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ORIGINAL RESEARCH

Trends, Predictors, and Outcomes of Cardiovascular Complications at Delivery Associated With Gestational Diabetes: A National Inpatient Sample Analysis (2004–2019)

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BACKGROUND: Gestational diabetes (GD) is associated with increased risk of long-term cardiovascular complications. However, data on acute peripartum cardiovascular complications are not well established. Hence, we aimed to investigate the association of GD with acute cardiovascular outcomes at the time of delivery admission.

METHODS AND RESULTS: We used data from the National Inpatient Sample (2004–2019). *International Classification of Diseases, Ninth Revision* (*ICD-9*) or *Tenth Revision* (*ICD-10*) codes were used to identify delivery hospitalizations and GD diagnosis. A total of 63 115 002 weighted hospitalizations for deliveries were identified, of which 3.9% were among individuals with GD (n=2 435 301). The prevalence of both GD and obesity increased during the study period (*P* trends<0.01). Individuals with GD versus those without GD had a higher prevalence of obesity, hypertension, and dyslipidemia. After adjustment for age, race or ethnicity, comorbidities, insurance, and income, GD remained independently associated with cardiovascular complications including preeclampsia (adjusted odds ratio [aOR], 1.97 [95% CI, 1.96–1.98]), peripartum cardiomyopathy (aOR, 1.15 [1.08–1.22]), acute kidney injury (aOR, 1.16 [1.11–1.21]), stroke (aOR, 1.15 [1.09–1.23]), and arrhythmias (aOR, 1.48 [1.46–1.50]), compared with no GD. Moreover, delivery hospitalizations among individuals with GD were associated with increased length (3 versus 2 days, *P*<0.01) and cost of hospitalization ($4909 versus $3682, *P*<0.01). Even in the absence of preeclampsia, GD was associated with elevated cardiovascular risk.

CONCLUSIONS: Individuals with GD had a higher risk of preeclampsia, peripartum cardiomyopathy, acute kidney injury, stroke, and arrhythmias during delivery hospitalizations. As rates of GD are increasing globally, efforts to improve preconception cardiometabolic health and prevent GD may represent important strategies to improve peripartum maternal outcomes and mitigate long-term cardiovascular risk.

Key Words: cardiovascular disease prevention ■ gestational diabetes ■ peripartum cardiomyopathy ■ preeclampsia

Gestational diabetes (GD) is defined as the new onset of hyperglycemia during pregnancy[1] and is known to affect up to 10% of the pregnancies in the United States.[1–4] The prevalence of GD is also rising worldwide.[1,5,6] According to a recent study, the rates of GD across all races and ethnicities in the United States have increased from 2011 to 2019.[5] Individuals who are diagnosed with GD have nearly 10-fold increased risk of

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CLINICAL PERSPECTIVE

What Is New?

- Gestational diabetes is independently associated with an increased risk of cardiovascular complications at the time of delivery hospitalization, including preeclampsia, peripartum cardiomyopathy, stroke, pulmonary edema, and cardiac arrhythmias.

What Are the Clinical Implications?

- Gestational diabetes is associated with heightened risk of adverse cardiovascular outcomes peripartum, and this was seen even in the absence of preeclampsia.
- Our study highlights that individuals with gestational diabetes should be counseled on the possible risk of developing acute in-hospital cardiovascular complications.
- These findings underscore the importance of optimizing cardiovascular health before, during, and after pregnancy to prevent gestational diabetes and its associated adverse cardiovascular complications.

Nonstandard Abbreviations and Acronyms

GD	gestational diabetes
NIS	National Inpatient Sample
PCOS	polycystic ovary syndrome
PPCM	peripartum cardiomyopathy

developing type 2 diabetes,[7] as well as 2-fold higher risk of incident cardiovascular disease (CVD).[8] Furthermore, the long-term risks of developing subclinical and clinical CVD associated with GD remain elevated even among those who return to and maintain normoglycemia after pregnancy.[8–11] Although these long-term risks of GD are well-described, the data on acute cardiovascular complications associated with GD at the time of delivery are less well established.

Patients with hypertensive disorders of pregnancy are known to be at an elevated risk for peripartum cardiomyopathy (PPCM).[12] However, it is less clear if patients with GD alone have an increased risk of developing acute cardiovascular complications during delivery admissions in the absence of preeclampsia. Meanwhile, in patients with GD, the predictors of PPCM have not been described, and it is not well known if GD acts independently as a risk factor for PPCM. PPCM is associated with high mortality rates ranging from 18% to 56%[13,14]; thus it is imperative that we evaluate possible risk factors for PPCM and acute peripartum cardiovsacular complications including GD, to implement preventive strategies aimed at reducing the rising maternal mortality rates.[15,16]

Hence, we aimed to study the trends, outcomes, and predictors of acute peripartum cardiovascular complications associated with GD during delivery hospitalizations. We hypothesize that GD is independently associated with acute cardiovascular complications, including PPCM, at the time of delivery.

METHODS

The National Inpatient Sample (NIS) data are publicly available. The specific data supporting this study's findings are available from the corresponding author upon request.

Study Data

This study used data from the NIS database from 2004 to 2019. The NIS is managed by the Agency for Healthcare Research and Quality through a federal-state-industry partnership called the Healthcare Cost and Utilization Project.[17,18] The NIS contains administrative claims data from more than 7 million inpatient hospitalizations annually in 47 participating states plus the District of Columbia, representing more than 97% of the US population. Because NIS data are compiled annually, the data can be used for the analysis of disease trends over time using trend weights compiled by the Healthcare Cost and Utilization Project. For the cost of care, charge to cost ratio supplied by the Healthcare Cost and Utilization Project derived from the Centers for Medicare and Medicaid Services was applied to total hospital charges.[19] This study was deemed exempt from institutional review board approval and informed consent because NIS data are de-identified and publicly available.

Study Design and Data Selection

We analyzed NIS data using *International Classification of Diseases, Ninth Revision, Clinical Modification* (*ICD-9-CM*) and *International Classification of Diseases, Tenth Revision, Clinical Modification* (*ICD-10-CM*) claims codes. We first identified delivery hospitalizations for adult patients (age≥18) using *ICD-9-CM* and *ICD-10-CM* codes (Table S1).[20] Among the selected cases, we used *ICD-9-CM* code 648.8 and *ICD-10-CM* code 0244x to identify delivery hospitalizations with GD. All diagnosis fields were queried to select and categorize the study population. Among the GD group, 0.1% (n=1695) had a secondary diagnosis of preexisting diabetes. This was deemed to be a coding error and hence we excluded these patients from the analysis as GD by definition is new-onset hyperglycemia during pregnancy. The key findings and a detailed flow chart are presented in Figures 1 and 2, respectively.

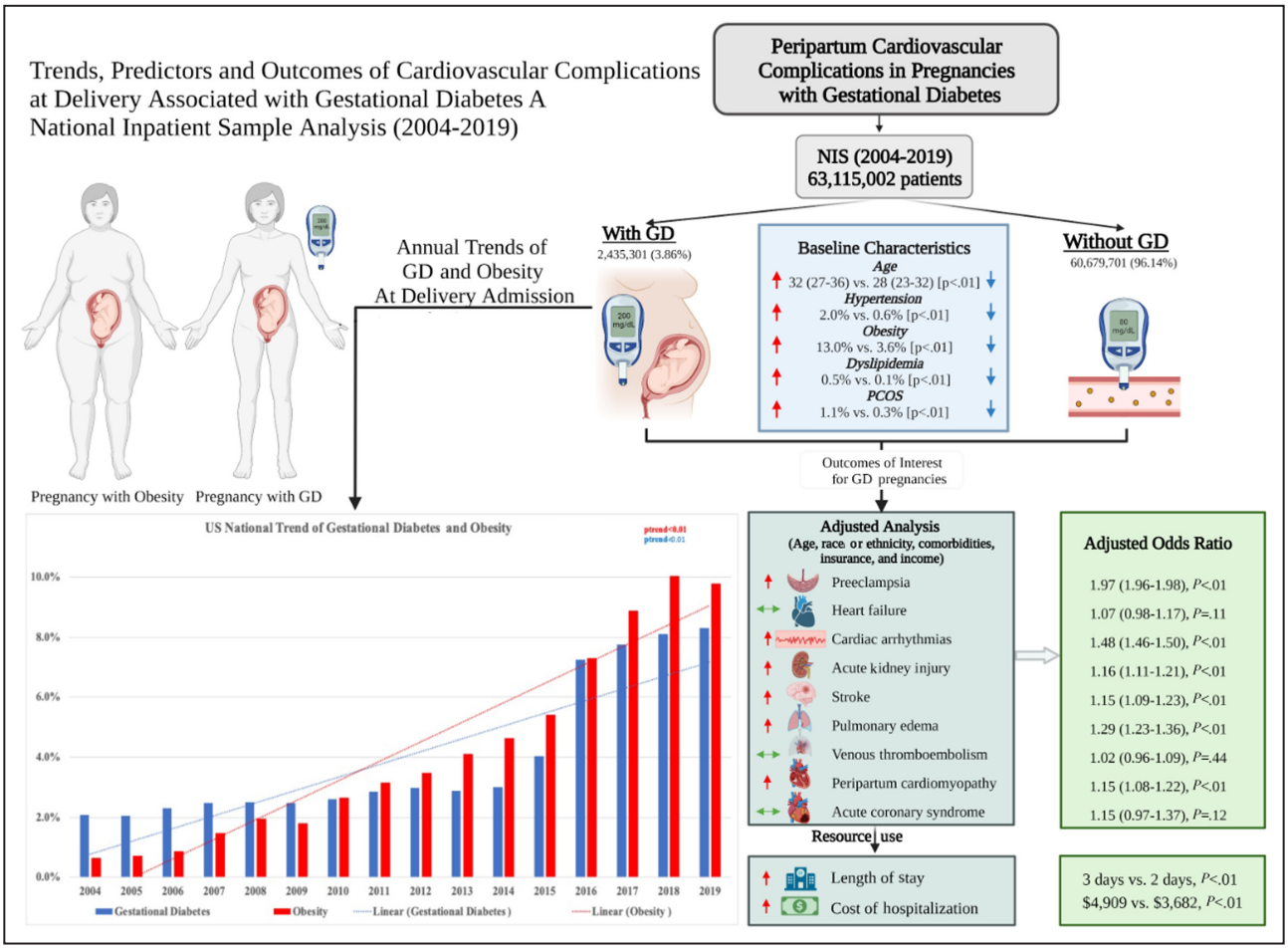

Figure 1. Key study findings.
Reported numbers are based on weighted hospitalizations. GD indicates gestational diabetes; and PCOS, polycystic ovary syndrome.

Study End Point

The coprimary study end points were preeclampsia, PPCM, and heart failure. Secondary end points included eclampsia, acute coronary syndrome, ischemic and hemorrhagic stroke, pulmonary edema, cardiac arrhythmias, acute kidney injury, venous thromboembolism, length of stay, and cost of hospitalization. Associated procedures and complications were identified using *ICD-9-CM* and *ICD-10-CM* codes. Because of the low number of eclampsia cases in the sample, they were categorized as preeclampsia (Table S1).

Statistical Analysis

Descriptive statistics were presented as frequencies with percentages for categorical variables and as medians with interquartile range for continuous variables. Baseline characteristics were compared using a Pearson chi-square test or Fisher's exact test as appropriate for categorical variables and the Mann–Whitney *U* test for continuous variables. Simple linear regression was used to assess temporal trends for GD and obesity during our study period. In the trend analysis, the calendar year was included as an independent variable whereas GD and obesity were used as the dependent variables. The *P* value for the slope was used to assess temporal trends.

Unadjusted odds ratios (OR) were derived using Cochran–Mantel–Haenszel test test. A multivariable logistic regression model was fitted to test the association of GD with in-hospital outcomes, adjusted for age, race or ethnicity, hospital region, prepregnancy comorbidities (chronic hypertension, dyslipidemia, heart failure, chronic kidney disease, coronary artery disease, obesity, polycystic ovary syndrome [PCOS]), smoking, multiple gestation, cesarean delivery, median household income, and primary insurance (Data S1). Given the known association of GD and preeclampsia/eclampsia,[21] we performed a sensitivity analysis by excluding these cases of preeclampsia/eclampsia, and retested the evaluation using the aforementioned multivariable logistic regression model to see if GD was associated with acute cardiovascular complications in the absence of preeclampsia/eclampsia. Similarly, a supplementary analysis was also performed after excluding cases of preexisting coronary artery disease, chronic heart failure,

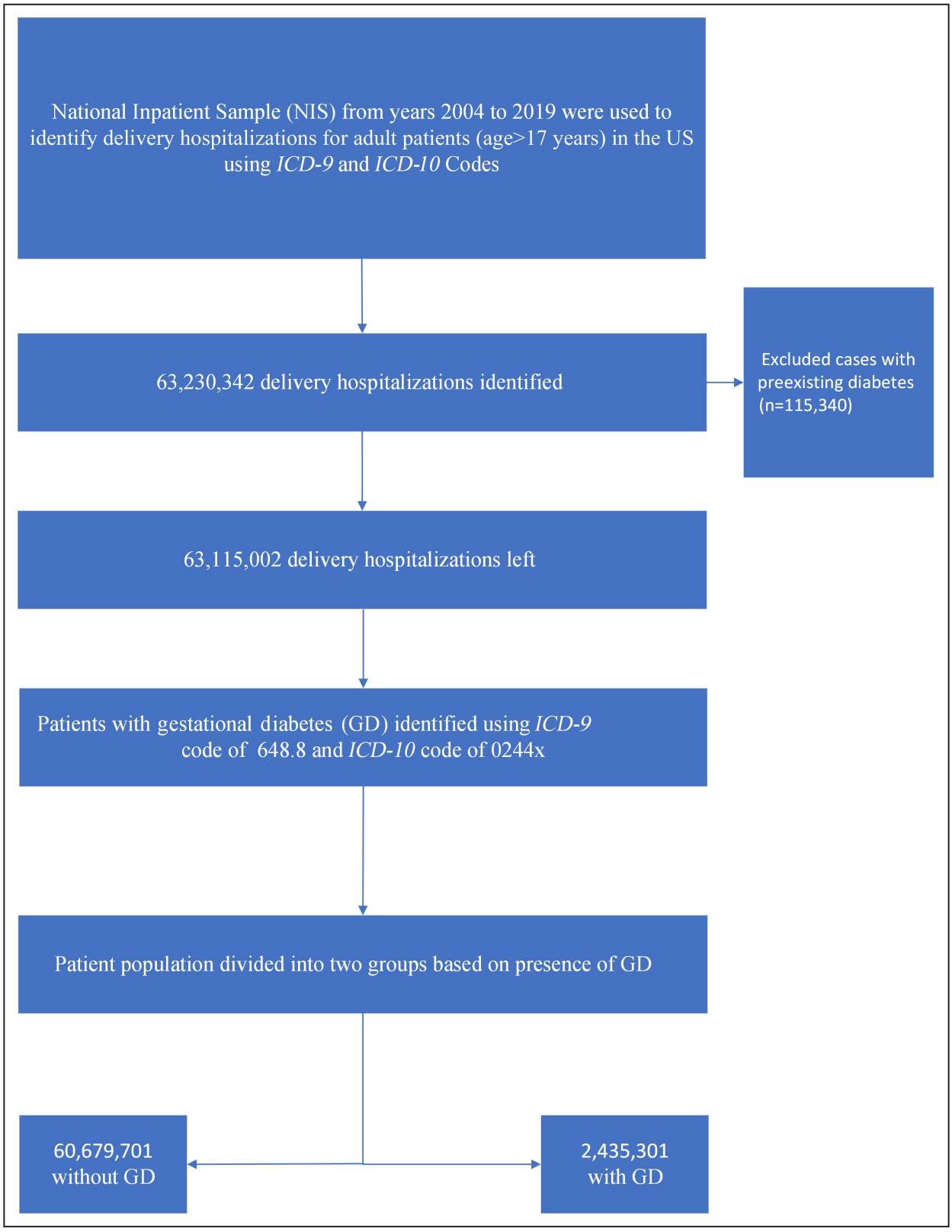

Figure 2. Study flow chart.
Reported numbers are based on weighted hospitalizations. GD indicates gestational diabetes; *ICD-9*, *International Classification of Diseases, Ninth Revision*; and *ICD-10*, *International Classification of Diseases, Tenth Revision*.

and chronic kidney disease to retest the association between GD and peripartum cardiovascular complications.

We assessed potential predictors of our primary outcome of PPCM among individuals with GD using a multivariable logistic regression model adjusted for age, race or ethnicity, hospital region, chronic hypertension, dyslipidemia, chronic kidney disease, coronary artery disease, obesity, PCOS, smoking, multiple gestation, cesarean delivery, median household income, and primary insurance (Data S2). A similar analysis was also performed in patients without GD to evaluate predictors of patients with PPCM.

To test differences in cardiovascular complications by race or ethnicity, we restricted analysis to patients with GD for White, Black, Hispanic, Asian or Pacific Islander, and Native individuals. A multivariable logistic regression model was constructed to test the association of race or ethnicity with in-hospital outcomes, adjusted for age, hospital region, chronic hypertension, dyslipidemia, heart failure, chronic kidney disease, coronary artery disease, obesity, PCOS, smoking, multiple gestation, cesarean delivery, median household income, and primary insurance. All covariates were selected based on prior literature review. The missing values present in the data set are reported in Table 1. The missing values were predominantly present in the race or ethnicity (13.6%) variable, which was recoded with the "Other" category. Given the overall low number of missing data (<1.6%) in other variables, we used listwise deletion and did not include missing data in the logistic regression analysis.

All statistical analyses were performed using Statistical Package for Social Science version 27 (IBM Corp). Given the complex survey design of NIS, sample weights, clusters and strata were applied to generate US national estimates.

RESULTS

Hospitalization Characteristics of the Study Population

A total of 63 115 002 weighted hospitalizations for deliveries were identified in the United States from 2004 to 2019. Of the included patients, 3.9% had a diagnosis of GD. Patients with GD had a higher median age of 32 years compared with 28 years for patients without GD. Individuals with versus without GD were less likely to be White and more likely to be Hispanic. Obesity, PCOS, chronic hypertension, and dyslipidemia were more frequent in the GD group when compared with patients without GD. The detailed baseline characteristics are given in Table 1.

Trends for Prevalence of GD and Obesity

During the study duration, the prevalence of GD increased from 2.1% in 2004 to 8.3% in 2019 (Table 1).

Table 1. Characteristics of Delivery Hospitalizations With and Without GD

Variable n (%)	Without GD (60 679 701)	With GD (2435301)	*P* value
Demographics and calendar year			
Age, y (median, interquartile range)	28 (23–32)	32 (27–36)	<0.01
Race or ethnicity			<0.01
White	27 846 783 (45.9)	1 004 121 (41.2)	
Black	7 472 351 (12.3)	270 854 (11.1)	
Hispanic	11 444 970 (18.9)	551 728 (22.7)	
Asian or Pacific Islander	2 775 377 (4.6)	239 914 (9.9)	
Native American	398 216 (0.7)	23 448 (1.0)	
Other*	10 742 004 (17.7)	345 236 (14.2)	
Hospital regions			<0.01
Northeast	10 077 907 (16.6)	384 799 (15.8)	
Midwest	12 934 919 (21.3)	484 136 (19.9)	
South	23 075 014 (38.0)	867 486 (35.6)	
Year			<0.01
2004	4 156 894 (97.9)	87 739 (2.1)	
2005	4 134 063 (97.9)	86 630 (2.1)	
2006	4 187 836 (97.7)	98 898 (2.3)	
2007	4 443 962 (97.5)	112 528 (2.5)	
2008	4 134 852 (97.5)	105 690 (2.5)	
2009	4 038 877 (97.5)	102 490 (2.5)	
2010	3 813 032 (97.4)	102 305 (2.6)	
2011	3 760 161 (97.2)	110 182 (2.8)	
2012	3 710 826 (97.0)	113 885 (3.0)	
2013	3 697 113 (97.1)	109 700 (2.9)	
2014	3 756 855 (97.0)	116 470 (3.0)	
2015	3 380 600 (96.0)	142 465 (4.0)	
2016	3 479 841 (92.7)	272 190 (7.3)	
2017	3 390 606 (92.2)	284 990 (7.8)	
2018	3 320 809 (91.9)	293 165 (8.1)	
2019	3 273 374 (91.7)	295 975 (8.3)	
Preexisting comorbidities			
Polycystic ovary syndrome	162 588 (0.3)	27 780 (1.1)	<0.01
Dyslipidemia	80 940 (0.1)	11 442 (0.5)	<0.01
Chronic hypertension	365 488 (0.6)	48 375 (2.0)	<0.01
Heart failure	36 498 (0.1)	3010 (0.1)	<0.01
Chronic kidney disease	9021 (0.0)	611 (0.0)	<0.01
Coronary artery disease	6787 (0.0)	646 (0.0)	<0.01
Obesity	2 201 319 (3.6)	316 404 (13.0)	<0.01
Smoking	1 151 272 (1.9)	55 535 (2.3)	<0.01
Obstetric characteristics			
Multiple gestation	1 125 874 (1.9)	88 880 (3.6)	<0.01
Cesarean delivery	18 686 405 (30.8)	1 222 301 (50.2)	<0.01

(*Continued*)

Table 1. Continued

Variable n (%)	Without GD (60 679 701)	With GD (2435301)	*P* value
Preterm birth	4 351 804 (7.2)	300 699 (12.3)	<0.01
Still birth	414 422 (0.7)	14 888 (0.6)	<0.01
Socioeconomic characteristics			
Median household income			<0.01
0–25th percentile	16 359 581 (27.4)	610 398 (25.4)	
26–50th percentile	14 965 650 (25.1)	597 310 (24.9)	
51–75th percentile	14 689 095 (24.6)	617 087 (25.7)	
76–100th percentile	13 666 407 (22.9)	577 220 (24.0)	
Missing	998 967 (1.6)	33 286 (1.4)	
Primary insurance			<0.01
Medicare	405 412 (0.7)	21 268 (0.9)	
Medicaid	25 482 953 (42.1)	978 327 (40.2)	
Private insurance	31 094 499 (51.3)	1 314 871 (54.1)	
Self-pay	1 845 445 (3.0)	55 774 (2.3)	
No charge	95 629 (0.2)	2997 (0.1)	
Other	1 660 859 (2.7)	58 931 (2.4)	
Missing	94 903 (0.2)	3133 (0.1)	

Descriptive statistics are based on complex survey design. Results presented as n (%). GD indicates gestational diabetes.

*Other denotes race/ethnicities not listed or multiracial

Moreover, during this same period, there was an increase in the prevalence of obesity from 0.6% in 2004 to 9.8% in 2019 during delivery hospitalizations. Obesity among individuals with GD increased from 2.3% in 2004 to 18.5% in 2019 whereas for patients without GD prevalence of obesity increased from 0.6% to 9% (*P*<0.01 for all) (Figure 3).

Cardiovascular Complications Associated With GD

Patients with GD had a higher incidence of cardiovascular complications compared with patients without GD during delivery hospitalizations (Table 2). Patients with GD had higher rates of development of preeclampsia. Similarly, GD was associated with higher rates of PPCM. Other cardiovascular complications, including stroke, cardiac arrhythmias, and pulmonary edema, were also more common with deliveries in individuals with GD.

Odds Ratios for In-Hospital Complications

After adjustment for age, race or ethnicity, comorbidities, insurance, and income, GD still remained an independent predictor of many cardiovascular complications (Figure 4). GD was independently associated with a higher risk of preeclampsia compared with patients without GD (adjusted OR [aOR], 1.97 [95% CI, 1.96–1.98], *P*<0.01). Similarly, deliveries among individuals with a history of GD were associated with higher adjusted odds of PPCM (aOR, 1.15 [95% CI, 1.08–1.22], *P*<0.01), stroke (aOR, 1.15 [95% CI, 1.09–1.23], *P*<0.01), pulmonary edema (aOR, 1.29 [95% CI, 1.23–1.36], *P*<0.01), acute kidney injury (aOR, 1.16 [95% CI, 1.11–1.21], *P*<0.01), and cardiac arrhythmias (aOR, 1.48 [95% CI, 1.46–1.50], *P*<0.01), compared with delivery hospitalizations for individuals without GD. However, odds of the acute coronary syndrome, heart failure, and venous thromboembolism associated with GD were not statistically significant on adjusted analysis.

In sensitivity analyses, after excluding individuals with preeclampsia/eclampsia (n=2 904 579), GD still remained independently associated with increased odds of aforementioned cardiovascular complications of PPCM, pulmonary edema, acute kidney injury, and cardiac arrhythmia (Table S2). An additional sensitivity analysis after excluding preexisting coronary artery disease, chronic heart failure, and chronic kidney disease mirrored our primary analysis by showing an association with an increased risk of acute cardiovascular complications at the time of delivery admissions (Table S3). A significant racial disparity was observed with as Black individuals with GD had higher odds of developing preeclampsia, PPCM, acute kidney injury, strokes, pulmonary edema, and cardiac arrhythmias, compared with White individuals (Table S4).

Predictors of PPCM Among Patients With GD

Among individuals with GD, the factors of older age>30 years, Black race, chronic hypertension, dyslipidemia, and obesity were identified as independent predictors of PPCM. Individuals with Medicare and Medicaid had higher odds of PPCM compared with those with private insurance. The detailed hospitalization characteristics and their association with the development of PPCM are illustrated in Figure 5. Predictors of PPCM in patients without GD were similar to patients with GD as shown in Figure S1.

Resource Use

In terms of resource use length of hospital stay was higher for deliveries among individuals with GD versus individuals without GD (3 versus 2 days, *P*<0.01). Similarly, deliveries for individuals with GD had a higher cost of hospitalization ($4909 versus $3682, *P*<0.01) (Table 2).

DISCUSSION

Our large contemporary, real-world population study, including 63 million delivery hospitalizations in the United States, yielded the following principal findings: (1) GD is independently associated with higher acute

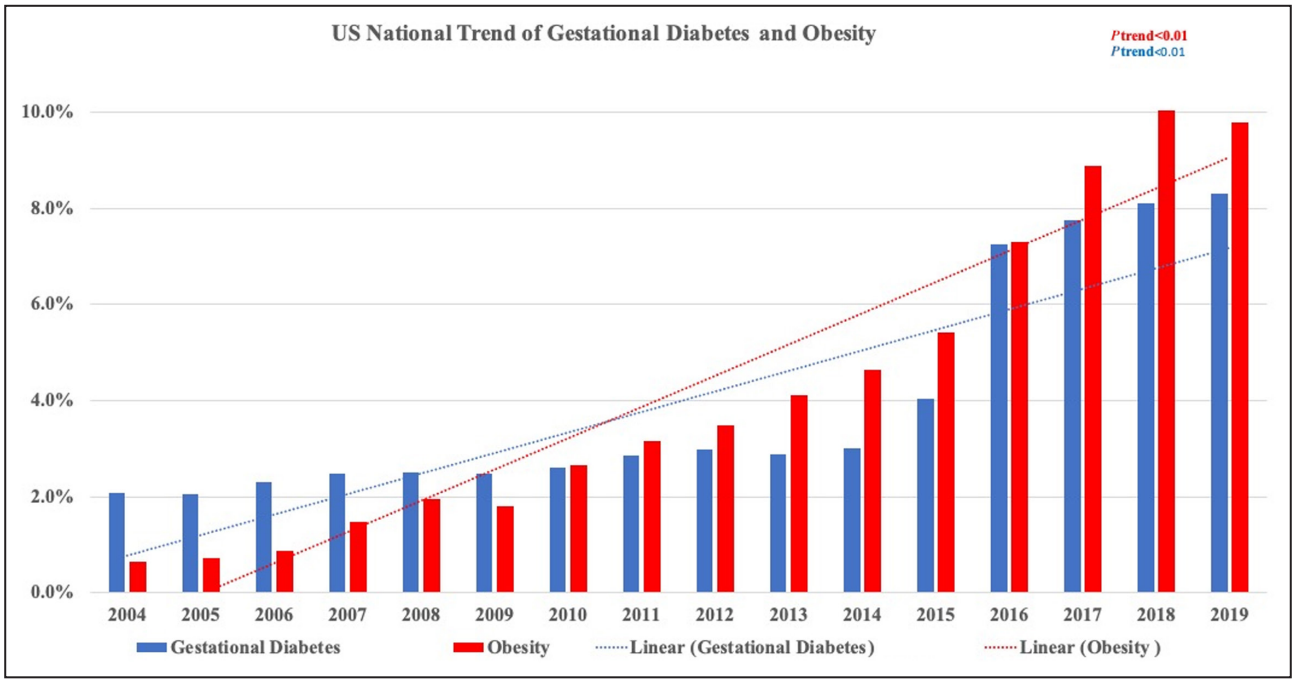

Figure 3. Trends of prevalence of gestational diabetes (GD) and obesity during delivery hospitalizationsanalysis are based on weighted hospitalizations.

cardiovascular complications during delivery hospitalizations including the development of preeclampsia, PPCM, stroke, pulmonary edema, acute kidney injury, and cardiac arrhythmias; and (2) the prevalence of GD and obesity during delivery hospitalizations is increasing in the United States over a 15-year period.

GD and Risk for CVD

It is well known that the preeclampsia is associated with acute cardiovascular risks at delivery[12]; however, the association of GD with acute cardiovascular complications, particularly in the absence of preeclampsia, had not been well established. According to previous literature, GD is strongly associated with a new diagnosis of type 2 diabetes after delivery.[7] Some longitudinal studies have established that GD independently is predictive of atherosclerotic CVD and heart failure development over the long term even after adjusting for traditional cardiovascular risk factors.[9,22–24] A history of GD is associated with subclinical and clinical CVD, even among women who do not develop interim

Table 2. Complication Rates (per 100000 Delivery Hospitalizations) and Hospital Resource Use in Patients With and Without GD

Variables	Without GD (60679701)	With GD (2435301)	*P* value
Complication rates (per 100000 delivery hospitalizations)			
Preeclampsia	4214	10916	<0.01
Peripartum cardiomyopathy	31	61	<0.01
Heart failure	41	91	<0.01
Acute kidney injury	50	95	<0.01
Acute coronary syndrome	<11*	<11*	<0.01
Stroke	31	49	<0.01
Pulmonary edema	35	83	<0.01
Cardiac arrhythmias	488	920	<0.01
Venous thromboembolism	35	50	<0.01
Resource use			
Length of stay, mean (IQR), days	2 (2–3)	3 (2–4)	<0.01
Cost of hospitalization, mean (IQR) $	3682 (2585–5333)	4909 (3429–7124)	<0.01

Descriptive statistics are based on complex survey design. GD indicates gestational diabetes.
* Cells with count <11 are not reportable per Healthcare Cost and Utilization Project (HCUP). guidelines. IQR indicates interquartile range.

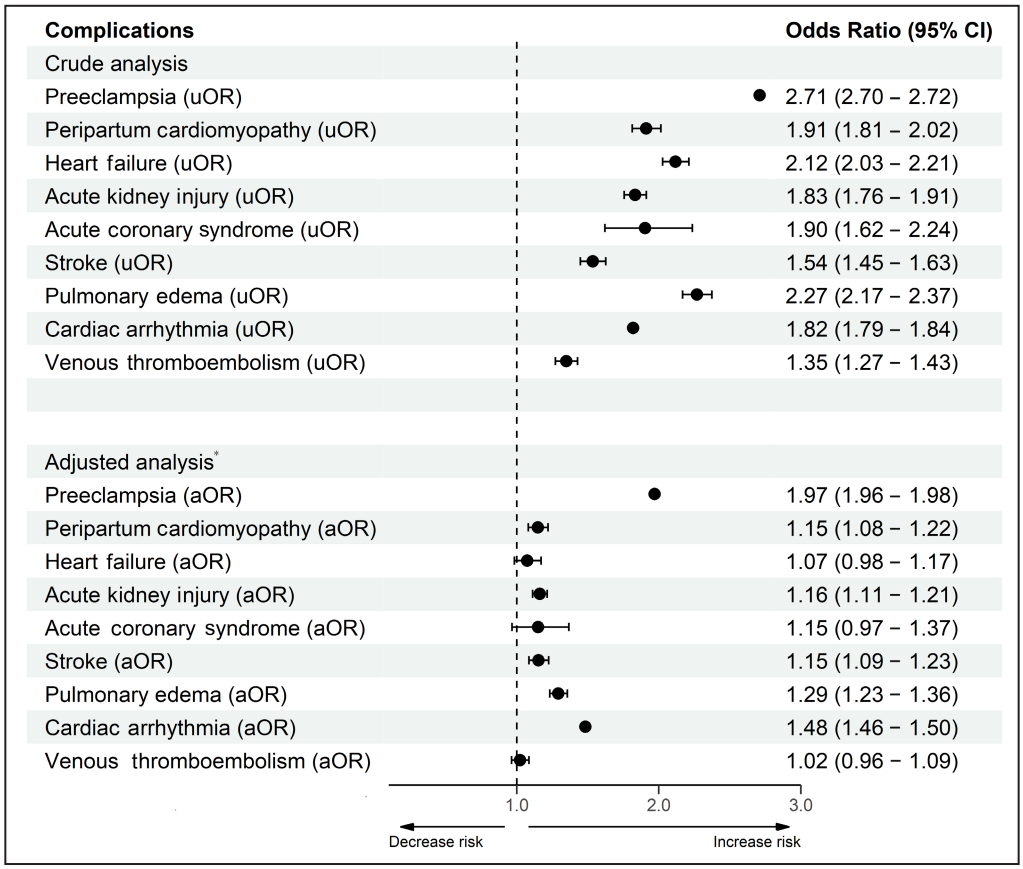

Figure 4. Adjusted and unadjusted odds ratio for in-hospital complications among people with gestational diabetes (GD) versus without GD.
aOR indicates adjusted odds ratio; and uOR, unadjusted odds ratio. Regression model is based on complex survey design. *Multivariable logistic regression model adjusted for age, race or ethnicity, region, chronic hypertension, dyslipidemias, heart failure, coronary artery disease, chronic kidney disease, obesity, polycystic ovary syndrome, smoking, multiple gestation, cesarean delivery, insurance, and median household income.

type 2 diabetes.[8–10] Even in the absence of obesity and current glucose intolerance, there still remain underlying insulin resistance and reduced insulin secretion in individuals with a prior history of GD.[25] The increased insulin resistance in GD can lead to endothelial dysfunction and metabolic derangements that contribute to worse long-term cardiovascular outcomes.[9,25–28]

Our findings are a significant addition to the current literature and it fills the gap in our knowledge regarding the association of acute cardiovascular complications in patients with GD, independently. We revealed that the in-hospital cardiovascular complication rate is elevated in individuals who are admitted for delivery with an associated diagnosis of GD, regardless of the presence or absence of concomitant preeclampsia diagnosis. Meanwhile, our data affirm the existing knowledge about GD's association with preeclampsia[6] and CVD risks.[8,22,29]

Adverse Temporal Trends of GD in the United States

In this analysis, we report concerning population trends in individuals of reproductive age in the United States. Individuals with GD had higher prevalence of CVD risk factors including obesity, hypertension, and dyslipidemia. There also was a slightly higher prevalence of PCOS among individuals with GD versus those without GD. PCOS is also characterized by insulin resistance[30] and associated with adverse pregnancy outcomes.[31]

Furthermore, our study shows an exponential increase in the prevalence of GD and obesity during a 15-year period from a nationally representative data set, consistent with other reported US statistics.[5] Our study supports findings of prior studies that have reported more than 200% increase in CVD risk factors among reproductive-age individuals.[32,33] Our study provides the most recent available data on population-level trends of GD that warrant an urgent public health intervention.

Predictors of PPCM in Patients With GD

Advanced age, Black race, chronic hypertension, preexisting diabetes, and multiple gestations are established risk factors for patients at high risk of developing PPCM.[34] We have now further extended

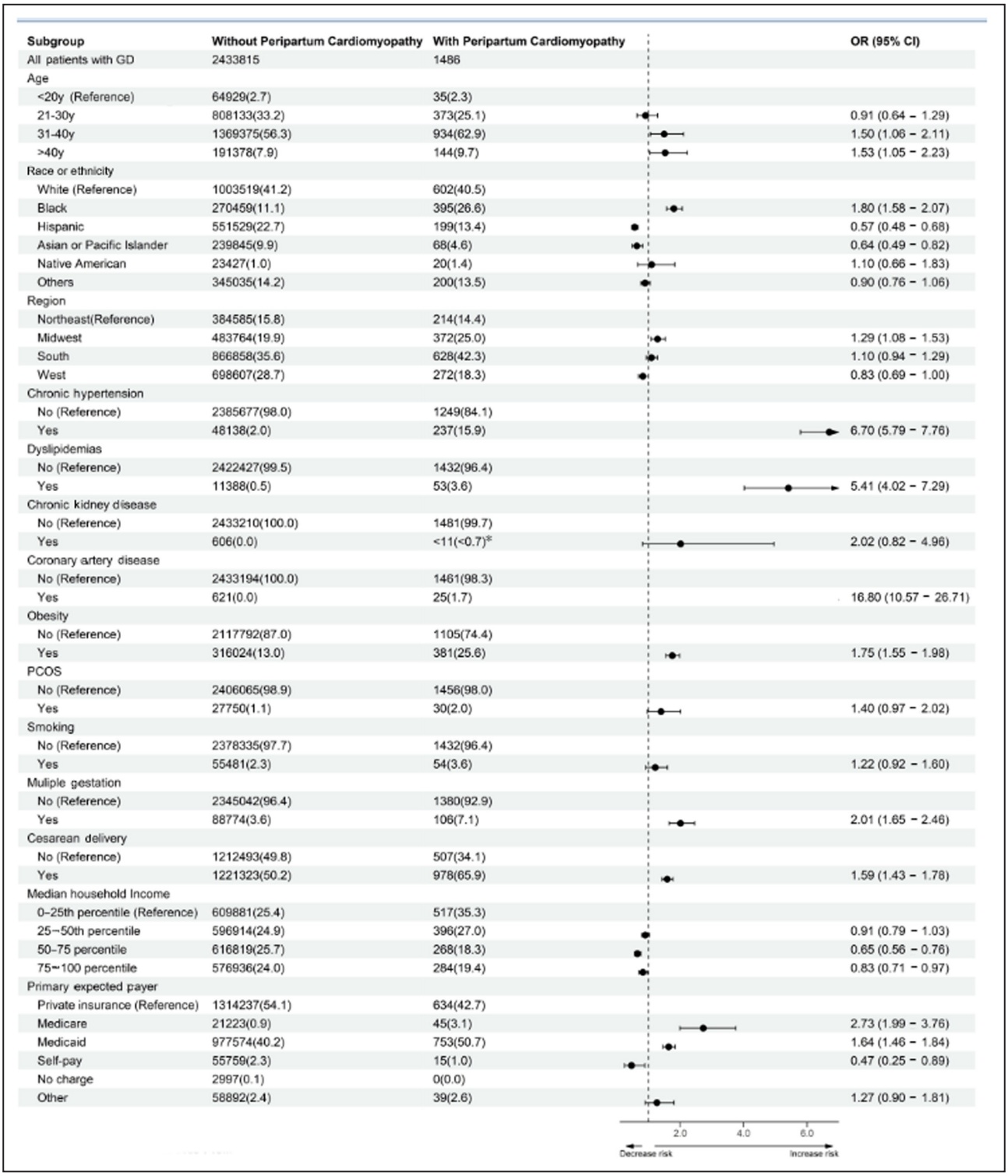

Figure 5. Predictors of peripartum cardiomyopathy (PPCM) in patients with GD.
Regression model is based on complex survey design. *Cell counts <11 are not reported as per Healthcare Cost and Utilization Project guidelines. GD indicates gestational diabetes; OR, odds ratio; and PCOS, polycystic ovary syndrome.

the evaluation of these predictors and quantified the risk of developing in-hospital PPCM in patients with GD during delivery admissions in the United States. As our study evaluated the risk for in-hospital PPCM and revealed the presence of association with GD, it is possible that GD may exaggerate the timing of onset of PPCM; however, this requires further prospective controlled studies to confirm this hypothesis.

Belonging to a higher socioeconomic class and having private insurance were associated with a lower risk of PPCM among individuals with GD, whereas Black individuals and patients with Medicare were found to have the greater odds for the development of PPCM. We believe that these findings suggest underlying health care disparities, structural racism, underscreening, and undertreatment of vulnerable groups in the United States.[35,36]

Resource Use

We report an increase in the length of stay and consequently the cost of hospitalization at the time of delivery in patients with a diagnosis of GD. We believe this to be a marker of adverse pregnancy outcomes in terms of increased cardiovascular complications associated with GD and possibly the greater frequency of cesarean delivery. According to estimates, GD pregnancies resulting in deliveries led to an increased expenditure of $3305 per hospitalization with an annual cost of $636 million.[37] Our reported cost analysis, underscores the impact of the cumulative cost of this hospitalization that warrants public health interventions to prevent GD and optimize preconception heath.

Implication of Study Findings for Prevention of CVD in People With GD

In light of our study findings, individuals with GD at the time of delivery admissions should be counseled on the possible risk of developing acute cardiovascular complications as well. Urgent steps are also needed for prepregnancy screening to identify risk factors and prevent GD development during pregnancy. Notably, the risk for GD is modifiable through maintaining a normal prepregnancy weight and following a healthy lifestyle including regular physical activity.[38] Optimizing the cardiovascular health of individuals before, during, and after pregnancy can reduce the risk of long-term cardiovascular complications.[39–41] Unfortunately, counseling of individuals with GD about their future risk of CVD has been typically suboptimally performed.[42]

Study Strengths and Limitations

Our study has many strengths as we analyzed a large multiethnic nationally representative sample of the US delivery population, which allowed us to have sufficient statistical power to examine cardiovascular complications associated with deliveries among individuals with GD. However, our study findings should be considered in the context of several important limitations. The NIS is an administrative claim-based database that uses *ICD* codes for diagnosis; although we have used diagnosis codes less prone to error, coding errors cannot be excluded. We were not able to include important variables such as gestational age at delivery, previous history of preeclampsia/eclampsia, or prepregnancy body mass index in our regression model because of the lack of specific *ICD* codes for these diagnoses. Fetal biometrics data to assess the severity of preeclampsia are also not available in the NIS database. There was a change in the methodology of NIS to improve national estimates in 2012 and a change in coding practices from *ICD-9* to *ICD-10* in the fourth quarter of 2015; that might have led to different estimates of disease prevalence in 2012 or 2015, although the trends we observed were present across the full study period.[43] Trends in the prevalence of obesity and GD over time may be because of better capturing of these diagnoses over time by *ICD* coding. Nevertheless, the true prevalence of obesity may be underestimated given reliance on *ICD* coding for diagnosis. Another limitation is that NIS collects data on inpatient discharges, and each admission is registered as an independent event. NIS samples are not designed to follow patients longitudinally, so long-term outcomes could not be assessed from the present data set. Only information at time of hospital delivery was available for analysis that has important implications for our study, as for instance, PPCM is most likely diagnosed 1 to 4 weeks postpartum. We also did not perform adjustment for multiple comparison. Hence, it is possible that 1 out of every 20 significant associations may be a false positive. Additionally, like any observational study, association does not imply causation and conclusions should be drawn cautiously. Further research maybe needed in order to determine and establish a causal relationship.

CONCLUSIONS

In conclusion, we report higher cardiovascular complication rates including preeclampsia, PPCM, stroke, pulmonary edema, and cardiac arrhythmia among individuals with GD, compared with those without GD, during delivery hospitalizations in the United States over a 15-year period. Further focused studies are needed to best strategize for the prevention and management of acute and long-term pregnancy-associated cardiovascular complications among individuals with GD.

ARTICLE INFORMATION

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Disclosures

Dr Michos reports advisory board participation for AstraZeneca, Amgen, Bayer, Boehringer Ingelheim, Esperion, Novartis, Novo Nordisk, and Pfizer. Dr Honigberg has received consulting fees from CRISPR Therapeutics, unrelated to the present work. No other authors report any disclosures.

Supplemental Material

Data S1-S2
Tables S1–S4
Figure S1

REFERENCES

1. McIntyre HD, Catalano P, Zhang C, Desoye G, Mathiesen ER, Damm P. Gestational diabetes mellitus. *Nat Rev Dis Primers*. 2019;5:47. doi: 10.1038/s41572-019-0098-8
2. Deputy NP, Kim SY, Conrey EJ, Bullard KM. Prevalence and changes in preexisting diabetes and gestational diabetes among women who had a live birth - United States, 2012–2016. *MMWR Morb Mortal Wkly Rep*. 2018;67:1201–1207. doi: 10.15585/mmwr.mm6743a2
3. Casagrande SS, Linder B, Cowie CC. Prevalence of gestational diabetes and subsequent Type 2 diabetes among U.S. women. *Diabetes Res Clin Pract*. 2018;141:200–208. doi: 10.1016/j.diabres.2018.05.010
4. DeSisto CL, Kim SY, Sharma AJ. Prevalence estimates of gestational diabetes mellitus in the United States, Pregnancy Risk Assessment Monitoring System (PRAMS), 2007–2010. *Prev Chronic Dis*. 2014;11:E104. doi: 10.5888/pcd11.130415
5. Shah NS, Wang MC, Freaney PM, Perak AM, Carnethon MR, Kandula NR, Gunderson EP, Bullard KM, Grobman WA, O'Brien MJ, et al. Trends in gestational diabetes at first live birth by race and ethnicity in the US, 2011–2019. *JAMA*. 2021;326:660–669. doi: 10.1001/jama.2021.7217
6. Venkatesh KK, Lynch CD, Powe CE, Costantine MM, Thung SF, Gabbe SG, Grobman WA, Landon MB. Risk of adverse pregnancy outcomes among pregnant individuals with gestational diabetes by race and ethnicity in the United States, 2014–2020. *JAMA*. 2022;327:1356–1367. doi: 10.1001/jama.2022.3189
7. Vounzoulaki E, Khunti K, Abner SC, Tan BK, Davies MJ, Gillies CL. Progression to type 2 diabetes in women with a known history of gestational diabetes: systematic review and meta-analysis. *BMJ*. 2020;369:m1361. doi: 10.1136/bmj.m1361
8. Kramer CK, Campbell S, Retnakaran R. Gestational diabetes and the risk of cardiovascular disease in women: a systematic review and meta-analysis. *Diabetologia*. 2019;62:905–914. doi: 10.1007/s00125-019-4840-2
9. Gunderson EP, Sun B, Catov JM, Carnethon M, Lewis CE, Allen NB, Sidney S, Wellons M, Rana JS, Hou L, et al. Gestational diabetes history and glucose tolerance after pregnancy associated with coronary artery calcium in women during midlife: the CARDIA study. *Circulation*. 2021;143:974–987. doi: 10.1161/CIRCULATIONAHA.120.047320
10. Minhas A, Countouris ME, Ndumele CE, Selvin E, Vaught AJ, Gandley R, Hays A, Ouyang P, Bennett WL, Catov JM, et al. Abstract 12986: association of gestational diabetes with subclinical cardiovascular disease on echocardiogram and endothelial function testing. *Circulation*. 2021;144:A12986. doi: 10.1161/circ.144.suppl_1.12986
11. Bellamy L, Casas JP, Hingorani AD, Williams D. Type 2 diabetes mellitus after gestational diabetes: a systematic review and meta-analysis. *Lancet*. 2009;373:1773–1779. doi: 10.1016/S0140-6736(09)60731-5
12. Minhas AS, Ogunwole SM, Vaught AJ, Wu P, Mamas MA, Gulati M, Zhao D, Hays AG, Michos ED. Racial disparities in cardiovascular complications with pregnancy-induced hypertension in the United States. *Hypertension*. 2021;78:480–488. doi: 10.1161/hypertensionaha.121.17104
13. Demakis JG, Rahimtoola SH, Sutton GC, Meadows WR, Szanto PB, Tobin JR, Gunnar RM. Natural course of peripartum cardiomyopathy. *Circulation*. 1971;44:1053–1061.
14. Witlin AG, Mabie WC, Sibai BM. Peripartum cardiomyopathy: an ominous diagnosis. *Am J Obstet Gynecol*. 1997;176:182–188.
15. Petersen EE, Davis NL, Goodman D, Cox S, Mayes N, Johnston E, Syverson C, Seed K, Shapiro-Mendoza CK, Callaghan WM, et al. Vital signs: pregnancy-related deaths, United States, 2011–2015, and strategies for prevention, 13 States, 2013–2017. *MMWR Morb Mortal Wkly Rep*. 2019;68:423–429. doi: 10.15585/mmwr.mm6818e1
16. Hoyert DL. *Maternal Mortality Rates in the United States, 2020*. NCHS Health E-Stats; 2022. doi: 10.15620/cdc:113967
17. Agency for Healthcare Research and Quality. *Overview of the National (nationwide) Inpatient Sample (NIS)*. AHRQ; 2021. Available at: https://www.hcup-us.ahrq.gov/nisoverview.jsp#about. Accessed December 29, 2021.
18. Healthcare Cost and Utilization Project (HCUP). *Agency for Healthcare Research and Quality*. 2021. Available at: https://www.hcup-us.ahrq.gov/nisoverview.jsp. Accessed December 29, 2021.
19. Cost-to-Charge Ratio Files. *Healthcare Cost and Utilization Project (HCUP)*. Agency for Healthcare Research and Quality; 2022. Available at: https://www.hcup-us.ahrq.gov/db/ccr/costtocharge.jsp. Accessed April 8, 2022.
20. Wier LM, Witt E, Burgess J, Elixhauser A. *Hospitalizations Related to Diabetes in Pregnancy, 2008. HCUP Statistical Brief#102*. Agency for Healthcare Research and Quality; 2010. Available at: http://www.hcup-us.ahrq.gov/reports/statbriefs/sb102.pdf. Accessed April 28, 2022.
21. Yang Y, Wu N. Gestational diabetes mellitus and preeclampsia: correlation and influencing factors. *Front Cardiovasc Med*. 2022;9:831297. doi: 10.3389/fcvm.2022.831297
22. Tobias DK, Stuart JJ, Li S, Chavarro J, Rimm EB, Rich-Edwards J, Hu FB, Manson JE, Zhang C. Association of history of gestational diabetes with long-term cardiovascular disease risk in a large prospective cohort of US women. *JAMA Intern Med*. 2017;177:1735–1742. doi: 10.1001/jamainternmed.2017.2790
23. Retnakaran R, Shah BR. Role of type 2 diabetes in determining retinal, renal, and cardiovascular outcomes in women with previous gestational diabetes mellitus. *Diabetes Care*. 2017;40:101–108. doi: 10.2337/dc16-1400
24. Echouffo-Tcheugui JB, Guan J, Retnakaran R, Shah BR. Gestational diabetes and incident heart failure: a cohort study. *Diabetes Care*. 2021. doi: 10.2337/dc21-0552
25. Damm P, Kuhl C, Hornnes P, Molsted-Pedersen L. A longitudinal study of plasma insulin and glucagon in women with previous gestational diabetes. *Diabetes Care*. 1995;18:654–665. doi: 10.2337/diacare.18.5.654
26. Broni EK, Ndumele CE, Echouffo-Tcheugui JB, Kalyani RR, Bennett WL, Michos ED. The Diabetes-cardiovascular connection in women: understanding the known risks, outcomes, and implications for care. *Curr Diab Rep*. 2022;22:11–25. doi: 10.1007/s11892-021-01444-x
27. Kuller LH, Catov J. Invited commentary: gestational hypertension and diabetes-a major public health concern. *Am J Epidemiol*. 2017;186:1125–1128. doi: 10.1093/aje/kwx265
28. Tobias DK, Hu FB, Forman JP, Chavarro J, Zhang C. Increased risk of hypertension after gestational diabetes mellitus: findings from a large prospective cohort study. *Diabetes Care*. 2011;34:1582–1584. doi: 10.2337/dc11-0268
29. Goueslard K, Cottenet J, Mariet AS, Giroud M, Cottin Y, Petit JM, Quantin C. Early cardiovascular events in women with a history of gestational diabetes mellitus. *Cardiovasc Diabetol*. 2016;15:15. doi: 10.1186/s12933-016-0338-0
30. Guan C, Zahid S, Minhas AS, Ouyang P, Vaught A, Baker VL, Michos ED. Polycystic ovary syndrome: a "risk-enhancing" factor for cardiovascular disease. *Fertil Steril*. 2022;117:924–935. doi: 10.1016/j.fertnstert.2022.03.009
31. Zahid S, Khan MZ, Gowda S, Faza NN, Honigberg MC, Vaught AJ, Guan C, Minhas AS, Michos ED. Trends, predictors, and outcomes of cardiovascular complications associated with polycystic ovary syndrome during delivery hospitalizations: a national inpatient sample analysis (2002–2019). *J Am Heart Assoc*. 2022;e025839. doi: 10.1161/JAHA.121.025839
32. Bornstein E, Eliner Y, Chervenak FA, Grunebaum A. Concerning trends in maternal risk factors in the United States: 1989–2018. *EClinicalMedicine*. 2020;29-30:100657. doi: 10.1016/j.eclinm.2020.100657

33. Perak AM, Ning H, Khan SS, Van Horn LV, Grobman WA, Lloyd-Jones DM. Cardiovascular health among pregnant women, aged 20 to 44 years, in the United States. *J Am Heart Assoc*. 2020;9:e015123. doi: 10.1161/JAHA.119.015123
34. Davis MB, Arany Z, McNamara DM, Goland S, Elkayam U. Peripartum cardiomyopathy: JACC state-of-the-art review. *J Am Coll Cardiol*. 2020;75:207–221. doi: 10.1016/j.jacc.2019.11.014
35. Shahu A, Okunrintemi V, Tibuakuu M, Khan SU, Gulati M, Marvel F, Blumenthal RS, Michos ED. Income disparity and utilization of cardiovascular preventive care services among U.S. adults. *Am J Prev Cardiol*. 2021;8:100286. doi: 10.1016/j.ajpc.2021.100286
36. Mannoh I, Hussien M, Commodore-Mensah Y, Michos ED. Impact of social determinants of health on cardiovascular disease prevention. *Curr Opin Cardiol*. 2021;36:572–579. doi: 10.1097/hco.0000000000000893
37. Chen Y, Quick WW, Yang W, Zhang Y, Baldwin A, Moran J, Moore V, Sahai N, Dall TM. Cost of gestational diabetes mellitus in the United States in 2007. *Popul Health Manag*. 2009;12:165–174. doi: 10.1089/pop.2009.12303
38. Whitaker KM, Ingram KH, Appiah D, Nicholson WK, Bennett WL, Lewis CE, Reis JP, Schreiner PJ, Gunderson EP. Prepregnancy fitness and risk of gestational diabetes: a longitudinal analysis. *Med Sci Sports Exerc*. 2018;50:1613–1619. doi: 10.1249/MSS.0000000000001600
39. Jowell AR, Sarma AA, Gulati M, Michos ED, Vaught AJ, Natarajan P, Powe CE, Honigberg MC. Interventions to mitigate risk of cardiovascular disease after adverse pregnancy outcomes: a review. *JAMA Cardiol*. 2022;7:346–355. doi: 10.1001/jamacardio.2021.4391
40. Hauspurg A, Ying W, Hubel CA, Michos ED, Ouyang P. Adverse pregnancy outcomes and future maternal cardiovascular disease. *Clin Cardiol*. 2018;41:239–246. doi: 10.1002/clc.22887
41. Michos ED, Khan SS. Modest gains confer large impact: achievement of optimal cardiovascular health in the US population. *J Am Heart Assoc*. 2021;10:e021142. doi: 10.1161/jaha.121.021142
42. Sutherland L, Neale D, Henderson J, Clark J, Levine D, Bennett WL. Provider counseling about and risk perception for future chronic disease among women with gestational diabetes and preeclampsia. *J Women's Health*. 2020;29(9):1168–1175. doi: 10.1089/jwh.2019.7767
43. Khera R, Angraal S, Couch T, Welsh JW, Nallamothu BK, Girotra S, Chan PS, Krumholz HM. Adherence to methodological standards in research using the national inpatient sample. *JAMA*. 2017;318:2011–2018. doi: 10.1001/jama.2017.17653

SUPPLEMENTAL MATERIAL

Data S1. List of variables used in logistic regression analysis to compute adjusted odds of in-hospital complications

1- Age
2- Race
3- Chronic Hypertension
4- Dyslipidemia
5- Congestive Heart Failure
6- Chronic Kidney Disease
7- Coronary Artery Disease
8- Obesity
9- Polycystic Ovary Syndrome
10- Smoking
11- Multiple Gestation
12- Cesarean Delivery
13- Median Household Income
14- Primary Insurance

Data S2. List of variables used in logistic regression analysis to compute independent predictors of peripartum cardiomyopathy in patients with GDM

1- Age
2- Race
3- Chronic Hypertension
4- Dyslipidemia
5- Congestive Heart Failure
6- Chronic Kidney Disease
7- Coronary Artery Disease
8- Obesity
9- Polycystic Ovary Syndrome
10- Smoking
11- Multiple Gestation
12- Cesarean Delivery
13- Median Household Income
14- Primary Insurance

Table S1. ICD procedure and diagnosis codes used

Variables	ICD-10	ICD-9
Delivery	10D0, 10E0, O60, O61, O62, O63, O64, O65, O66, O67, O68, O69, O70, O71, O72, O73, O74, O75, O76, O77, O80, O82, Z37, Z38	72, 73,75, 650, 651, 652, 653, 654, 655, 656, 657, 658, 659, 660, 662, 663, 664, 665, 666, 667, 668, 669, V27
Gestational Diabetes Mellitus	648.8	0244x
PCOS	E282	256.4
Preeclampsia/ Eclampsia	O1400, O140, O1402, O1403, O1404, O1405, O1490, O1492, O1493, O1494, O1495, O149, O141, O1410, O1412, O1413, O1414, O1415, O11, O111, O112, O113, O114, O115, O119, O142, O1420, O1422, O1423, O1424,O1425, O15, O150, O1500, O1502, O1503, O151, O152, O159	64241, 64242, 64243, 64244, 64250, 64251, 64252, 64253, 64254, 64270, 64271, 64272, 64273, 64274, 64260, 64261, 64262, 64263, 64264
Peripartum Cardiomyopathy	O903	6745
Heart Failure	I5021, I5031, I5033, I5041, I5043	42821, 42823, 42831, 42841, 42843
Acute Kidney Injury	N17	584,
Acute Coronary Artery Disease	I2101, I2102, I2109, I211, I2119, I2111, I212, I2129, I213, I214, I219	41000, 41001, 41002, 41010, 41011, 41012, 41020, 41021, 41022, 41030, 41031, 41032, 41040, 41041, 41042, 41050, 41051, 41052, 41060, 41061, 41062, 41080, 41081, 41082, 41090, 41091, 41092

Stroke	I60, I61, I62, I63, I650, I688, O873, O2250, O2251, O2252	430, 431, 432, 433, 437, 6715
Pulmonary Edema	J810, J811, I501	514
Cardiac Arrhythmias	Z450, Z950, T821, R001, R008, R000, I459, I456, I441, I442, I443, I47, I48, I49	4260, 42613, 4267, 4269, 42610, 42612, 4270, 4271, 4272, 4273, 4274, 4276, 4277, 4278, 4279, 7850, 99601, 99604, V450, V533
Venous Thromboembolism	I82	453

ICD: International Classification of Diseases

Table S2. Adjusted predictors of cardiovascular complications among women with GDM after exclusion of preeclampsia and eclampsia cases (n=2,904,579)

Variables	aOR	p-value
Peripartum Cardiomyopathy	1.20 (1.12-1.31)	<0.01
Heart Failure	1.04 (0.94-1.16)	0.40
Acute Kidney Injury	1.10 (1.03-1.18)	0.01
Acute Coronary Syndrome	1.17 (0.94-1.46)	0.16
Stroke	1.36 (1.27-1.45)	<0.01
Pulmonary Edema	1.47 (1.37-1.59)	<0.01
Cardiac Arrhythmias	1.48 (1.46-1.50)	<0.01
Venous Thromboembolism	1.08 (1.02-1.15)	0.02

Descriptive statistics are based on complex survey design
aOR: Adjusted Odds Ratio; GDM: Gestational Diabetes Mellitus
Adjusted for age, race/ethnicity, chronic hypertension, diabetes, dyslipidemia, heart failure, chronic kidney disease, coronary artery disease, obesity, PCOS, smoking, multiple gestation, Cesarean delivery, median household income and primary insurance.

Table S3. Adjusted predictors of cardiovascular complications among women with GDM after exclusion of preeclampsia/eclampsia (n=2,904,579), coronary artery disease (n=7433), heart failure (n=39508), and chronic kidney disease (n=9631) cases

Variables	aOR	p-value
Peripartum Cardiomyopathy	1.27 (1.16-1.41)	<0.01
Acute Kidney Injury	1.13 (1.05-1.21)	<0.01
Acute Coronary Syndrome	1.08 (0.81-1.43)	0.58
Stroke	1.35 (1.26-1.45)	<0.01
Pulmonary Edema	1.47 (1.36-1.58)	<0.01
Cardiac Arrhythmias	1.48 (1.46-1.50)	<0.01
Venous Thromboembolism	1.08 (1.02-1.15)	0.02

Descriptive statistics are based on complex survey design
aOR: Adjusted Odds Ratio; GDM: Gestational Diabetes Mellitus
Adjusted for age, race/ethnicity, chronic hypertension, diabetes, dyslipidemia, heart failure, chronic kidney disease, coronary artery disease, obesity, PCOS, smoking, multiple gestation, Cesarean delivery, median household income and primary insurance.

Table S4. Racial/ethnic disparities in outcomes of cardiovascular complications among women with GDM

Complications	aOR	p-value
Preeclampsia		
White (Reference)		
Black	1.33 (1.31-1.35)	<0.01
Hispanics	0.99 (0.98-1.00)	0.12
Asian or Pacific Islander	0.71 (0.69-0.72)	<0.01
Native American	1.26 (1.21-1.31)	<0.01
Peripartum Cardiomyopathy		
White (Reference)		
Black	1.34 (1.16-1.56)	<0.01
Hispanics	0.62 (0.51-0.74)	<0.01
Asian or Pacific Islander	0.64 (0.49-0.83)	<0.01
Native American	1.04 (0.61-1.78)	0.89
Heart Failure		
White (Reference)		
Black	1.15 (0.91-1.47)	0.24
Hispanics	1.39 (1.03-1.88)	0.03
Asian or Pacific Islander	1.05 (0.71-1.57)	0.79
Native American	5.01 (1.83-13.71)	<0.01
Acute Kidney Injury		
White (Reference)		
Black	2.79 (2.48-3.13)	<0.01
Hispanics	1.04 (0.92-1.19)	0.53

Asian or Pacific Islander	1.66 (1.42-1.93)	<0.01
Native American	1.80 (1.24-2.61)	<0.01
Acute Coronary Syndrome		
White (Reference)		
Black	1.53 (0.98-2.41)	0.06
Hispanics	0.79 (0.50-1.24)	0.30
Native American	3.78 (1.51-9.46)	0.01
Stroke		
White (Reference)		
Black	1.30 (1.08-1.56)	0.01
Hispanics	0.89 (0.75-1.04)	0.15
Asian or Pacific Islander	1.06 (0.86-1.31)	0.57
Native American	0.48 (0.20-1.18)	0.11
Pulmonary Edema		
White (Reference)		
Black	1.53 (1.34-1.74)	<0.01
Hispanics	0.85 (0.74-0.97)	0.02
Asian or Pacific Islander	1.19 (1.00-1.41)	0.04
Native American	1.74 (1.20-2.52)	<0.01
Cardiac Arrhythmias		
White (Reference)		
Black	1.54 (1.48-1.60)	<0.01
Hispanics	0.93 (0.89-0.96)	<0.01
Asian or Pacific Islander	1.07 (1.02-1.13)	0.01
Native American	0.83 (0.71-0.97)	0.02

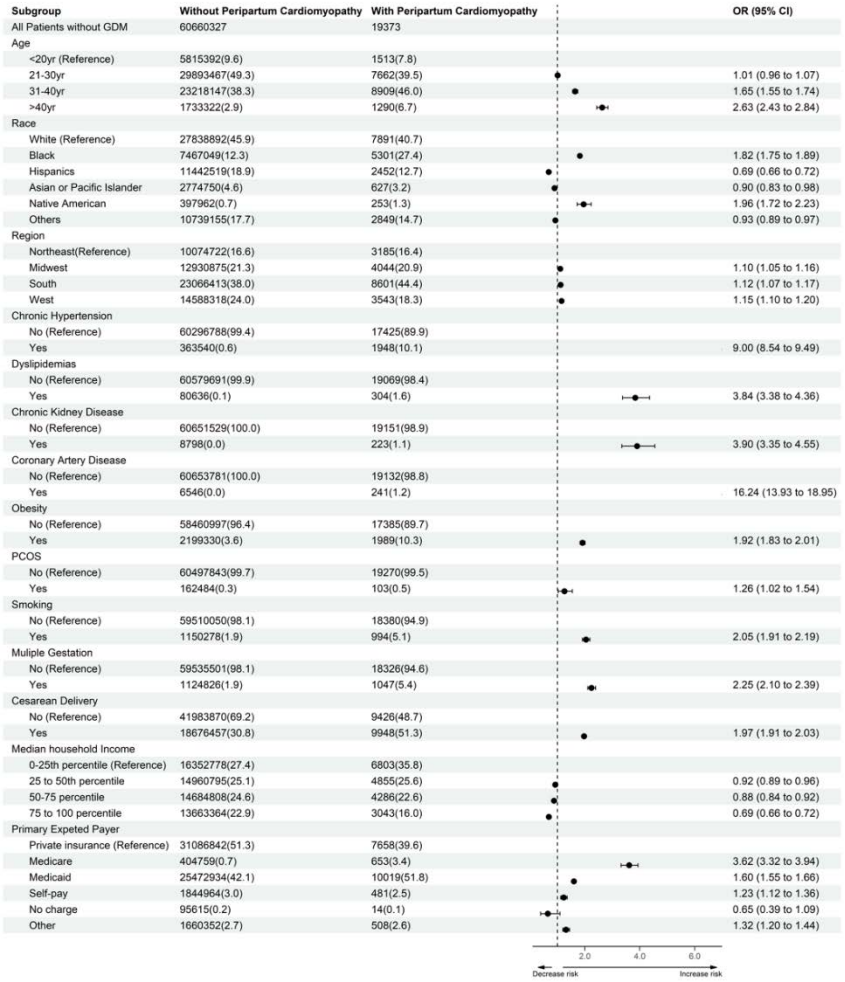
Venous Thromboembolism		
White (Reference)		
Black	1.06 (0.89-1.27)	0.53
Hispanics	0.75 (0.64-0.89)	<0.01
Asian or Pacific Islander	0.74 (0.59-0.92)	0.01
Native American	1.20 (0.72-2.01)	0.49

Descriptive statistics are based on complex survey design

aOR: Adjusted Odds Ratio; GDM: Gestational Diabetes Mellitus

Adjusted for age, chronic hypertension, diabetes, dyslipidemia, heart failure, chronic kidney disease, coronary artery disease, obesity, PCOS, smoking, multiple gestation, Cesarean delivery, median household income and primary insurance.

Figure S1. Predictors of peripartum cardiomyopathy in patients without GDM



Subgroup	Without Peripartum Cardiomyopathy	With Peripartum Cardiomyopathy	OR (95% CI)
All Patients without GDM	60660327	19373	
Age			
<20yr (Reference)	5815392(9.6)	1513(7.8)	
21-30yr	29893467(49.3)	7662(39.5)	1.01 (0.96 to 1.07)
31-40yr	23218147(38.3)	8909(46.0)	1.65 (1.55 to 1.74)
>40yr	1733322(2.9)	1290(6.7)	2.63 (2.43 to 2.84)
Race			
White (Reference)	27838892(45.9)	7891(40.7)	
Black	7467049(12.3)	5301(27.4)	1.82 (1.75 to 1.89)
Hispanics	11442519(18.9)	2452(12.7)	0.69 (0.66 to 0.72)
Asian or Pacific Islander	2774750(4.6)	627(3.2)	0.90 (0.83 to 0.98)
Native American	397962(0.7)	253(1.3)	1.96 (1.72 to 2.23)
Others	10739155(17.7)	2849(14.7)	0.93 (0.89 to 0.97)
Region			
Northeast(Reference)	10074722(16.6)	3185(16.4)	
Midwest	12930875(21.3)	4044(20.9)	1.10 (1.05 to 1.16)
South	23066413(38.0)	8601(44.4)	1.12 (1.07 to 1.17)
West	14588318(24.0)	3543(18.3)	1.15 (1.10 to 1.20)
Chronic Hypertension			
No (Reference)	60296788(99.4)	17425(89.9)	
Yes	363540(0.6)	1948(10.1)	9.00 (8.54 to 9.49)
Dyslipidemias			
No (Reference)	60579691(99.9)	19069(98.4)	
Yes	80636(0.1)	304(1.6)	3.84 (3.38 to 4.36)
Chronic Kidney Disease			
No (Reference)	60651529(100.0)	19151(98.9)	
Yes	8798(0.0)	223(1.1)	3.90 (3.35 to 4.55)
Coronary Artery Disease			
No (Reference)	60653781(100.0)	19132(98.8)	
Yes	6546(0.0)	241(1.2)	16.24 (13.93 to 18.95)
Obesity			
No (Reference)	58460997(96.4)	17385(89.7)	
Yes	2199330(3.6)	1989(10.3)	1.92 (1.83 to 2.01)
PCOS			
No (Reference)	60497843(99.7)	19270(99.5)	
Yes	162484(0.3)	103(0.5)	1.26 (1.02 to 1.54)
Smoking			
No (Reference)	59510050(98.1)	18380(94.9)	
Yes	1150278(1.9)	994(5.1)	2.05 (1.91 to 2.19)
Muliple Gestation			
No (Reference)	59535501(98.1)	18326(94.6)	
Yes	1124826(1.9)	1047(5.4)	2.25 (2.10 to 2.39)
Cesarean Delivery			
No (Reference)	41983870(69.2)	9426(48.7)	
Yes	18676457(30.8)	9948(51.3)	1.97 (1.91 to 2.03)
Median household Income			
0-25th percentile (Reference)	16352778(27.4)	6803(35.8)	
25 to 50th percentile	14960795(25.1)	4855(25.6)	0.92 (0.89 to 0.96)
50-75 percentile	14684808(24.6)	4286(22.6)	0.88 (0.84 to 0.92)
75 to 100 percentile	13663364(22.9)	3043(16.0)	0.69 (0.66 to 0.72)
Primary Expeted Payer			
Private insurance (Reference)	31086842(51.3)	7658(39.6)	
Medicare	404759(0.7)	653(3.4)	3.62 (3.32 to 3.94)
Medicaid	25472934(42.1)	10019(51.8)	1.60 (1.55 to 1.66)
Self-pay	1844964(3.0)	481(2.5)	1.23 (1.12 to 1.36)
No charge	95615(0.2)	14(0.1)	0.65 (0.39 to 1.09)
Other	1660352(2.7)	508(2.6)	1.32 (1.20 to 1.44)

Regression model is based on complex survey design