OBSTETRICS

Severe cardiovascular morbidity in women with hypertensive diseases during delivery hospitalization

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BACKGROUND: Cardiovascular disease is the leading cause of pregnancy-related death in the United States. Identification of short-term indicators of cardiovascular morbidity has the potential to alter the course of this devastating disease among women. It has been established that hypertensive disorders of pregnancy are associated with increased risk of cardiovascular disease 10—30 years after delivery; however, little is known about the association of hypertensive disorders of pregnancy with cardiovascular morbidity during the delivery hospitalization.

OBJECTIVE: We aimed to identify the immediate risk of cardiovascular morbidity during the delivery hospitalization among women who experienced a hypertensive disorder of pregnancy.

MATERIALS AND METHODS: This retrospective cohort study of women, 15—55 years old with a singleton gestation between 2008 and 2012 in New York City, examined the risk of severe cardiovascular morbidity in women with hypertensive disorders of pregnancy compared with normotensive women during their delivery hospitalization. Women with a history of chronic hypertension, diabetes mellitus, or cardiovascular disease were excluded. Mortality and severe cardiovascular morbidity (myocardial infarction, cerebrovascular disease, acute heart failure, heart failure or arrest during labor or procedure, cardiomyopathy, cardiac arrest and ventricular fibrillation, or conversion of cardiac rhythm) during the delivery hospitalization were identified using birth certificates and discharge record coding. Using multivariable logistic regression, we assessed the association between hypertensive disorders of pregnancy and severe cardiovascular morbidity, adjusting for relevant sociodemographic and pregnancy-specific clinical risk factors.

RESULTS: A total of 569,900 women met inclusion criteria. Of those women, 39,624 (6.9%) had a hypertensive disorder of pregnancy: 11,301 (1.9%) gestational hypertension; 16,117 (2.8%) preeclampsia without severe features; and 12,206 (2.1%) preeclampsia with severe features, of whom 319 (0.06%) had eclampsia. Among women with a hypertensive disorder of pregnancy, 431 experienced severe cardiovascular morbidity (10.9 per 1000 deliveries; 95% confidence interval, 9.9—11.9). Among normotensive women, 1780 women experienced severe cardiovascular morbidity (3.4 per 1000 deliveries; 95% confidence interval, 3.2—3.5). Compared with normotensive women, there was a progressively increased risk of cardiovascular morbidity with gestational hypertension (adjusted odds ratio, 1.18; 95% confidence interval, 0.92—1.52), preeclampsia without severe features (adjusted odds ratio, 1.96; 95% confidence interval, 1.66—2.32), preeclampsia with severe features (adjusted odds ratio, 3.46; 95% confidence interval, 2.99—4.00), and eclampsia (adjusted odds ratio, 12.46; 95% confidence interval, 7.69—20.22). Of the 39,624 women with hypertensive disorders of pregnancy, there were 15 maternal deaths, 14 of which involved 1 or more cases of severe cardiovascular morbidity.

CONCLUSION: Hypertensive disorders of pregnancy, particularly preeclampsia with severe features and eclampsia, are significantly associated with cardiovascular morbidity during the delivery hospitalization. Increased vigilance, including diligent screening for cardiac pathology in patients with hypertensive disorders of pregnancy, may lead to decreased morbidity for mothers.

Key words: cardiovascular morbidity, preeclampsia, severe maternal morbidity

Each year in the United States, an increasing number of women are dying from pregnancy-related causes, including complications from cardiovascular disease (CVD).[1,2] In fact, the pregnancy-related mortality ratio has nearly tripled, from 6.8 in 100,000 live births in 1987 to 17.3 in 100,000 live births in 2014.[3,4] Women who die from pregnancy-related complications most often progress through a continuum from health to morbidity, to severe maternal morbidity (SMM), and eventually to death.[5] SMM, as defined by the US Centers for Disease Control and Prevention (CDC), is more common than maternal death. For each maternal death, 75—100 additional women experience severe complications as a result of the pregnancy.[6] Many causes of either maternal mortality or SMM are preventable, with some studies suggesting that 35% to 44% of cases (deaths or SMM) are likely preventable.[2,6—8]

Ten percent of pregnancies worldwide are complicated by hypertensive disorders of pregnancy (HDP); therefore, HDP, including preeclampsia, constitute 1 of the most significant causes of maternal and perinatal morbidity.[9] For every preeclampsia-related death in the United States, there are 50—100 other women who experience "near-miss" significant maternal morbidity that stops short of death but still results in significant healthcare cost.[10] Even though it is well established that preeclampsia and other HDP are associated with SMM such as eclampsia, hemolysis, elevated liver enzymes, low platelet count (HELLP) syndrome, renal failure, and disseminated intravascular coagulation,[11] little is known about the association between HDP and cardiovascular (CV) morbidity and mortality during delivery hospitalization. Cardiovascular

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AJOG at a Glance

Why was this study conducted?

To examine the association between hypertensive disorders of pregnancy and immediate cardiovascular morbidity and mortality during the delivery hospitalization.

Key findings

There is a progressively increased risk of maternal cardiovascular morbidity and mortality with increasing severity of hypertensive disorders of pregnancy.

What does this add to what is known?

Hypertensive disorders of pregnancy are associated with severe morbid cardiovascular complications during delivery hospitalization in a diverse urban cohort.

disease is the leading cause of pregnancy-related death in the United States and the most common reason for mortality in women.[1,12] The California Pregnancy-Associated Mortality Review recently examined a case series of all CV pregnancy-related deaths between 2002 and 2006, and found that one-fifth included a concomitant diagnosis of hypertension or preeclampsia during pregnancy; however, the specific association between HDP and mortality from CVD was not explored in detail.[1] There is a paucity of data on the association between severe cardiac morbidity and HDP during the delivery hospitalization. An analysis by Cain et al was 1 of the first to examine the short-term association of placental syndromes and increased risk of subsequent CVD; however, their analysis did not specifically examine this association during the delivery hospitalization, as they looked on average at a follow-up time of 4.9 years and did not focus exclusively on HDP.[13] Given the increasing maternal morbidity and mortality rates from potentially preventable CV causes, our aim was to analyze the association in the very short-term period of the delivery hospitalization.

To address this gap, our study objective was to examine the association between HDP and severe CV morbidity during the delivery hospitalization, not only to identify those women at greatest risk for maternal mortality and morbidity from CV causes, but also to aid in the prevention of devastating CV events in the immediate peripartum period.

Materials and Methods

We conducted a retrospective cohort study using birth certificate data from the New York City Department of Health and Mental Hygiene linked to hospital discharge data from the Statewide Planning and Resource Cooperative System for all deliveries of a live infant from 2008 to 2012 in New York City.[14,15] The Statewide Planning and Resource Cooperative System (SPARCS) tracks all inpatient hospital discharges; their dataset includes length of stay, International Classification of Diseases, 9th Edition, Clinical Modification (ICD-9-CM) diagnosis and procedure codes, and hospital charges for both maternal and neonatal health records. Of the deliveries in New York City, 99% occur in hospitals, and thus their associated data are included in the SPARCS dataset. The New York State Department of Health matched SPARCS delivery hospitalizations and birth certificates using a validated algorithm created by the state. The analytical sample contained 613,314 total deliveries with 588,232 total birth certificates that successfully matched to a hospital discharge record. The overall match rate was 95.9%.[15]

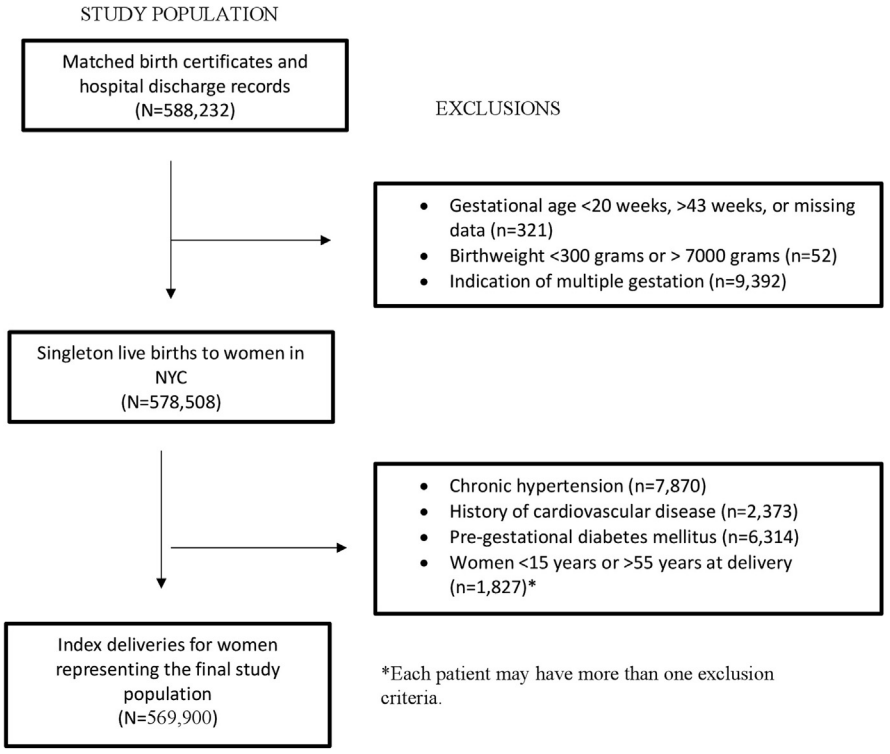
Women with multiple gestations and those who delivered an infant with an implausible gestational age or an implausible birthweight were excluded (Figure 1). We also excluded women with a history of chronic hypertension, pre-pregnancy diabetes mellitus, preexisting CVD defined by ICD-9-CM codes, or a maternal age <15 years or >55 years at delivery. We chose to exclude women with these preexisting medical conditions because of their increased baseline risk for CVD regardless of any HDP.

The primary outcome of incident CV morbidity was measured on the basis of selected ICD-9-CM codes, based on both the CV complications included in the US Center for Disease Control and Prevention (CDC) list of 21 severe maternal complications as well as conditions identified from an analysis by 2 maternal fetal medicine specialists and a cardiologist after review of the existing literature (H.S.L., K.H.C., E.S.).[4] We looked at cardiomyopathy as a separate entity. Although the majority of cardiomyopathies associated with pregnancy are cardiomyopathies secondary to identifiable primary causes, peripartum cardiomyopathy was a more common diagnosis among cardiomyopathy-associated pregnancy-related deaths.[16] All women with the presence of at least 1 ICD-9-CM diagnosis code indicative of myocardial infarction, cerebrovascular disease, acute heart failure, heart failure or arrest during labor or procedure, cardiomyopathy, cardiac arrest and ventricular fibrillation, or an ICD-9-CM procedure code for cardioversion (as noted in the CDC SMM definition) were considered to have a severe CV morbidity. These conditions were examined first as 1 composite measure and then assessed individually. A detailed list of the ICD-9-CM codes used to define CV morbidity is presented in Supplementary Table 1. These conditions were not mutually exclusive (meaning that women may have more than 1 incidence of severe CV morbidity during the delivery hospitalization).

HDP were categorized as gestational hypertension, preeclampsia without severe features (PE), and preeclampsia with severe features (severe PE) including eclampsia. Eclampsia was also analyzed as an independent subset of severe PE. These conditions were defined by ICD-9 codes (Supplementary Table 1).

Maternal demographics, socioeconomic status, and pregnancy-specific medical variables were examined as covariates and potential confounders. Maternal information derived from

FIGURE 1
Flow diagram representing final determination of study population, with inclusion and exclusion criteria that informed the final study population



Ackerman et al. Preeclampsia and immediate cardiovascular morbidity. Am J Obstet Gynecol 2019.

birth certificates included age, parity, race or ethnicity, level of education, insurance status, neighborhood poverty level, adequacy of prenatal care based on the Kotelchuck index, and tobacco use during pregnancy.[17] Neighborhood-based poverty was defined based on household income data from the American Community Survey collected by the US Census Bureau and linked with the delivery record by census tract of residence.[15] Age was categorized as <20, 20−29, 30−34, 35−39, 40−44, and ≥45. These categories were used because advanced maternal age (≥35 years) and teenage pregnancy (<20 years) are associated with increased risk for some complications (Table 1).

We examined bivariate associations between maternal characteristics and HDP status using χ^2 tests. Absolute rates of severe CV morbidity and 95% confidence intervals (CI) were calculated for each type of HDP and each subset of CV morbidity. In addition, the frequency of mortality and association with each of the CV morbidities was calculated. Logistic regression was then used to estimate adjusted odds ratio (aOR) and 95% CIs to express the association of HDP with severe CV morbidity, while adjusting for patient sociodemographic and clinical risk factors. Covariates that were significant in bivariate analysis with a P value <.05 were included in the multivariable model. All potential confounders were significant based on this criterion and thus were retained in the final multivariable logistic regression. Mode of delivery was not included as a potential confounder because cesarean delivery may be in the causal pathway between HDP and severe CV morbidity. Analyses were conducted using SAS System 9.3 (SAS Institute, Cary, NC). The Yale University School of Medicine Human Investigation Committee considered this study exempt.

Results

A total of 588,232 live births were identified in New York City from 2008 through 2012. Births with multiple gestations (n = 9392), infants with a gestational age <20 weeks or >43 weeks (n = 321), or infants with a birthweight <300 g or >7000 g (n = 52), as well as women with a history of chronic hypertension (n = 7870), pre-pregnancy diabetes mellitus (n = 6314), preexisting CVD (n = 2373), or a maternal age <15 or >55 years at delivery (n = 1827) were excluded, leaving a population of 569,900 women (Figure 1).

Of those women, 39,624 (6.9%) had a hypertensive disorder of pregnancy: 11,301 (1.9%) gestational hypertension; 16,117 (2.8%) preeclampsia without severe features (PE); 12,206 (2.1%) severe preeclampsia (severe PE); and 319 (0.008%) of those with severe PE had eclampsia. There were statistically significant differences in maternal age, obesity, health insurance, race/ethnicity, parity, maternal birth place, neighborhood-based poverty, and maternal education among women with HDP compared to normotensive women (P <.001). Women with HDP were more likely to be >35 years of age, obese, and African American, and to have less than a high school education and to have Medicaid insurance (Table 1). In addition, women with a HDP who died were more likely to be African American and older than their normotensive counterparts (Supplementary Table 2).

There were 2217 cases of severe CV morbidity among the study population. The incidence of CV morbidity was significantly higher among women with HDP compared to normotensive controls. Among women with a HDP, the rate of severe CV morbidity was 10.9 per 1000 deliveries (95% CI, 4.3−7.0) (n = 431). Among normotensive women, the rate of severe CV morbidity was 3.4 per 1000 deliveries (95% CI, 3.2−3.5) (n = 1780). The most common CV morbidity among both normotensive women and women with HDP was heart failure or arrest during labor or procedure (n = 1397 for normotensive women; n = 295 for women with HDP), followed by ce-

TABLE 1
Distribution of women with and without HDP by selected maternal sociodemographic and pregnancy-specific medical variables, New York City, 2008–2012

	Normotensive n = 530,276 n (%)	HDP n = 39,624 n (%)	*P* value
Age, y			<.001
<20	28,571 (5.39)	3400 (8.58)	
20–29	242,752 (45.78)	17,203 (43.42)	
30–34	147,788 (27.87)	9516 (24.02)	
35–39	86,730 (16.36)	6835 (17.25)	
40–45	22,792 (4.30)	2405 (6.07)	
>45	1643 (0.31)	265 (0.67)	
Nonobese (BMI, kg/m^2)	303,820 (57.29)	14,383 (36.30)	<.001
Obesity (BMI, kg/m^2)	226,456 (42.69)	25,241 (67.7)	<.001
Class I (BMI 30–34.9)	131,000 (24.70)	11,141 (28.12)	
Class II (BMI 35–39.9)	51,028 (9.62)	7007 (17.68)	
Class III (BMI > 40.0)	27,335 (5.15)	5592 (14.11)	
Missing	17,093 (3.22)	1501 (3.79)	
Health insurance			<.001
Medicaid	307,655 (58.02)	24,574 (62.02)	
Other government (ie Medicare)	8613 (1.62)	741 (1.87)	
Private	200,883 (37.89)	13,144 (33.17)	
Self-pay	7182 (1.35)	689 (1.74)	
Other	3065 (0.58)	194 (0.49)	
Missing	2878 (0.54)	282 (0.71)	
Race/ethnicity			<.001
Black	106,531 (20.09)	13,401 (33.82)	
White	164,672 (31.05)	7854 (19.82)	
Asian Pacific Islander	83,546 (15.76)	3358 (8.47)	
Puerto Rican	39,592 (7.47)	3843 (9.70)	
Other Latina	126,048 (23.77)	10,467 (26.42)	
Other non-Latina	2092 (0.39)	152 (0.38)	
≥2 Races/ethnicities	6953 (1.31)	478 (1.21)	
Unknown	842 (0.16)	71 (0.18)	
Parity			<.001
0	237,870 (44.86)	23,523 (59.37)	
1+	292,013 (55.07)	16,054 (40.52)	
Missing	393 (0.07)	47 (0.12)	

Ackerman et al. Preeclampsia and immediate cardiovascular morbidity. Am J Obstet Gynecol 2019. *(continued)*

rebrovascular disease for normotensive women (n = 160) and cardiomyopathy for women with HDP (n = 62). Women with eclampsia had the highest rates of severe CV morbidity, 56.4 per 1000 deliveries (95% CI, 31.1–81.7) (n = 18). This rate was driven primarily by heart failure or arrest during labor or procedure among women with eclampsia, 28.2 per 1000 deliveries (95% CI, 10.0–46.4) (n = 9) (Table 2).

After adjusting for maternal demographic and social factors, women with a HDP had significantly higher odds of severe CV morbidity during the delivery hospitalization compared to normotensive women (aOR, 2.48; 95% CI, 2.22–2.77). However, when we analyzed each category of HDP, only those women with PE, severe PE or eclampsia had a statistically significant higher odds of severe CV morbidity during the delivery hospitalization. Women with gestational hypertension did not have a higher odds of severe CV morbidity during the delivery hospitalization (aOR, 1.18; 95% CI, 0.92–1.52). There was a statistically significant and progressively increased risk of CV morbidity with PE (aOR, 1.96; 95% CI, 1.66–2.32), severe PE (aOR, 3.46; 95% CI, 2.99–4.00), and eclampsia (aOR, 12.46; 95% CI, 7.69–20.22) (Table 3).

Of the 569,900 women in the study population, there were 41 cases of maternal mortality (rate, 0.07 in 1000 deliveries). Of the 39,624 women with HDP, there were 15 maternal deaths (rate, 0.37 in 1000 deliveries) as compared to a rate of severe CV morbidity of 10.9 in 1000 deliveries. In all, 93.3% of the cases of maternal mortality among women with HDP had 1 or more cases of severe CV morbidity. Cardioversion was the most common severe CV morbidity among those women with HDP who died (n = 7), followed by heart failure or arrest during labor or procedure (n = 5), and cardiac arrest or ventricular fibrillation (n = 5) (Supplementary Table 3).

Comment

In this large retrospective cohort study, we found that women with PE, severe PE, and eclampsia had a significantly increased odds for severe CV morbidity during the delivery hospitalization, whereas women with gestational hypertension did not have an increased risk for CV disease when compared to normotensive women. This association was driven primarily by heart failure or arrest during labor or procedure. The more

TABLE 1
Distribution of women with and without HDP by selected maternal sociodemographic and pregnancy-specific medical variables, New York City, 2008–2012 *(continued)*

	Normotensive n = 530,276 n (%)	HDP n = 39,624 n (%)	*P* value
Birthplace			<.001
US-born	254,566 (48.01)	21,276 (53.69)	
Foreign-born	275,368 (51.93)	18,330 (46.26)	
Missing	342 (0.06)	18 (0.05)	
Neighborhood-based poverty			<.001
<10%	75,871 (14.31)	4430 (11.18)	
10 to <20%	152,402 (28.74)	10,908 (27.53)	
20 to <30%	140,018 (26.40)	11,231 (28.34)	
>30%	122,065 (23.02)	10,489 (26.47)	
Missing	39,920 (7.53)	2566 (6.48)	
Maternal education			<.001
Less than high school	124,217 (23.42)	9855 (24.87)	
High school graduate	120,834 (22.79)	8980 (22.66)	
Some college	114,390 (21.57)	10,253 (25.88)	
College graduate or higher	168,892 (31.85)	10,322 (26.05)	
Missing	1943 (0.37)	214 (0.54)	

BMI, body mass index.
Ackerman et al. Preeclampsia and immediate cardiovascular morbidity. Am J Obstet Gynecol 2019.

severe the HDP, the greater the magnitude of association with severe CV morbidity, with an approximately 2.5-fold increase for severe PE and 12.5-fold increase for eclampsia.

In response to increasing rates of both maternal mortality and SMM, there are numerous renewed calls to focus on maternal health from a public health perspective.[14] National strategies include increased collaboration among maternal health stakeholders such as maternity providers from multiple professions, facility-based review of SMM cases, and the development of national guidelines or bundles that target the most common underlying causes.[18,19] Data from the California Pregnancy Associated Mortality Review (CA-PAMR) of deaths occurring from 2002 to 2006 show that CVD accounts for >33% of all pregnancy-related deaths in the United States and 25% of pregnancy-related deaths in California (2002–2006), and only a small fraction of these women had a known diagnosis of CVD prior to death.[1] The investigators also found that 25% of these deaths may have been prevented if heart disease had been diagnosed earlier.[1]

In an effort to reverse the increasing rates of preventable maternal mortality and "near-miss" SMM, the American College of Obstetricians and Gynecologists (ACOG) recently launched the Safe Motherhood Initiative. The Safe Motherhood Initiative includes the Maternal Safety Bundle for Severe Hypertension in Pregnancy, which outlines strict recommendations for treatment of severe maternal hypertension in the antepartum, intrapartum, and postpartum periods.[19] This ground-breaking initiative has informed several state-wide collaboratives such as in Illinois and California aimed at effectively implementing ACOG recommendations for treatment of severe hypertension to reduce rates of SMM.[20] These initiatives include recommendations for heightened awareness for cardiopulmonary symptomology and a suggestion for yearly monitoring of blood pressure, lipids, fasting blood glucose, and body mass index to prevent long-term CVD. These recommendations by ACOG dovetail with the American Heart Association (AHA) statement that preeclampsia is an established risk factor for CVD and can be considered equivalent to a failed stress test. Thus, the AHA recommends any patient with a history of preeclampsia undergo an evaluation for other CV disease risk factors including obesity, smoking, and hyperlipidemia.[21] These bundles by both ACOG and AHA are critically important in addressing acute management of severe hypertension; however, a review of the current hypertensive bundle as proposed by ACOG and the Safe Motherhood Initiative does not highlight the unique risk of CV morbidity in the peripartum period for women with preeclampsia. Although the postdischarge evaluation does mention evaluating for signs of congestive heart failure in the home/office or triage, this is not part of the immediate postpartum checklist, as compared to brain imaging if unremitting headache or neurological symptoms occur. Increased vigilance should occur as soon as HDP is diagnosed in the antepartum period, intensified during the delivery hospitalization, and continued through with earlier postpartum visits or home evaluations. Given the findings in our study, we would recommend a low threshold for CV evaluation, especially in women who had preeclampsia. Specifically, any patient with a cardiopulmonary symptom that does not resolve with initial conservative measures or is associated with vital sign abnormalities warrants further diagnostic evaluation. We recommend revision of the current bundle to include a low threshold for further cardiopulmonary evaluation including an electrocardiogram, echocardiogram, and cardiology referral. Clinicians need to be alert to the symptoms of congestive heart failure, including shortness of breath,

TABLE 2
Rates of cardiovascular morbidity by type (rates per 1000 deliveries with 95% confidence intervals) for women with hypertensive disorders of pregnancy[a]

	Normotensive n = 530,276		All HDP n = 39,624		GHTN n = 11,301		PE n = 16,117		Severe PE n = 12,206		Eclampsia n = 319	
Cardiovascular outcomes/procedures	No.	Rate per 1000 (95% CI)	No.	Rate per 1000 (95% CI)	No.	Rate per 1000 (95% CI)	No.	Rate per 1000 (95% CI)	No.	Rate per 1000 (95% CI)	No.	Rate per 1000 (95% CI)
Any cardiovascular morbidity	1780	3.4 (3.2–3.5)	431	10.9 (9.9–11.9)	64	5.7 (4.3–7.0)	153	9.5 (8.0–11.0)	214	17.5 (15.2–19.9)	18	56.4 (31.1–81.7)
Myocardial infarction	13	0.02 (>0.0 to <0.03)	4	0.1 (<0.01 to 0.2)	1	0.09 (>0.0 to <0.3)	2	0.12 (>0.0 to <0.3)	1	0.08 (>0.0 to <0.2)	0	0
Cerebrovascular disease	160	0.3 (0.3–0.3)	53	1.33 (1.0–1.7)	4	0.4 (0.1–0.9)	16	1.0 (0.5–1.5)'	33	2.7 (1.8–3.6)	6	18.8 (3.9–33.7)
Acute heart failure	60	0.1 (0.1–0.1)	39	1.0 (0.7–1.3)	4	0.4 (0.1–0.9)	5	0.3 (0.1–0.7)	30	2.5 (1.6–3.3)	0	–
Heart failure/arrest during labor or procedure	1397	2.6 (2.5–2.8)	295	7.4 (6.6–8.3)	48	4.2 (3.0–5.4)	116	7.2 (5.9–8.5)	131	10.7 (9.0–12.7)	9	28.2 (10.0–46.4)
Cardiomyopathy	168	0.3 (0.3–0.4)	62	1.6 (1.2–2.0)	9	0.8 (0.3–1.3)	19	1.2 (0.6–1.7)	34	2.8 (1.9–3.9)	3	9.4 (1.9–27.2)
Cardiac arrest/ventricular fibrillation	21	0.04 (>0.0 to <0.1)	11	0.3 (0.1–0.4)	0	0	2	0.1 (<0.0 to <0.4)	9	0.7 (0.3–1.2)	2	6.3 (0.8–22.5)
Conversion of cardiac rhythm	32	0.06 (>0.0 to <0.1)	9	0.2 (0.1–0.4)	0	0	4	0.25 (0.1–0.6)	5	0.4 (0.1–0.8)	1	3.1 (0.1–17.3)

CI, confidence interval; *GHTN*, gestational hypertension; *HDP*, hypertensive disorders of pregnancy; *PE*, preeclampsia.

[a] Cardiovascular morbidity subtypes are not mutually exclusive.

Ackerman et al. Preeclampsia and immediate cardiovascular morbidity. Am J Obstet Gynecol 2019.

exertional dyspnea, orthopnea, paroxysmal nocturnal dyspnea and lower extremity edema. Recognizing that these symptoms often overlap with symptoms of pregnancy, clinicians should have a low threshold to obtain an echocardiogram and a cardiology consultation. In addition, any symptoms of chest pain should raise concern and should prompt immediate referral to a cardiologist.[22] These recommendations are based on expert opinion, given the results of this study; however, further research on how to optimize care of the parturient and postpartum patient at risk for CV morbidity is essential.

Our study has several important strengths. Primarily, the database included a large cohort of women with HDP (n > 39,000). The robust database was comprehensive and allowed for the adjustment of multiple CV disease risk factors in our statistical model. Furthermore, our study sample came from an urban city and consisted of an ethnically and socioeconomically diverse population. Hence our results can be instrumental for informing future research and policy discussion and may be generalizable to other urban populations.

However, our study also has limitations. The validity of birth certificate data had been called into question.[23] A previous evaluation found that NYC birth certificates were 100% complete in regard to variables such as maternal demographics, but only approximately 95% specific and 72% sensitive regarding maternal and neonatal characteristics.[24] We linked birth certificate and hospital discharge data and thus, significantly improved the quality of the clinical outcomes data.[25] In addition, our study captured only those instances of CV morbidity that occurred within the immediate postpartum period during the delivery hospitalization, potentially underestimating the true incidence. Although data were collected from delivery hospitalizations and thus offered insight into short-term CV risks, it was not possible to differentiate between CV complications during extended antepartum and intrapartum/postpartum periods. However, CVD was coded during this hospitalization and

TABLE 3
Overall risk of severe cardiovascular morbidity during delivery hospitalization in women with HDP compared to normotensive women

	Unadjusted OR (95% CI)	Adjusted OR (95% CI)[a]
All HDP	3.27 (2.94–3.63)	2.48 (2.22–2.77)
GHTN	1.48 (1.15–1.89)	1.18 (0.92–1.52)
PE	2.57 (2.18–3.03)	1.96 (1.66–2.32)
Severe PE	4.97 (4.31–5.72)	3.46 (2.99–4.00)
Eclampsia (subset of severe PE)	15.47 (9.60–24.94)	12.46 (7.69–20.22)

CI, confidence interval; *GHTN,* gestational hypertension; *HDP,* hypertensive disorders of pregnancy; *OR,* odds ratio; *PE,* preeclampsia.

[a] Adjusted for race/ethnicity, medical insurance, neighborhood-based poverty, maternal education, parity, obesity, and maternal age.

Ackerman et al. Preeclampsia and immediate cardiovascular morbidity. Am J Obstet Gynecol 2019.

therefore was relevant to the period surrounding delivery.

In addition, there were several limitations related to the use of ICD-9 codes. First, the codes for cerebrovascular disease did not specify the etiology of the cerebrovascular disease. Therefore, we were unable to distinguish between cerebrovascular diseases secondary to ischemia versus that secondary to hemorrhage. Second, the ICD-9 code for cardioversion did not differentiate between mechanical cardioversion with defibrillation versus medical cardioversion. Finally, a significant amount of data on substance abuse, particularly smoking use, was missing from the dataset. As smoking is an important risk factor for CVD disease, it should be included if possible in any additional data collection and analysis.

In summary, the association of preeclampsia with short-term cardiovascular morbidity during the delivery hospitalization is extremely relevant to both clinicians and researchers as we work together to implement preventive measures from both a clinical and policy perspective. Increased vigilance, including diligent screening for cardiac and vascular pathology in patients with hypertensive disorders of pregnancy, has significant potential to decrease morbidity for mothers. Further investigation is needed to determine the most-effective screening methods to prevent the potentially devastating cardiovascular complications in women with hypertensive disorders of pregnancy. ■

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SUPPLEMENTARY TABLE 1

Diagnosis and procedure codes used to identify selected clinical conditions

Condition	ICD-9-CM codes
Hypertensive disorder of pregnancy	
Gestational hypertension	642.3x
Preeclampsia without severe features	642.4, 642.9
Preeclampsia with severe features	642.5x, 642.6x
Eclampsia (subset of severe preeclampsia)	642.6x
Chronic hypertension	401—405x, 642.0x, 642.1x, 642.2x, 642.7x
Superimposed preeclampsia	642.7x
Cardiovascular outcomes	
Myocardial infarction	410x
Cerebrovascular disease	430—437x, 671.5x, 674.0x, 997.02
Acute heart failure	428.1, 428.0, 428.21, 428.23, 428.31, 428.33, 428.41, 428.43
Heart failure/arrest during labor or procedure	669.4, 997.1
Cardiomyopathy	674.5, 425.x
Cardiac arrest/ventricular fibrillation	427.41, 427.5
Conversion of cardiac rhythm	99.6x
Clinical comorbidities	
Pregestational diabetes mellitus	249x, 250x, 648.0x

ICD-9-CM, International Classification of Diseases, Ninth Revision, Clinical Modification.

Ackerman et al. Preeclampsia and immediate cardiovascular morbidity. Am J Obstet Gynecol 2019.

SUPPLEMENTARY TABLE 2

Distribution of maternal deaths in women with and without HDP by selected maternal sociodemographic and pregnancy-specific medical variables, New York City, 2008–2012

	Maternal deaths among normotensive women n = 26 (%)	Maternal deaths among HDP women n = 15 (%)
Age, y		
<20	4 (15.4)	0 (0)
20–29	9 (34.6)	4 (26.7)
30–34	6 (23.1)	8 (53.3)
35–39	4 (15.4)	1 (6.7)
40–45	3 (11.5)	2 (13.3)
>45	0 (0)	0 (0)
Nonobese (BMI kg/m^2)	11 (42.3)	4 (26.7)
Obesity (BMI kg/m^2)		
Class I (BMI 30–34.9)	7 (26.9)	3 (20.0)
Class II (BMI 35–39.9)	0 (0)	3 (20.0)
Class III (BMI > 40.0)	3 (11.5)	3 (20.0)
Missing	5 (19.2)	2 (13.3)
Health insurance		
Medicaid	16 (61.5)	12 (80.0)
Other government (ie, Medicare)	3 (20.0)	0 (0)
Private	7 (26.9)	3 (20.0)
Self-pay	1 (3.9)	0 (0)
Other	1 (3.9)	0 (0)
Missing	1 (3.9)	0 (0)
Race/ethnicity		
Black	9 (34.6)	12 (80.0)
White	1 (3.9)	1 (6.7)
Asian Pacific Islander	6 (23.1)	1 (6.7)
Puerto Rican	1 (3.9)	0 (0)
Other Latina	9 (34.6)	1 (6.7)
Other non-Latina	0 (0)	0 (0)
≥2 Races/ethnicities	0 (0)	0 (0)
Unknown	0 (0)	0 (0)
Parity		
0	13 (50.0)	7 (46.7)
1+	12 (46.2)	8 (53.3)
Missing	1 (3.9)	0 (0)
Birthplace		
US-born	8 (30.8)	6 (40)
Foreign-born	18 (69.2)	9 (60)
Missing	0 (0)	0 (0)

Ackerman et al. Preeclampsia and immediate cardiovascular morbidity. Am J Obstet Gynecol 2019. *(continued)*

SUPPLEMENTARY TABLE 2

Distribution of maternal deaths in women with and without HDP by selected maternal sociodemographic and pregnancy-specific medical variables, New York City, 2008–2012 *(continued)*

	Maternal deaths among normotensive women n = 26 (%)	Maternal deaths among HDP women n = 15 (%)
Neighborhood-based poverty		
<10%	2 (7.7)	1 (6.7)
10 to <20%	6 (23.1)	4 (26.7)
20 to <30%	13 (50.0)	5 (33.3)
>30%	4 (15.4)	5 (33.3)
Missing	1 (3.9)	0 (0)
Maternal Education		
Less than high school	7 (26.9)	2 (13.3)
High school graduate	9 (34.6)	5 (33.3)
Some college	6 (23.1)	4 (26.7)
College graduate or higher	4 (15.4)	1 (6.7)
Missing	0 (0)	3 (20.0)

BMI, body mass index; *HDP,* hypertensive disorders of pregnancy.

Ackerman et al. Preeclampsia and immediate cardiovascular morbidity. Am J Obstet Gynecol 2019.

SUPPLEMENTARY TABLE 3

Distribution of deaths associated with cardiovascular morbidity in the cohort

	Normotensive women n = 26 (%)	HDP women n = 15 (%)
Any cardiovascular morbidity	16 (61.5)	14 (93.3)
Myocardial infarction	1 (3.8)	1 (6.7)
Cerebrovascular disease	2 (7.7)	2 (13.3)
Acute heart failure	0 (0)	1 (6.7)
Heart failure/arrest during labor or procedure	7 (26.9)	5 (33.3)
Cardiomyopathy	0 (0)	1 (6.7)
Cardiac arrest/ventricular fibrillation	9 (34.6)	5 (33.3)
Conversion of cardiac rhythm	12 (46.1)	7 (46.7)
No cardiovascular morbidity	10 (38.5)	1 (6.7)

HDP, hypertensive disorders of pregnancy.

Ackerman et al. Preeclampsia and immediate cardiovascular morbidity. Am J Obstet Gynecol 2019.