sensitivity: 43%; specificity: 98.6%) was moderately improved compared to chronic but overall the prevalence of gestational hypertension reported in the birth certificate was lower than in the hospital discharge data. The burden of gestational hypertension was similar on average for Black and White birthing people, although there was an excess of chronic hypertension cases for Black birthing people (20 per 1,000 live births). Percent uninsured and rurality were associated with higher rates of both hypertension types regardless of record type and spatial scale.

Conclusions: This pattern is also seen for chronic hypertension, although the differences are much smaller when using different outcome measures (i.e. birth certificate versus hospital discharge). Using varying spatial scales did not change the conclusions from county level measures to census tract measures.

Background

Hypertensive disorders of pregnancy (HDPs) are a dangerous condition for birthing people and a contributor to morbidity and mortality. Documented hypertensive disorders (chronic, gestational, preeclampsia) are present in a third of deaths during delivery hospitalization, whether it is chronically occurring or onset during the gestational period.[20] Despite the important impact they have during gestation, they can be challenging to diagnose if the patient does not have regular interactions with the health care system. Accurate reporting of hypertension type is important for research given gaps in knowledge about the etiology of gestational hypertension and preeclampsia. Being able to distinguish pregnancy-induced types from chronic or pre-existing hypertension is valuable to disentangle potential markers of risk and drivers of pregnancy-onset hypertension, in addition to meeting treatment recommendation. The American College of Obstetrics and Gynecology has differing treatment guidelines for time to delivery and antihypertensive treatment dependent on when the hypertension was onset.[22]

There are notable differences in reporting between data sources that make estimating disease burden challenging to accomplish.[56,67] Hypertension during pregnancy is documented on birth certificate records and often used for research studies to estimate overall prevalence as well as its association with other pregnancy outcomes such as severe maternal morbitity.[67] Accurate reporting of clinical hypertension is difficult to achieve because of some discordance between birth certificate record response options and clinically relevant hypertension types, and as a result maternal morbidities are often misreported from hospital records to birth certificate records.[6,85] Although the types of hypertensive disorders of pregnancy are recognized with ICD-10 classification for hospital discharge records, national vital records reporting has different specification such that a pregnancy is reported as “Prepregnancy hypertension”, “Gestational hypertension” and “Eclampsia” if the birthing person experiences hypertension during the prenatal period. Prepregnancy hypertension refers to chronic hypertension, and gestational hypertension is an umbrella term for pregnancy onset hypertension and occurrence of preeclampsia, superimposed or not. The various definitions and categorizations create a challenge for disaggregation of types and summarizing literature.

At a population level, the use of hospital discharge records may be better for surveillance compared to birth certificate records because they include physician-diagnosed ICD-9 and ICD-10 codes from medical charts instead of the multiple reporting from birth certificates, which may include parents and other hospital staff. Studies from other countries have suggested using discharge records are not without their limitations although the efficacy of hospital records has not been fully explored in the US.[56,86,87] Valid identification of burden of hypertensive disorders of pregnancy may improve our understanding of how hypertensive disorders of pregnancy types are spatially and socially structured.

At a minimum seeing a provider is necessary for diagnosis of high blood pressure, in addition to proper identification of hypertension type during pregnancy. There are a number of considerations to make health care accessible to populations of pregnant people, ranging from having a provider in their neighborhood or county, having the means to seek care, or having childcare, transportation, or other systemic barriers to address health needs.[45,75] Social and health resources are unevenly distributed geographically and identification of spatial patterns in disease burden may provide meaningful insight to decompose the epidemiology of the types of HDPs since chronic and gestational hypertension share several risk factors but have differing mechanisms of disease onset.[2] Reduction in health access and opportunity for health is a culmination of place-based risk factors, such as neighborhood poverty, lower income/wealth, lower educational attainment, food deserts and elements of social cohesion.[52] The intersection of racism and urbanism contributes to even greater disparities because rural settings tend to have healthcare shortage or have fewer specialists and providers, which may modify the relationship between access to care and HDPs.[45,88,89]

The objective of this study is to estimate the association of small-area (census tract and county) geographic access to healthcare and HDP types in Georgia to explore how these domains and measures of access to care may be associated with higher rates of HDPs. We also compare reporting of linked hospital discharge records to birth certificate records with respect to chronic and gestational hypertension for validity and data quality concerns.

Methods

Study Population

We linked Georgia Birth Certificate Records (BC) and Georgia Hospital Discharge Records (HD) from the Georgia Department of Public Health to create a cohort of birthing people ages 15 to 44 who gave birth during 2014 to 2019. Residential census tract and county were available for the birthing people in order to link with area-based exposures. Detailed diagnostic information is available in the discharge records, allowing for identification of specific types of the HDPs. The discharge data include information on socio-demographics for pregnant people delivering live births such as age, race/ethnicity, and comorbidities (i.e. chronic kidney disease, diabetes, multiparity). The cohort included women in the US who are (1) 15 to 44 years of age (2) identify as Non-Hispanic Black (NHB) or Non-Hispanic White (NHW) and (3) experience a live birth from 2014 to 2019.

Outcome assessment

Indicators of hypertensive disorders of pregnancy are estimated separately from hospital discharge records and birth certificates, and summarized at the census tract and county scale. Birth certificate records collapse hypertensive disorders during pregnancy into the following categories: pre-pregnancy or chronic hypertension, gestational hypertension (including both gestational and preeclampsia), focusing on the variation between chronic and gestational hypertension. Individuals who experienced eclampsia without indication of either chronic or gestation hypertension diagnosis were excluded from the cohort. Hospital discharge records have more granular categorization of hypertension based on ICD-9 and ICD-10 codes. ICD-9 and ICD-10 codes for HDPs were extracted from Georgia hospital discharge records and linked to birth records to identify hypertensive type and discharge diagnoses.[56] These codes classify the specific HDPs (chronic, gestational, preeclampsia, and chronic superimposed with preeclampsia) and catalog hypertension during and prior to pregnancy. or data quality comparison, we focus on the umbrella diagnoses of chronic hypertension and gestational hypertension (inclusive of preeclampsia) to compare with the Georgia birth certificate data. We assumed hospital discharge records were the gold standard to compare against the birth records. The binary of "chronic" and "gestational" is used to report prevalence statistics and for evaluation in this study.

Exposure measurement

In an effort to understand the relationship between HDP types and having access to healthcare, we considered proxy measures of health care access at the county level and at the census tract level. The measures of access are largely ecologic (place-based) and the primary measures are explored at the county-level. We use 1) primary care physicians per 100,000 population, and 2) Health Provider Shortage Areas, 3) Percent uninsured population, and 4) Rural-Urban continuum codes for county level metrics and 1) Percent uninsured population and 2) Rural-Urban continuum codes at the census tract level for comparison. We describe each exposure in more detail below and elsewhere (Aim 2).

The number of physicians per 100,000 population is extracted from 2017-18 Health Resources and Services Administration (HRSA) Area Health Resource Files. Providers are classified as any physician (MD or DO) that provides primary or obstetric care.[54] Data from the American Community Survey (ACS) 5-year estimates were extracted to capture the percent of individuals who were uninsured from (2014 to 2018). This dimension of access to care may be a fiscal approximation of affordability to receive care from a provider. We calculated this measure for both spatial scales in the analyses by estimating the of residents that were uninsured divided by the total population of the areal unit (census tract or county). The distinction between rural and urban regions is captured with 2013 Rural-Urban continuum codes.[50]

Studies have shown that residents in rural communities have to commute further to receive care compared to urban residents, in addition to having more shortage of health care workers[48,79] We will use metro and non-metro designations for each county and census tract. HRSA uses scoring criteria to identify geographic areas with healthcare shortage. The criteria are population-to-provider ratio, percent of population below 100% of the Federal Poverty Level, and travel time to the nearest source of care outside the Health Provider Shortage Area (HPSA) designation area. Counties are then designated as “not a shortage area”, “partial shortage area”, or “shortage area”.

Covariates

Individual-level covariates (e.g. race, insurance type, parity, plurality, age) were available from birth certificate records and we chose to incorporate age, race, and year of birth in the models. We also included a model with parity as it is a strong predictor of the outcome. Analyses were stratified by race because we recognize that the social production of racialized spaces means that the same place is not always experienced equally across race groups, here in reference to access and experiences with health care and resources. Therefore, we evaluated if the magnitude of the association between healthcare access proxies and HDP varies between race groups.

Statistical analysis

We explored the association of access to health care and HDP type based on each data source to test if the conclusions are harmonious between hospital discharge records and birth certificate data. We examined if exposure of health care access (provider ratio, rurality, percent uninsured, HPSA) have similar associations with counts of HDP type (birth records and hospital discharge records, separately) using a Bayesian spatial model with a Queen contiguity neighbor matrix. Relationships between access to care and HDP types were assessed with spatial Bayesian Poisson regression using Integrated Nested Laplace Approximation (INLA) to account for smoothing among counties. Adjusted rate ratios estimate the association of lower access to care indicators with hypertension, adjusting for age of birthing person and plurality. In the instance of missing data for covariates of interest, complete case analysis was performed. To further compare the reporting of hypertensive type from hospital discharge to birth certificate records, we used the categories of no diagnosis, chronic hypertension, gestational hypertension, and missing. We created a permutation table to check the concordance of each variable between data source, with hospital discharge records serving as the gold standard.

We repeated the county level analyses using hospital discharge records stratifying on race/ethnicity for the relationship between access to care and HDP. For the stratified Poisson models using Integrated Nested Laplace Approximation (INLA) we smooth across county as the spatial scale. We also fit census tract level models and compared the results to the county-level models. The access to care measures available at the census tract level were percent uninsured and Rural-Urban continuum codes – we were unable to use the PCP ratio and HPSA models.

Results

The linked cohort of Georgia hospital discharge records and birth certificate data consisted of 621,422 live births to Black and White birthing people from 2014 to 2019. Comparing between the data types, we see that gestational hypertension is reported more often in the hospital discharge records (10.0%) compared the birth certificate records. This increase in reporting is also seen for cases of chronic hypertension at a smaller magnitude (2.6% vs. 2.3%). Irrespective of reporting data, chronic hypertension prevalence increases with age with highest proportion among the 35- to 44-year-olds. Also, having a first order pregnancy or multiple gestation is associated with greater prevalence of gestational hypertension. Among first order births, the proportion of gestational hypertension is higher compared to that of second or greater order births regardless of reporting (HD: 1st order = 14%; 2nd order = 8%). (**Table 4.1**)

Table 4.1. Descriptive Statistics of cohort, 2014 to 2019

Table 1. Descriptive Statistics of cohort, 2014 to 2019							
	Birth Certificate Records			Hospital Discharge Records			Overall
Variable	No diagnosis	Gestational	Chronic	No diagnosis	Gestational	Chronic	
N	568,094 (91.4)	38,965 (6.3)	14,353 (2.3)	542,621 (87.3)	62,450 (10.0)	16,371 (2.6)	621,442
Age (years)							
15-24	173,293 (92.6)	11,678 (6.2)	2,186 (1.2)	165,992 (88.7)	18,742 (10.0)	2,430 (1.3)	187,164
25-34	312,779 (91.5)	21,179 (6.2)	7,893 (2.3)	299,135 (87.5)	33,633 (9.8)	9,098 (2.7)	341,866
35-44	82,022 (88.8)	6,108 (6.6)	4,274 (4.6)	77,494 (83.9)	10,075 (10.9)	4,843 (5.2)	92,412
Race/Ethnicity							
Black	244,473 (90.1)	17,510 (6.5)	8,641 (3.2)	231,227 (85.4)	29,601 (10.9)	9,804 (3.6)	270,632
Gest. Diabetes							
Yes	23731 (81.2)	3,904 (13.4)	1,584 (5.4)	21,345 (73.1)	5,820 (19.9)	2,054 (7.0)	29,219
Insurance							
Private	251,685 (91.9)	16,394 (6.0)	5,741 (2.1)	240,268 (87.7)	26,933 (9.8)	6,622 (2.4)	273,823
Public	274,651 (90.9)	20,047 (6.6)	7,608 (2.5)	261,930 (86.6)	31,631 (10.5)	8,748 (2.9)	302,309
Self-pay	15,911 (94.5)	672 (4.0)	241 (1.4)	15,467 (91.9)	1,141 (6.8)	217 (1.3)	16,825
Missing	25,847 (90.7)	1,852 (6.5)	763 (2.7)	24,956 (87.6)	2,745 (9.6)	784 (2.8)	28,485
Plurality							
Singleton	556,173 (91.8)	37,538 (6.2)	13870 (2.3)	531,462 (87.5)	60,167 (9.9)	15,962 (2.6)	607,591
Twin or more	9,674 (84.1)	1,424 (12.1)	442 (3.8)	9,040 (77.1)	2,285 (19.5)	401 (3.4)	1,172
Missing	2,064 (97.0)	3 (0.1)	41 (1.9)	2,119 (99.6)	1 (0.0)	8 (0.4)	2,128
Parity							
1st	210,320 (90.1)	18,709 (8.0)	4,486 (1.9)	196,680 (84.2)	31,932 (13.7)	4,904 (2.1)	233,516
2nd	166,462 (92.5)	9,508 (5.3)	3,926 (2.2)	160,673 (89.3)	14,398 (8.0)	4,825 (2.7)	179,896
3rd or more	64,841 (90.4)	4,318 (6.0)	2,584 (3.6)	62,287 (86.8)	6,424 (9.0)	3,035 (4.2)	71,746
Missing	126,471 (92.8)	6,430 (4.7)	3,357 (2.5)	122,981 (90.2)	9,696 (7.1)	3,607 (2.6)	136,284
Marital Status							
Married	302,088 (91.8)	19,844 (6.0)	7,112 (2.2)	290,826 (88.4)	30,343 (9.2)	7,890 (2.4)	329,059
Single	262,825 (90.9)	19,070 (6.0)	7,165 (2.2)	248,638 (86.0)	32,030 (11.1)	8,406 (2.9)	289,074
Missing	3,181 (96.1)	51 (1.5)	76 (2.3)	3,157 (95.4)	77 (2.3)	75 (2.3)	3,309

Footnotes. Data are presented for both sources of outcome measurement and strata of hypertension. Data are displayed as count and column percent.

- 30 cases are dropped due to missingness in the birth certificate records

Prevalence of chronic hypertension is similar at face value across data sources (BC: 2.3%; HD: 2.6%) and has a specificity of 98%, compared to the hospital discharge records there was only 37% sensitivity of the birth certificate records. Using HD records as the gold standard, the sensitivity and specificity of the birth certificate records is slightly improved for gestational hypertension (sensitivity: 43%; specificity: 98.6%). Most of those cases were misclassified as no hypertension (**Table 4.2**). Other differences can be seen with the estimated rates of gestational hypertension illustrated in **Figure 4.1**. The range of estimates for the county is much greater for hospital discharge records (6 per 1,000 to 180 per 1,000 live births) and there are counties represented by different quintiles of disease burden depending on the data source.

Table 4.2. Comparison of Birth Certificate Records to Hospital Discharge Record

Table 2. Comparison of Birth Certificate Records to Hospital Discharge Record

		Hospital Discharge Records			
		No Hypertension Diagnosis	**Gestational Hypertension**	**Chronic Hypertension**	**Row Totals (BC)**
Birth Certificate Records	**No Hypertension Diagnosis**	528,699 (97%)	31,550 (51%)	7,845 (48%)	568,094
	Gestational Hypertension	9,692 (2%)	26,788 (43%)	2,485 (15%)	38,965 Est. prevalence: 6%
	Chronic Hypertension	4,200 (1%)	4,112 (6%)	6,041 (37%)	14,353 Est. prevalence: 2%
	Missing	30	0	0	30
	Column Totals (HD)	542,621	62,450 Est. prevalence: 10%	16,371 Est. prevalence: 3%	621,442

Footnote:
Data are presented for 2014 to 2019. The row totals represent the percent of births by hypertension type according to birth certificate records (BC) and the column totals are the percent for hospital discharge (HD) records. The diagonal interior percentages represent the percent correctly classified if we assume that HD records are the true counts and the surrounding cells represent the proportion incorrectly classified.

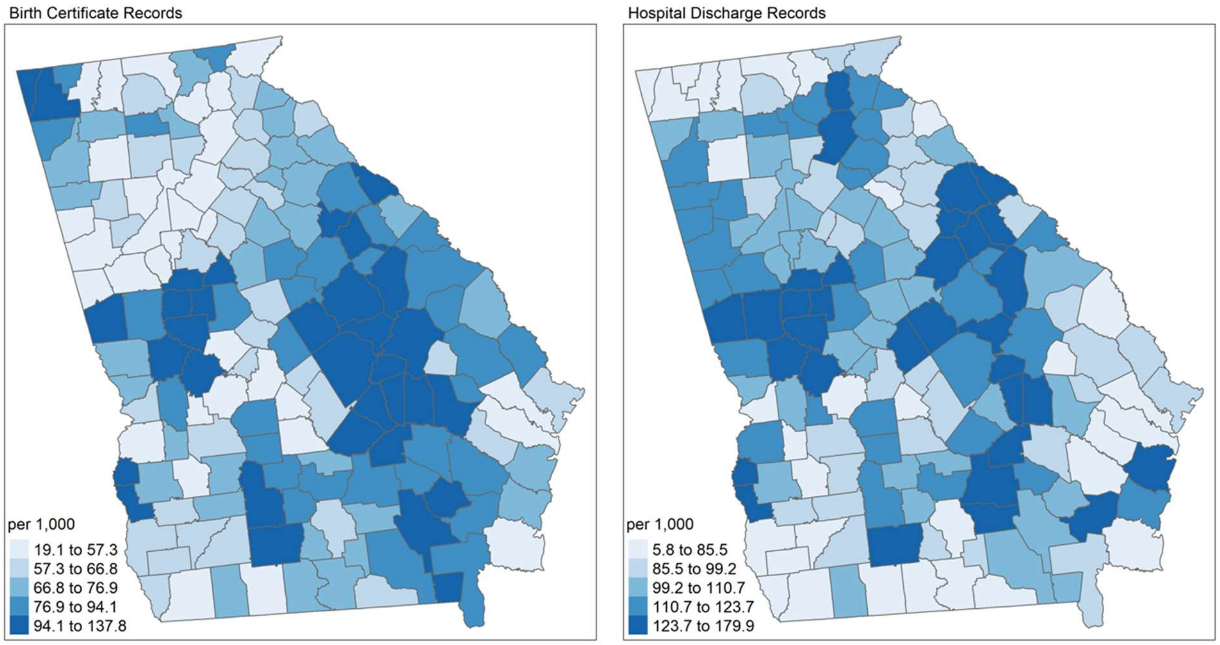


Figure 4.1. County-specific rates of gestational hypertension using hospital discharge and birth certificate records

As we explored measure of access to care with county-level rates of HDPs, the results suggest PCP ratio is not a strong predictor of chronic or gestational hypertension among either records type. Associations between other access to care measures and hypertension types were more variable. Rurality is a predictor of chronic hypertension regardless of data source, suggesting counties in non-metro areas tended to have a higher rate of chronic hypertension compared to metro counties (HD aRR: 1.23, CI= 1.09, 1.40). Rurality was not statistically significant in the relationship with gestational hypertension by hospital discharge records but it followed a similar trajectory (HD aRR: 1.10, CI= 0.99, 1.21). The association with percent uninsured is variable in statistical significance based on the data source but generally the counties with higher percent of uninsured person was related with higher rates of HDP. This measure consistently showed that an increase in uninsured populations with associated with greater rates of chronic and gestational hypertension among hospital discharge, but not significant using birth certificate. Lastly, living in a full HPSA was associated with increased rates of chronic hypertension compared to no HPSA, although only among the birth certificate records for an incomplete picture. There was a weak association with gestational hypertension that increased with increasing shortage and the association appears to be stronger for the birth certificate data than for the discharge data (**Table 4.3**).

Table 4.3.Comparing associations of access to care with birth certificate and hospital discharge records (county-level)

Table 3. Comparing associations of access to care with birth certificate and hospital discharge records (county-level)				
	Gestational Hypertension		**Chronic Hypertension**	
Exposure	Birth Certificate Rate ratio (95% CI)	Hospital discharge Rate ratio (95% CI)	Birth Certificate Rate ratio (95% CI)	Hospital Discharge Rate ratio (95% CI)
PCP Ratio Increase of one standard deviation in providers per capita	0.98 (0.93, 1.01)	0.99 (0.95 1.03)	0.98 (0.94, 1.01)	1.00 (0.95, 1.05)
Rurality Non-Metro vs. Metro	**1.16** **(1.04, 1.27)**	1.10 (0.99, 1.21)	**1.17** **(1.02, 1.34)**	**1.23** **(1.09, 1.40)**
% Uninsured Increase of one standard deviation of uninsured percent	1.03 (0.98, 1.09)	**1.07** **(1.02, 1.13)**	1.08 (1.00, 1.16)	**1.12** **(1.06, 1.19)**
HPSA No Shortage	*Ref*	*Ref*	*Ref*	*Ref*
HPSA Partial Shortage	**1.25** **(1.04, 1.49)**	1.10 (0.90, 1.32)	**1.33** **(1.03, 1.72)**	1.16 (0.93, 1.45)
HPSA Full Shortage	**1.27** **(1.04, 1.54)**	1.13 (0.92, 1.40)	**1.47** **(1.11, 1.94)**	1.49 (0.92, 1.50)
Footnotes. Models are adjusted for year, age, plurality. Full models drop n = 2,128 cases due to missingness in plurality				

Results of the race-stratified estimates showed that the largest disparity exists for Black birthing people with chronic hypertension compared to White birthing people (42 per 1,000 vs 22 per 1,000) (**Table 4.4**). This is displayed in the rate difference maps for chronic hypertension which presents a strong story with higher burden to Black birthing people compared to White birthing people in every county in the state and averaging around 20 excess cases (**Figure 4.2**). There are trade-offs in higher burden between race groups for gestational hypertension, where they are not consistently higher for Black or White birthing people. It is worth noting that the average rate difference for Black and White birthing people is 1 using BC records, but there is a higher rate of gestational hypertension to Black individuals when using HD records (RD = 9 per 1,000 live births). For the associations with access to care, we see similar results with the overall models expect for full HPSA was more associated with higher rates of chronic and gestational hypertension among Black birthing people compared to White birthing people.

Table 4.4. Table 4. Race-stratified associations of access to care and hospital discharge records

Table 4. Race-stratified associations of access to care and hospital discharge records						
	Overall Cohort		Black Birthing People		White Birthing People	
Exposure	Gestational Hypertension Rate ratio (95% CI)	Chronic Hypertension Rate ratio (95% CI)	Gestational Hypertension Rate ratio (95% CI)	Chronic Hypertension Rate ratio (95% CI)	Gestational Hypertension Rate ratio (95% CI)	Chronic Hypertension Rate ratio (95% CI)
Estimated Rate	104 per 1,000	29 per 1,000	108 per 1,000	42 per 1,000	99 per 1,000	22 per 1,000
PCP Ratio Increase of one standard deviation in providers per capita	0.99 (0.95 1.03)	1.00 (0.95, 1.05)	1.01 (0.97, 1.05)	0.99 (0.94, 1.04)	0.98 (0.93 1.03)	0.94 (0.89, 1.00)
Rurality Non-Metro vs. Metro	1.10 (0.99, 1.21)	**1.23** **(1.09, 1.40)**	1.05 (0.95, 1.16)	**1.25** **(1.11, 1.41)**	1.13 (1.00, 1.26)	**1.22** **(1.05, 1.41)**
% Uninsured Increase of one standard deviation of uninsured percent	**1.07** **(1.02, 1.13)**	**1.12** **(1.06, 1.19)**	**1.08** **(1.03, 1.13)**	1.06 (0.99, 1.12)	1.05 (0.99, 1.11)	**1.10** **(1.02, 1.19)**
HPSA No Shortage	*Ref*	*Ref*	*Ref*	*Ref*	*Ref*	*Ref*
HPSA Partial Shortage	1.10 (0.90, 1.32)	1.16 (0.93, 1.45)	1.16 (0.98, 1.37)	1.08 (0.88, 1.32)	1.00 (0.81, 1.25)	0.99 (0.74, 1.33)
HPSA Full Shortage	1.13 (0.92, 1.40)	1.49 (0.92, 1.50)	**1.23** **(1.02, 1.48)**	1.18 (0.94, 1.48)	0.99 (0.79, 1.26)	0.99 (0.76, 1.28)
Footnotes. ***a.** Models are adjusted for year, age, plurality						

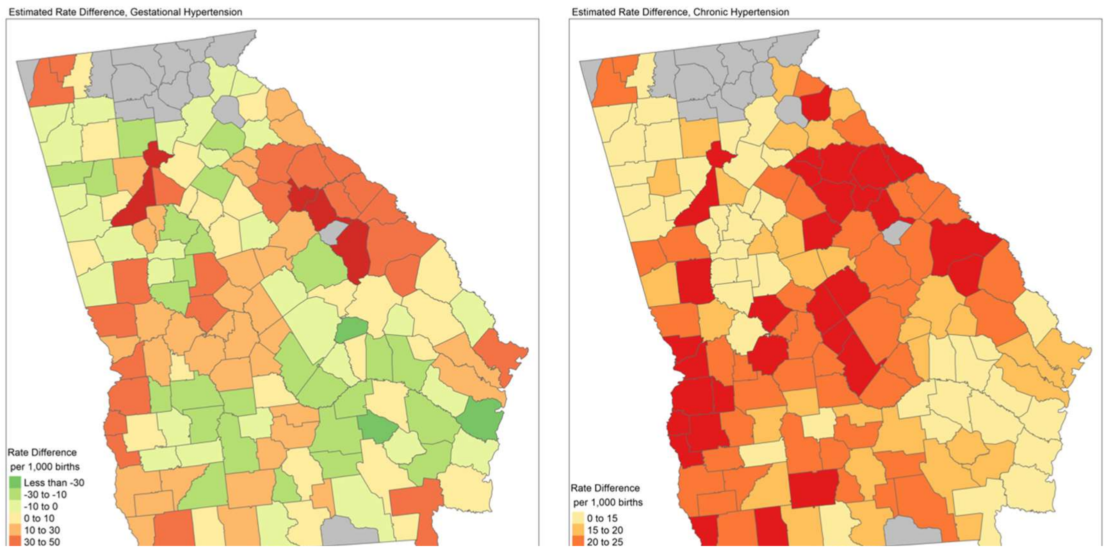


Figure 4.2. Race-stratified estimated rates of hypertensive disorders of pregnancy with rate difference estimate

For comparisons of access to care at varying spatial scales, we found gestational hypertension was not strongly associated with rurality at the census tract or county level and showed consistent results across spatial scale. Chronic hypertension was associated with rurality on both scales but was attenuated for the at the census tract level (RR: 1.13, CI: 1.03, 1.24). Lastly, percent uninsured is the same across scales for gestational hypertension and for chronic hypertension, where an increase in uninsured population is associated with a county or census tract level increase in disease rate (**Table 4.5**). Estimated rates of gestational hypertension at the county and census tract-level are displayed in **Figure 4.3** to highlight the geographic differences that spatial scale can make for disease estimation.

Table 4.5. Comparing associations of access to care and hospital discharge records with varying spatial scales

Table 5. Comparing associations of access to care and hospital discharge records with varying spatial scales				
	Gestational Hypertension		Chronic Hypertension	
Exposure	Census tract[a]	County[a]	Census tract[a]	County[a]
Rurality Non-Metro vs. Metro	1.05 (1.00, 1.09)	1.10 (0.99, 1.22)	**1.13** **(1.03, 1.24)**	**1.23** **(1.09, 1.40)**
% Uninsured Increase of one standard deviation of uninsured percent	**1.06** **(1.04, 1.07)**	**1.07** **(1.02, 1.13)**	**1.15** **(1.12, 1.18)**	**1.12** **(1.06, 1.19)**
Footnotes. Models are adjusted for year, age, plurality				

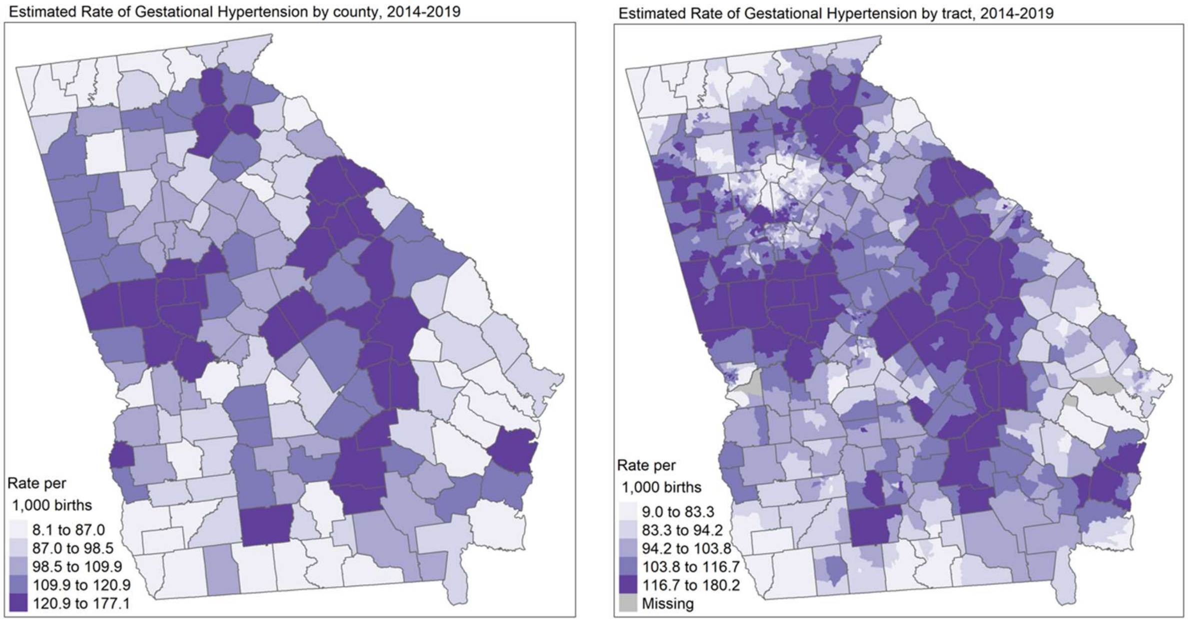


Figure 4.3. Estimated gestational hypertension rates using hospital discharge records, at the county and tract-level

Discussion

This study was a multi-faceted approach to explore consistency of reporting among hypertensive types and how the data source may impact the conclusions we wished to draw with proxies of access to healthcare. Overall, birth certificate records consistently underestimate reporting of hypertension types compared to the gold standard of hospital discharge records. When considering the association with access to care, the data sources presented similar associations across the four measures despite some variation in significance. For race-stratified models, there is consistently a higher burden of chronic hypertension among Black birthing people regardless of record type. Based on hospital discharge records, spatial scale did not change our estimated associations between access to care and HDP type. Overall, we continue to see differences between chronic and gestational hypertension in their relationships to access to care. This work emphasizes that it is worth looking at gestational and chronic hypertension separately and that accuracy of classification differs by data source.

Reliance on surveillance tools such as hospital discharge records, electronic medical records, or birth certificate records may have varying results in capturing true disease burden.[56] For the state of

Georgia, hospital discharge records were shown to be a valid measure for documenting hypertensive types when compared to electronic medical records.[56] The use of birth certificate records is shown to have poor case ascertainment for other maternal outcomes, such severe maternal morbidity, and underestimated Black-White disparities compared to hospital discharge records.[7] Dependent on the data source, we see changes in estimates of disease burden, particularly for gestational hypertension.[56,90] In this study, the rate of chronic hypertension and gestational hypertension were assessed using hospital discharge and birth certificate records. Other studies have used state-specific birth certificate data, MarketScan commercial claims data, and national hospital discharge records which result in different estimates of disease burden.[41,90] Additionally, studies may vary in estimation based on the years of data collected because changes in diagnostic criteria and physician awareness may be driving some of the increases in HDPs over time, although markers of risk such as obesity and advanced maternal age may also play a role.[91]

Using hospital discharge records as the gold standard, we sought to explore access to healthcare using smaller spatial units including census tract to approximate neighborhood as well as county which had more access to care measures available measures. For example, we used physicians per capita with the hypothesis that the presence of nearby providers means that geographically, there are greater opportunities to see a physician and potentially shorter wait times. We found no relationship with chronic or gestational hypertension in any of our analyses, using either record type. This could be due to inequitable barriers, such that having a physician in the area does not mean that every person living in the area has equal access.[92] For individuals who have barriers to accessing healthcare, whether it is monetary resources, transportation, childcare burdens, mistrust of the medical system or a combination of these factors, having a physician nearby may be insufficient.[92] Additionally, not all patients see a MD or DO as their primary provider and there are many cases managed by nurse practitioners, midwives, or specialist care.

Rural-urban health disparities have been described for other maternal and child health outcomes. Rural populations tend to have worse pregnancy outcomes compared to urban counterparts with fewer chances to receive obstetric services.[45,48] In this study, we did see associations with rurality for gestational hypertension for increased rates in non-metro counties. This association was stronger for chronic hypertension, and it was seen across records type, race-strata, and spatial scale. This may be due to a lower likelihood of routine preventative care to address chronic hypertension or other diagnoses related to HDP onset. Challenges often seen in rural settings include more hospital and delivery service closures, travel time, and small numbers of providers.[45]

Based on these findings, living in a county with greater populations of uninsured person is related to higher rates of chronic and gestational hypertension. We note that magnitude of the association is stronger with hospital discharge records for both hypertension types. Although the discharge records may be more representative, birth certificates are often more accessible than discharge data and are commonly used studies that evaluate associations between facets of HDPs. These associations could be misleading given that birth certificates underestimates HDPs, however the associations between access to care and HDPs followed similar patterns across birth certificates and discharge data despite a tendency to be attenuated. This may be due to substantial misclassification of HDP types as no hypertension on the birth certificates. In this study we hypothesized that would see a relationship with HDP types and percent insurance because individuals living in low resource area are less likely to seek prenatal care and receive adequate treatment.[92,93] This study also explored how reporting impacts analyses of racial disparities in HDP burden. It is not surprising that rates of HDP types are higher for Black birthing people when considering structural racism, socio-economic inequities, unequal resource allocation and forgone healthcare, but it appears that birth certificate records may be underestimating disease burden for both Black and White birthing people.

Strengths and limitations

One strength of this work using a cohort of birthing people from the state of Georgia, which is a diverse setting such that race and social class are not as tightly correlated as they are in other regions of the US. While there is a long and persistent history of inequality, there is also a strong and vibrant Black middle class and there is a sizable population of Black individuals residing in rural counties, unlike in other states where race and urbanicity are more tightly linked.[45] This allowed for an element of intersectionality by exploring low access areas among Black birthing people. Additionally, in this study we were able to use of multiple data sources to assess discordance in measurement for a linked population of birthing people. This allowed us to assess the relationship of HDP types with access to care over two commonly used data sources. Another strength of this work is the granularity of spatial resolution where we can use the census tract as the geographic unit of analysis to compare with county level estimates. Census tract may be a better approximation than county of the neighborhood and may provide more discrete information about "place". Lastly, we use a Bayesian spatiotemporal framework to stabilize rate estimates for these smaller areal units. This allows for estimations of census tract level rates that are informed by neighboring units to inform issues of small numerators and denominators.

For all of the study aims, there are concerns of data quality of both ICD-10 reporting from hospital discharge records for the state of Georgia and HDP specification on birth certificate records.[86] Despite this shortcoming, other work validated hospital discharge records against electronic medical records and found them to be representative of the data.[56] For access to care measures, PCP ratio may be an incomplete measure. Using specialist care is the recommended course of treatment for some of the related comorbidities and other provider types are available to aid the prenatal period such as midwives, nurses and doulas. Additionally, there labor and delivery units have been closing across the state which may impact the true number of providers or HPSA designation. Although, we do not use number of birthing facilities or number of obstetric providers as a measure of access, although Georgia experiences low numbers of these facilities and providers in rural settings.[45] Lastly, the experience in Georgia is not transportable to other populations. Georgia is a state without Medicaid expansion, and this presents further challenges for accessing care due to the more stringent guidelines for eligibility for public assistance so future. Future studies could compare Medicaid expansion changes among other states and the impact on maternal and child health.

Conclusion

We found discordance between reporting of hospital discharge records and birth certificate data between both chronic and gestational hypertension. Overall, gestational hypertension reported in the birth certificate is lower than in the hospital discharge data, and that although this pattern is also seen for chronic hypertension, the differences are much smaller we used different outcome measures (i.e. birth certificate versus hospital discharge). Depending on the data source, the strength of the estimate may dictate slightly different results. Using varying spatial scales did not change the conclusions when we changed from county level measures to census tract.

5. Conclusions

These specific aims intend to identify areas of high-burden chronic and gestational hypertension, hypothesize place-based drivers of risk, and provide a comparison of two data sources for estimating the rates of chronic and gestational hypertension. In the first aim we described county-level patterns of hypertensive disorder of pregnancy types and identified characteristics of counties with high burden using Bayesian spatial analysis to address challenges in small-area estimation. We found that place-based sociodemographic covariates differed in counties with high-burden chronic hypertension compared to those without, whereas high-burden gestational hypertension was only weakly associated with racial density of counties and did not exhibit a clear correlation with the identified place-based markers of risk (**Chapter 2**). For the second aim, we examined whether area-based indicators of access to health care during pregnancy are associated with increased rates of chronic and gestational hypertension at the county-level. These findings suggest that living in low access areas (i.e. living in a rural area, having fewer providers per capita, and living in an area with a larger proportion of uninsured persons) is associated with higher rates of chronic hypertension and that measures of geographic access were more strongly associated with chronic compared to gestational hypertension (**Chapter 3**). For the third aim, we estimated the association of small-area (census tract and county) geographic access to care and HDP types in Georgia to explore how other spatial scales of access to care may be associated with higher rates of hypertension during pregnancy. We also compare reporting of linked hospital discharge records to birth certificate records with respect to chronic and gestational hypertension for validity and data quality concerns. We found discordance between reporting of hospital discharge records and birth certificate data between both chronic and gestational hypertension, such that birth certificate data seemed to under report compared to hospital discharge data. These discrepancies resulted in differing estimates regarding the association between access to health care and each hypertensive type when we used different outcome measures (i.e. birth certificate versus hospital discharge), although overall, race-stratified and spatial scale did not change the conclusions when we changed between record types and from county level measures to census tract (**Chapter 4**).

Aim 1 Summary

We were interested in estimating the geographic high-burden areas of chronic and gestational hypertension with a valid and reliable methodology to account for instability in estimation. Given the small area of analysis (in this case county) and the relatively rare outcomes with either disorder accounting for less than 10% of births, we estimated smoothed rates by borrowing information from the global rates and the surrounding counties. By using Bayesian spatial models, we were able to extract county specific rates of hypertensive types in addition to utilizing the posterior distribution of the estimates to calculate the probability of each county exceeding the national average. Results of this study showed that chronic hypertension is more spatially clustered compared to gestational hypertension, which presents as a more diffuse pattern over the US. We also highlight counties with high burden chronic hypertension was associated with the proportion of Black individuals and exhibits a stronger correlation with rural-urban designation. In counties in the southeastern US, there is a disproportionate risk of chronic hypertension for Black birthing people compared to White birthing people. Contrary to expectation, gestational hypertension did not follow the same socio-demographic patterns as chronic hypertension. There was not clear evidence that counties with a high burden of gestational hypertension shared the same associations with rurality, percent Black residents, and percent uninsured persons as seen for chronic hypertension, despite also having pockets of high burden in the southeastern US. The results of this aim highlight why we need to continue to study differences between hypertensive types because they are not as interrelated as expected despite sharing common risk factors. One takeaway from this work is Bayesian modeling is a valuable method to apply when working with more granular geographic areas and relatively small case counts. We are able to improve upon the crude estimation to stabilize the rates, while taking into consideration that places that are nearer to each other tend to be more similar. We also recommend continuing to separate types of hypertensive disorders of pregnancy because by exploring the disorders in aggregate, we may be glossing over vital information and making incorrect conclusions about separate drivers of chronic and gestational hypertension.

Aim 2 Summary

For the second aim, we explored the association of area-based indicators of access to health care associated with increased rates of chronic and gestational hypertension to better understand this potential driver of disease burden. We were able to build upon the models from Aim 1 and add the measures of access that we hypothesized to be related to these disorders by using Penchansky and Thomas's framework in tandem with other studies to identify proxies of geographic access to health care. We found there is heterogeneity in how geographic access is measured and this results in counties with "high" access in some measures that are also "low" when using a different proxy. Physician per capita is a highly variable measure that did not show any strong geographic patterning although it is weakly related to both chronic and gestational hypertension with more providers associated with lower rates. We can compare this to counties with high and low populations of uninsured persons which has a distinct spatial pattern of low access in the south and higher access in the northeast and Midwest. Similar to Aim 1, chronic hypertension seems to be more consistently related to the prevalence of uninsured populations compared to gestational hypertension. Of note, low access to care has a stronger association with rates of chronic hypertension for Black birthing people compared to White birthing people, indicating healthcare access could contribute to Black-White disparities in HDP. Results of this aim elucidated that geography continues to have a strong relationship with chronic hypertension but is variable for gestational hypertension. These results suggest that areas of care deprivation, such as rural areas and under resourced areas, are detrimental for chronically occurring hypertension among birthing people. This identifies potential opportunities to prevent chronic hypertension through improved resource allocation to the communities where health care may be sparse and improve quality of care for rural communities. Access to health care facilities and the means to afford health care have a stronger impact for Black birthing and prioritizing Black communities is essential for reducing inequities in chronic hypertension.

Aim 3 Summary

We estimated the association of small-area (census tract and county) geographic access to care and HDP types in Georgia to explore how other spatial scales of access to care may be associated with higher rates of hypertension during pregnancy. We also compare reporting of linked hospital discharge records to birth certificate records with respect to chronic and gestational hypertension to examine validity and data quality. Lastly, we were interested in how the rate difference between Black and White birthing people may differ by reporting data source. Overall, birth certificate records consistently underestimate reporting of hypertension types compared to the gold standard of hospital discharge records. When considering the association with access to care, the data sources presented similar associations across the four measures. For race-stratified models, there is consistently a higher burden of chronic hypertension among Black birthing people regardless of record type. Based on hospital discharge records, spatial scale did not change our estimated associations between access to care and HDP type. Overall, we continue to see differences between chronic and gestational hypertension in their relationships to access to care. We found discordance between reporting of hospital discharge records and birth certificate data between both chronic and gestational hypertension. Overall, gestational hypertension reported in the birth certificate is lower than in the hospital discharge data (i.e. birth certificate versus hospital discharge). Using varying spatial scales did not change the conclusions when we changed from county level measures to census tract. These findings differed from the national level (Aim 2), where we do see some relationship of access to care for gestational hypertension in Georgia despite the previous mostly null results. This work emphasizes that it is worth looking at gestational and chronic hypertension separately and that accuracy of classification differs by data source.

Strengths

An overall strength of this dissertation is the use of spatial Bayesian methods to handle smaller area estimates. Bayesian analysis presented solutions for not only identifying counties, but also utilizing the posterior distributions for exceedance probabilities. This work expands on previous studies by including Bayesian modeling techniques to estimate more precise rates at the county scale and in a national setting. The benefit of using the Bayesian smoothing methods addresses the concerns with unstable rate estimates, given rare outcomes and small population sizes. The use of prior information allows for a reduction in random error introduced by sparse data and improvement in stability when compared to an unsmoothed estimate. Our study also extends this research by estimating contextual factors associated with "high-burden" counties. This approach allowed us to contextualize high-burden areas in terms of low versus high rates of chronic and gestational hypertension. There is value in comparing the high burden areas of chronic and gestational hypertension separately to disentangle where place-based associations may differ between the types. Another strength is the use of multiple years of data to address some of the small numbers and suppression concerns of previous work.

A strength of the second and third aims is the use of an access framework to support the selection of access to care proxy measures. We begin to disentangle hypertension types to explore place-based risk factors because there are many commonalities in shared risk factors that it is a challenge to discern between types. Lastly, in the third aim we used multiple spatial scales to address modifiable areal unit problems and see if neighborhood (with census tract as a proxy) may also be valuable in the relationship between hypertension types and access to care measures. There are various challenges to overcome with conducting spatial analyses, including defining appropriate areal units, determining the method for identifying clusters or areas with excess burden, and considerations of small area analysis when there are low case counts. We use multiple spatial scales to take a robust approach to estimation of the relationship of HDP types and access to healthcare.

Limitations

One limitation of Aim 1 and 2 that became evident with the results of the third aim is birth certificate data may be misclassified such that hypertension types are not aligned with hospital discharge records. Irrespective of this limitation, we are still able to pick up a signal in Aim 1 and Aim 2 despite the noise so there is value in using a widely available data source despite potential shortcomings. Another limitation affecting Aim 2 and 3 is the potential for misclassification of hypertension type in relation to access to care. Access to care may be associated with probability of diagnosis with a hypertensive disorder or misclassification of diagnosis. Individuals who do not have contact with the health care system prior to pregnancy may not be screened for hypertension before their prenatal visit and they may not return for care post-partum. The absence of pre-pregnancy contact could make it challenging to make an accurate diagnosis of hypertension type. Thus, access to care could be associated with reporting bias. Although this is a limitation, gestational hypertension is recorded after 20 weeks of pregnancy, so there is an amount of time for a pregnant person to have contact with the healthcare system in order to have blood pressure screening. While not a goal of the present aims, we were unable to disentangle gestational hypertension and preeclampsia using either data type. Just as there is value in learning about the discordance between chronic and gestational hypertension, future research could explore differences between preeclampsia and super-imposed preeclampsia although sample sizes may prove to be quite small. Similarly, access to care continues to be a complicated concept to label as an exposure and we chose proxy measures documented in the literature to attempt to characterize a complex topic. In this dissertation, we are using insurance status and maternal care desert categories to represent having access to care. Although they are not direct measures of the constructs, they are available in the data sources we were leveraging for the analyses, and they have been used in prior literature to examine similar relationships. For example, the presence of nearby providers means that geographically, there are greater opportunities to see a physician, but having a physician in the area does not mean that it is equitable for every person that lives in the area. Additionally, provider type may be more important and number of OBGYN may be better measure or incorporating other disciplines such as nurse practitioners and midwifes could improve representativeness of provider availability. Using a live birth database may introduce bias because birthing people who are hypertensive have greater chances of maternal and fetal mortality and they would be excluded from the live births. Limiting to live births data may underestimate the true burden of HDPs and we may have a competing risk of still births. In these aims we focus on Black/White disparities and other race/ethnic groups are excluded from race stratified analyses. We chose these race groups to emphasize the legacy of racism and disproportionate disenfranchisement of Black people, and to address sample size concerns with less populous minoritized groups. Future research is needed to tailor the study designs to address the unique challenges with systemic racism and interactions with the health care system for other groups like American Indian/Alaskan native populations, Hispanic populations, and undocumented persons face.

Potential impact

Based on this work, we propose potential implications for population health. This work highlights the value in improving accessibility of small area estimation. These tools may help researchers and local health agencies better estimate disease burden and work with special interest groups (i.e. small populations, minoritized groups, rare outcomes). Also, identifies opportunities to prevent chronic hypertension through improved resource allocation to the communities where health care may be sparse and improve quality of care for rural communities. Prioritizing Black communities is essential for reducing inequities in chronic hypertension. Additionally, these findings show that individual risk factors may be more related for gestational hypertension, and we can consider other exposures such as air pollution or other built environment factors. Lastly, this work highlights that health care access is needed across the life course. Measures of access should include specialist care and other health care workers both during and outside of pregnancy and preconception care and experience across the life course is important for chronic conditions and health outcomes, not just in pregnancy.

Future directions

We would like to end this dissertation by highlighting some future directions for this work. First, we propose disentangling preeclampsia types using other surveillance tool, such as Electronic Medical Records, to examine preeclampsia types and differentiate preeclampsia from gestational hypertension. Second, we propose using and considering other measures of access to health such as the implementation of qualitative studies to explore barriers to care seeking. Third, we are interested in monitoring of the post-partum period because access to healthcare is not only needed prior and during pregnancy, but also in the postpartum period. Preeclampsia, eclampsia, and HELLP syndrome can occur up to six weeks postpartum and being near is a provider is critical for these conditions as they are a large proportion of maternal morbidity and mortality.[9,90] Fourth, we propose exploring if discrepancies in reporting are place-based or more common among high-risk sub populations. Geographic drivers of poor reporting could be a valuable sensitivity analysis to extend upon this work. Fifth, a complete bias analysis comparing published validation studies to adjust for bias that may arise from misclassification of hypertensive types, particularly between chronic and gestational hypertension, could support our understanding of reporting error. Lastly, we propose seeking to understand why gestational hypertension does not follow the same trends in racial disparities as chronic hypertension.

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