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
developing type 2 diabetes, as well as 2-fold higher risk of incident cardiovascular disease (CVD). 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. Although these long-term risks of GD are well-described, the data on acute cardiovascular complications associated with GD during delivery 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. The NIS contains administrative claims data from more than 7 million inpatient hospitalizations derived from the Centers for Medicare and Medicaid Services was applied to total hospital charges. This study was deemed exempt from institutional review board approval and informed consent because NIS data are de-identified and publicly available.

Nonstandard Abbreviations and Acronyms

| Abbreviation | Definition |
|--------------|------------|
| GD           | gestational diabetes |
| NIS          | National Inpatient Sample |
| PCOS         | polycystic ovary syndrome |
| PPCM         | peripartum cardiomyopathy |

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.

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). 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.
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 percentates 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,
National Inpatient Sample (NIS) from years 2004 to 2019 were used to identify delivery hospitalizations for adult patients (age > 17 years) in the US using **ICD-9** and **ICD-10** Codes.

63,230,342 delivery hospitalizations identified

63,115,002 delivery hospitalizations left

Patients with gestational diabetes (GD) identified using **ICD-9** code of 648.8 and **ICD-10** code of 0244x

Patient population divided into two groups based on presence of GD

60,679,701 without GD

2,435,301 with GD

Excluded cases with preexisting diabetes (n=115,340)

**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 “Other” category, 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).

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### Table 1. Characteristics of Delivery Hospitalizations With and Without GD

| Variable n (%) | Without GD (60 679 701) | With GD (243 5301) | 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 | 368 216 (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 | 41 568 94 (0.9) | 87 739 (2.1) | |
| 2005 | 4 134 063 (0.9) | 86 630 (2.1) | |
| 2006 | 4 187 836 (0.9) | 9 689 (2.3) | |
| 2007 | 4 443 962 (0.9) | 112 528 (2.5) | |
| 2008 | 4 134 852 (0.9) | 105 690 (2.5) | |
| 2009 | 4 038 877 (0.9) | 102 490 (2.5) | |
| 2010 | 3 813 032 (0.9) | 102 305 (2.6) | |
| 2011 | 3 760 161 (0.9) | 110 182 (2.8) | |
| 2012 | 3 710 826 (0.9) | 113 885 (3.0) | |
| 2013 | 3 697 113 (0.9) | 110 700 (2.9) | |
| 2014 | 3 756 855 (0.9) | 116 470 (3.0) | |
| 2015 | 3 380 600 (0.9) | 142 465 (4.0) | |
| 2016 | 3 479 841 (0.9) | 272 190 (7.3) | |
| 2017 | 3 390 606 (0.9) | 284 990 (7.8) | |
| 2018 | 3 320 809 (0.9) | 293 165 (8.1) | |
| 2019 | 3 273 374 (0.9) | 295 975 (8.3) | |
| Preexisting comorbidities | | | |
| Polycystic ovary syndrome | 162 588 (0.3) | 27 780 (1.1) | <0.01 |
| Dyslipidemia | 80 940 (0.1) | 1 144 2 (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) | 88 830 (3.6) | <0.01 |
| Cesarean delivery | 18 686 405 (30.8) | 1 223 301 (60.2) | <0.01 |
Association of GD With Peripartum Cardiovascular Complications

Table 1. Continued

| Variable n (%) | Without GD (60,679,701) | With GD (243,530) | 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      | 14,965,850 (25.1) | 597,310 (24.9) |
| 51–75th percentile      | 14,689,095 (24.8) | 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

| 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)   | 2,997 (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.

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 arrhythmias (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 ($4,909 versus $3,682, 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
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; 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. 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. A history of GD is associated with subclinical and clinical CVD, even among women who do not develop interim

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

**Table 2.** Complication Rates (per 100 000 Delivery Hospitalizations) and Hospital Resource Use in Patients With and Without GD

| Variables                              | Without GD (60679701) | With GD (2435301) | P value |
|----------------------------------------|-----------------------|-------------------|---------|
| **Complication rates (per 100 000 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.
type 2 diabetes. 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. The increased insulin resistance in GD can lead to endothelial dysfunction and metabolic derangements that contribute to worse long-term cardiovascular outcomes.

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 and CVD risks.

### 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 and associated with adverse pregnancy outcomes. 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. Our study supports findings of prior studies that have reported more than 200% increase in CVD risk factors among reproductive-age individuals. 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. We have now further extended...
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.

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.
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, under-screening, 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 pre-conception health.

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 pre-pregnancy 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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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
| 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, I2112, 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 |
| Condition                        | Code Details                                                                 | ICD                      |
|---------------------------------|-------------------------------------------------------------------------------|--------------------------|
| **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    |
| Condition                        | Reference Group | Comparative Group | Ratio (95% CI) | p-Value |
|---------------------------------|-----------------|-------------------|----------------|---------|
| **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

Regression model is based on complex survey design.