Original Research

Trends in and Maternal Outcomes of Delivery Hospitalizations of Patients With an Asthma Diagnosis

Alexander M. Friedman, MD, MPH, Emily A. DiMango, MD, Jean R. Guglielminotti, MD, PhD, Yongmei Huang, MD, MPH, Jason D. Wright, MD, Mary E. D'Alton, MD, and Timothy Wen, MD, MPH

OBJECTIVE: To characterize asthma prevalence and outcomes during U.S. delivery hospitalizations.

METHODS: For this repeated cross-sectional analysis, deliveries to women aged 15–54 years with asthma were identified in the 2000–2018 National Inpatient Sample, which approximates a 20% stratified sample of all hospitalizations nationally. Temporal trends in asthma were analyzed using joinpoint regression to estimate the average annual percent change with 95% CIs. The association of asthma with other comorbid conditions was analyzed. The relationship between asthma and several adverse maternal outcomes was analyzed with unadjusted and adjusted logistic regression models, with unadjusted odds ratios and adjusted odds ratios (aORs) as measures of effect. Risk for and trends in a composite of rare, but severe, respiratory complications also were analyzed.

RESULTS: An estimated 73,109,790 delivery hospitalizations from 2000 to 2018 were included in the analysis, of which 2,221,644 (3.0%) had a diagnosis of asthma. (Unweighted, the study sample included 15,213,024 deliveries, of which 462,276 [3.0%] had a diagnosis of asthma.) Asthma diagnoses rose from 1.2% in 2000 to 5.3% in 2018, representing an average annual percent change of 8.3% (95% CI 7.4–9.2%). Asthma was more common among women with obesity and chronic hypertension. In adjusted analyses, asthma was associated with severe maternal morbidity (aOR 1.50, 95% CI 1.45–1.55), preeclampsia and gestational hypertension (aOR 1.29, 95% CI 1.26–1.30), postpartum hemorrhage (aOR 1.21, 95% CI 1.19–1.24), cesarean delivery (aOR 1.16, 95% CI 1.15–1.18), gestational diabetes (aOR 1.20, 95% CI 1.18–1.21), venous thromboembolism (aOR 1.79, 95% CI 1.65–1.95), and preterm delivery (aOR 1.27, 95% CI 1.25–1.29). From 2000 to 2018, severe respiratory complications decreased from 72 per 10,000 deliveries with asthma to 14 per 10,000 deliveries with asthma (average annual percent change −9.4%, 95% CI −13.3% to −5.3%). This decreasing risk was offset on a population level by an increase in the risk of asthma.

CONCLUSION: Asthma is increasing during deliveries, is associated with adverse maternal outcomes, and is associated with comorbid conditions. Severe respiratory complications are decreasing proportionately among deliveries with asthma, but are stable on a population basis.

(Obstet Gynecol 2022;139:52–62)

DOI: 10.1097/AOG.0000000000004635

Asthma is one of the most common comorbid medical conditions present during pregnancy, with an estimated prevalence of 4–8%.[1] A recently published study of U.S. discharge data from the Nationwide Inpatient Sample found that the presence of asthma during

delivery hospitalizations increased from 2% to 4% between 2003 and 2011.[2] Asthma is associated with a wide range of adverse pregnancy outcomes and complications, including preeclampsia, gestational hypertension, preterm birth, cesarean delivery, venous thromboembolism, and severe maternal morbidity.[2–4] However, the association between asthma and adverse maternal outcomes is less well characterized than it is for conditions such as pregestational diabetes, chronic hypertension, and cardiac disease. Additionally, there is evidence that asthma is not well controlled during pregnancy in the United States.[5] Analysis of longitudinal data from nonobstetric patients has demonstrated that adverse consequences of asthma may be decreased with optimal medical management.[6]

National epidemiologic data on asthma in pregnancy beyond 2011 are lacking. Therefore, we conducted a cross-sectional analysis using a national database to evaluate temporal trends in and outcomes associated with delivery hospitalizations with asthma. We hypothesized that asthma diagnoses would continue to increase proportionally beyond 2011.

METHODS

Data were obtained from the 2000–2018 National Inpatient Sample from the HCUP (Healthcare Cost and Utilization Project) for this repeated cross-sectional analysis.[7] The National Inpatient Sample is one of the largest publicly available, all-payer inpatient databases in the United States and approximates a 20% stratified sample of all hospitalizations nationally. More than 7 million hospital stays are included in the National Inpatient Sample annually. In 2018, data from 47 states were included in the National Inpatient Sample.[8] The National Inpatient Sample includes population weight files that can be applied to the raw data (20% of hospitalizations nationally) to create national estimates of 100% of hospitalizations in the United States. The HCUP recommends applying weights to create population estimates when evaluating temporal trends.[9] This study applied National Inpatient Sample trend weights from HCUP in evaluating trends and presents both raw data and weighted data representative of national estimates for other analyses.

Given that this study period included the switch (on October 1, 2015) from International Classification of Diseases, Ninth Revision, Clinical Modification (ICD-9-CM) to International Classification of Diseases, Tenth Revision, Clinical Modification (ICD-10-CM) coding, billing data from National Inpatient Sample in the form of both ICD-9-CM and ICD-10-CM codes were included in the analysis.[10] For these analyses ICD-9-CM codes were translated to ICD-10-CM codes through an algorithm using the publicly available General Equivalence Mappings provided by the Centers for Medicare & Medicaid Services and National Center for Health Statistics.[11,12]

This study had three objectives. The first objective was to estimate temporal trends in the prevalence of asthma during delivery hospitalizations. The second was to estimate risks for common adverse maternal outcomes and obstetric conditions based on the presence or absence of asthma. We analyzed the following adverse outcomes: severe maternal morbidity, preeclampsia or gestational hypertension, preterm delivery, postpartum hemorrhage, cesarean delivery, gestational diabetes, venous thromboembolism (including deep vein thrombosis and pulmonary embolism), and maternal mortality. Severe maternal morbidity was defined based on a composite measure from the Centers for Disease Control and Prevention (CDC).[13] The CDC composite includes 21 diagnoses and conditions, including transfusion, shock, stroke, heart failure, sepsis, and other conditions identified by ICD-9-CM and ICD-10-CM codes. Because transfusion is the most common diagnosis in the severe maternal morbidity composite, is unlikely to lead to long-term sequelae, may be a process measure, and is not necessarily representative of large volume transfusion,[14] this analysis excluded transfusion from the composite and evaluated risk for the remaining 20 diagnoses and conditions.

The third objective of this analysis was to evaluate trends in risk for a composite of rare, but severe, respiratory complications including: mechanical ventilation, temporary tracheostomy, adult respiratory distress syndrome, and status asthmaticus. ICD-9-CM and ICD-10-CM codes from the CDC were used to identify these conditions (Appendix 1, available online at http://links.lww.com/AOG/C517). Risk for the severe respiratory composite during delivery hospitalizations was analyzed by year among women with asthma. As an ancillary objective, risks for ventilation or temporary tracheostomy and adult respiratory distress syndrome were analyzed based on the presence compared with the absence of asthma.

Women aged 15–54 years who underwent delivery from 2000 through 2018 in the National Inpatient Sample were included in this analysis. Data through 2018 were analyzed because this was the latest National Inpatient Sample available at the time of analysis. Delivery hospitalizations were identified based on diagnosis codes using approaches that ascertain more than 95% of deliveries.[15,16] Women with asthma were identified based on ICD-9-CM codes 493.x and ICD-10-CM

codes J45.x. Data on comorbid medical conditions, obstetric characteristics, demographic factors, and hospital characteristics were evaluated based on the presence or absence of asthma. Comorbid medical conditions included chronic hypertension, pregestational diabetes, and obesity. Obstetric diagnoses included prior cesarean delivery and multiple gestation. These medical and obstetric risk factors, evaluated based on ICD-9-CM and ICD-10-CM codes (Appendix 1, http://links.lww.com/AOG/C517), were included as they are common in the obstetric population and are generally associated with increased risk for adverse outcomes.[17] Demographic factors included year of delivery, maternal age, self-reported maternal race and ethnicity, insurance type (Medicaid, private, Medicare, other, uninsured), and ZIP code income quartile. Hospital characteristics included location and teaching status (urban teaching, urban nonteaching, and rural) and geographic region (Northeast, Midwest, South, or West). Race was included in this study given that there are known large differentials in asthma by race among the nonobstetric population.

For the first objective evaluating trends in asthma diagnoses during pregnancy, we reported the proportion of deliveries by year with an asthma diagnosis. Additionally, we conducted trends analysis during the study time period (2000–2018) using the National Cancer Institute's Joinpoint Regression Program 4.8.0.1.[18,19] This program allows the identification of when a trend change is produced and calculates the annual percentage change in rates between trend-change points. The program also estimates the average annual percentage change in the whole period studied. The average annual percentage change is derived by first estimating the underlying joinpoint model that best fits the data. The average annual percentage change is calculated using a weighted average of the slope coefficients of the underlying joinpoint regression line, with the weights equal to the length of each segment. The final step of the calculation transforms the weighted average of slope coefficients.[20,21]

For the second objective evaluating the association between asthma and adverse outcomes, we performed unadjusted and adjusted logistic regression for each of the adverse outcomes. For the unadjusted models, risk for each of the adverse outcomes was determined for women with compared with without asthma. Then, adjusted models were performed including the aforementioned demographics, hospital factors, and comorbid medical conditions. The adjusted risk for women with asthma compared with those without asthma was then determined. Results are presented as unadjusted odds ratio and adjusted odds ratio (aOR) with 95% CI. Women with pregestational diabetes were excluded from the analyses for gestational diabetes. Adjusted analyses were not performed for maternal mortality because of the small number of outcomes. For the logistic regression models two sets of analyses were performed. The first set of models included population weights and survey adjustment for strata in the National Inpatient Sample (per HCUP recommendations). The second set of models was performed analyzing raw data without population weights and additional survey adjustment. Additionally, joinpoint regression was used to calculate the average annual percent change in adverse outcomes among deliveries with asthma with the entire delivery population as the denominator.

For the third objective evaluating trends in the severe respiratory composite, we analyzed risk during delivery hospitalizations with an asthma diagnosis by year. Risk for the composite was also analyzed with the Joinpoint Regression Program, and the average annual percentage change with 95% CIs was determined. Because risk for asthma changed over the study period, we additionally evaluated likelihood of the composite among deliveries with asthma for the entire delivery population (including those without an asthma diagnosis) by year.

For all trends analyses, weighted data representative of national estimates were used per HCUP recommendations. Comparisons of comorbid medical conditions, demographic characteristics, and hospital factors was compared between women with and without asthma by analyzing the absolute standardized mean difference, with a value greater than 0.1 (10%) interpreted as a meaningful magnitude of difference between the two groups.[22] Standardized mean difference was used instead of P values, because the latter frequently demonstrate statistically significant, but not meaningful, differences with large data samples. All analyses were performed with SAS 9.4 (SAS Institute, Cary, North Carolina), with the exception of the temporal trends analysis performed with the Joinpoint Regression Program. We adhered to the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines for cross-sectional studies for this analysis.[23] Because the National Inpatient Sample creates population estimates, the anticipated sample size was 20% of U.S. delivery hospitalizations for the unweighted data and

an estimate of 100% of delivery hospitalizations with the weighted data. Given that the data are de-identified, the analysis was deemed exempt by the Columbia University Institutional Review Board (IRB-AAAE8144).

RESULTS

An estimated 73,109,790 delivery hospitalizations from 2000 to 2018 were included in the analysis, of which 2,221,644 (3.0%) had a diagnosis of asthma. Unweighted, the study sample included 15,213,024 deliveries, of which 462,276 (3.0%) had a diagnosis of asthma (Fig. 1). Over the study period, the presence of asthma during delivery hospitalizations rose from 1.2% in 2000 to 5.3% in 2018, a 342% increase (Fig. 2). The joinpoint model demonstrated an average annual percent change increase of 8.3% (95% CI 7.4–9.2%) over the study period.

Evaluating other demographic factors, asthma was most common among deliveries covered by Medicaid (3.5%) and Medicare insurance (7.6%) (standardized mean difference for payer 14.0%) (weighted data Table 1, unweighted data Appendix 2, available online at http://links.lww.com/AOG/C517). Asthma was more common among non-Hispanic Black (5.2%) women and non-Hispanic White women (3.4%) than Hispanic women (2.2%) (standardized mean difference for maternal race 32.2%). Asthma was most common in the lowest ZIP code income quartile (standardized mean difference for ZIP code income quartile 12.9%). Asthma was more common among women with medical comorbidities, including obesity (9.2%, standardized mean difference 31.9%), and chronic hypertension (6.9%,

standardized mean difference 12.3%). Deliveries with asthma were more common in urban teaching hospitals (standardized mean difference 33.4% for hospital location) and hospitals in the Northeast (standardized mean difference 19.3% for hospital region).

Evaluating unadjusted risk for adverse outcomes, asthma was broadly associated with increased risk. Asthma was associated with increased risk for severe morbidity, preeclampsia and gestational hypertension, venous thromboembolism, preterm delivery, postpartum hemorrhage, cesarean delivery, gestational diabetes, and maternal death. In adjusted analyses accounting for demographic, hospital, and medical and obstetric risk factors, increased risks for several of these adverse outcomes were attenuated but were still significant. Increased risk was present for severe maternal morbidity (aOR 1.50, 95% CI 1.45–1.55), preeclampsia and gestational hypertension (aOR 1.29, 95% CI 1.26–1.30), and postpartum hemorrhage (aOR 1.21, 95% CI 1.19–1.24), as well as preterm delivery, cesarean delivery, gestational diabetes, and venous thromboembolism (Table 2; weighted numbers of adverse outcomes are presented in Table 3). Similar estimates were noted in adjusted analyses, with unweighted data not accounting for the survey structure of the data (Appendix 3, available online at http://links.lww.com/AOG/C517, unweighted number of adverse outcomes are presented in Appendix 4, available online at http://links.lww.com/AOG/C517).

Evaluating temporal trends in the risk for the composite of severe respiratory complications (including ventilation, temporary tracheostomy, adult

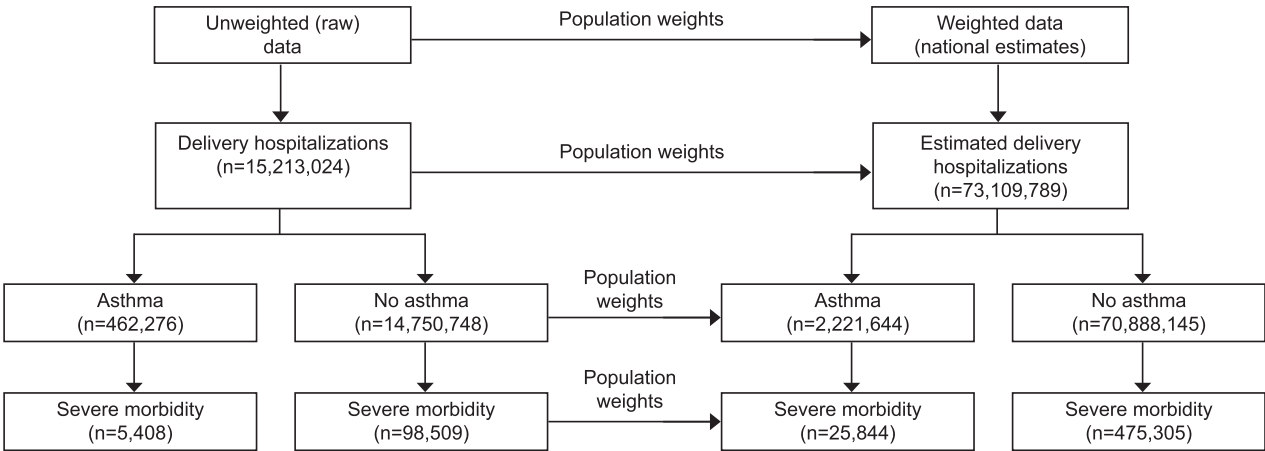**Fig. 1.** Application of population weights to create national estimates. The figure demonstrates derivation of the study population. Population weights from the National Inpatient Sample are applied to raw (unweighted) data to create national estimates of both delivery hospitalizations and adverse events used in trends analyses.

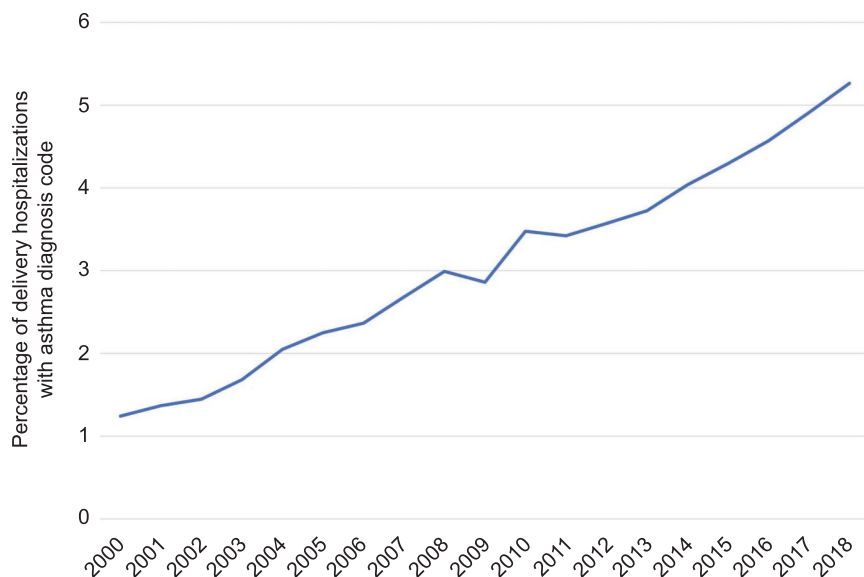*Friedman. Delivery Hospitalizations and Asthma. Obstet Gynecol 2021.*

Fig. 2. Proportion of delivery hospitalizations with an asthma diagnosis by year.

Friedman. Delivery Hospitalizations and Asthma. Obstet Gynecol 2021.

respiratory distress syndrome, and status asthmaticus) among deliveries with asthma, risk decreased from 72 per 10,000 deliveries in 2000 to 14 per 10,000 in 2018 (Fig. 3A). The joinpoint model demonstrated an average annual percent change of −9.4% (95% CI −13.3% to −5.3%) over the study period. This decreasing risk was offset by an increase in the risk of asthma in the study population. Evaluating risk for the composite of severe respiratory complications with the entire delivery population as the denominator (including deliveries to patients without asthma), risk was similar over the study period with risk in 2018 (7.3/10,000 deliveries) slightly lower than risk in 2000 (9.0/100,000 deliveries) (Fig. 3B); for these trends, the joinpoint model demonstrated a nonsignificant annual percentage change over the study period of −0.2% (95% CI −3.8% to 3.6%). In comparison, calculating the average annual percent change among patients with asthma with the entire delivery population as the denominator, risks increased for severe maternal morbidity (9.1%, 95% CI 6.9–11.4%), preeclampsia and gestational hypertension (11.0%, 95% CI 10.1–11.2%), postpartum hemorrhage (10.7%, 95% CI 10.1–11.2%), as well as gestational diabetes, cesarean delivery, and preterm delivery (Appendix 5, available online at http://links.lww.com/AOG/C517).

In ancillary analyses, risks for temporary tracheostomy or mechanical ventilation (odds ratio 4.42, 95% CI 3.85–5.06) and adult respiratory distress syndrome (RR 3.57, 95% CI 3.31–3.85) were higher with asthma (Appendix 6, available online at http://links.lww.com/AOG/C517).

DISCUSSION

In this serial cross-sectional study, diagnoses of asthma more than quadrupled over the study period. This increase was significantly larger than a small contemporary increase in asthma prevalence among adults in the general population from 7.1% in 2001 to 7.7% in 2018.[24] Asthma was associated with modest risk across a broad range of adverse maternal outcomes, including severe maternal morbidity, preeclampsia and gestational hypertension, postpartum hemorrhage, gestational diabetes, maternal mortality, and venous thromboembolism. As asthma was also associated with higher likelihood of other chronic medical conditions such as obesity, pregestational diabetes, and chronic hypertension, risk for adverse outcomes was attenuated in adjusted models. Demographic characteristics associated with asthma included Medicaid and Medicare insurance, being of non-Hispanic Black race, lower ZIP code income quartile, and younger age, factors also consistent with asthma in the general U.S. population.[25,26]

Despite risk for asthma increasing over the study period, this study did not find that risk for the most serious respiratory complications increased significantly. Relative to the number of patients with asthma, risk for a severe respiratory complication actually decreased over time, with risk on a population-basis stable and offset by rising asthma prevalence. These findings may suggest that pregnant woman with asthma received more comprehensive asthma care over the course of the study period. Alternatively, they may suggest that the diagnosis of

Table 1. Characteristics of the Study Population by Presence or Absence of Asthma (Weighted Data)*

Characteristic	No Asthma	Asthma	Absolute SMD (%)
Demographics			
All deliveries	70,888,146	2,221,644	
Year of delivery			49.4
2000	3,767,429 (5.3)	47,420 (2.1)	
2001	3,698,466 (5.2)	51,327 (2.3)	
2002	3,846,906 (5.4)	56,499 (2.5)	
2003	3,797,066 (5.4)	64,997 (2.9)	
2004	3,917,024 (5.5)	81,975 (3.7)	
2005	3,919,119 (5.5)	90,221 (4.1)	
2006	3,964,443 (5.6)	96,060 (4.3)	
2007	4,212,444 (5.9)	116,096 (5.2)	
2008	3,891,994 (5.5)	120,045 (5.4)	
2009	3,805,012 (5.4)	112,054 (5.0)	
2010	3,557,030 (5.0)	128,122 (5.8)	
2011	3,522,373 (5.0)	124,818 (5.6)	
2012	3,615,791 (5.1)	133,885 (6.0)	
2013	3,589,208 (5.1)	138,815 (6.3)	
2014	3,631,620 (5.1)	152,805 (6.9)	
2015	3,577,565 (5.1)	160,500 (7.2)	
2016	3,609,676 (5.1)	172,810 (7.8)	
2017	3,521,001 (5.0)	181,830 (8.2)	
2018	3,443,979 (4.9)	191,365 (8.6)	
Maternal race[†]			32.2
Hispanic	13,523,244 (19.1)	298,793 (13.5)	
Non-Hispanic White	31,083,033 (43.9)	1,073,512 (48.3)	
Non-Hispanic Black	7,961,617 (11.2)	436,256 (19.6)	
Other	6,451,116 (9.1)	140,961 (6.3)	
Unknown	11,869,136 (16.7)	272,121 (12.3)	
Maternal age (y)			8.7
15–19	6,132,704 (8.7)	226,627 (10.2)	
20–24	16,495,751 (23.3)	569,785 (25.7)	
25–29	19,800,668 (27.9)	600,359 (27.0)	
30–34	17,763,087 (25.1)	510,009 (23.0)	
35–39	8,713,160 (12.3)	254,148 (11.4)	
40–54	1,982,776 (2.8)	60,715 (2.7)	
Payer			14.0
Medicare	391,352 (0.6)	31,923 (1.4)	
Medicaid	29,139,766 (41.1)	1,036,556 (46.7)	
Private insurance	37,040,240 (52.3)	1,058,393 (47.6)	
Self-pay	2,203,992 (3.1)	35,561 (1.6)	
No charge	132,358 (0.2)	1,938 (0.1)	
Other	1,862,144 (2.6)	54,108 (2.4)	
Unknown	118,294 (0.2)	3,165 (0.1)	
ZIP code income quartile			12.9
1	16,726,230 (23.6)	636,188 (28.6)	
2	17,162,638 (24.2)	521,872 (23.5)	
3	17,270,670 (24.4)	530,850 (23.9)	
4	18,608,842 (26.3)	499,264 (22.5)	
Unknown	1,119,767 (1.6)	33,469 (1.5)	
Obstetric and medical factors			
Obesity	2,730,918 (3.9)	277,078 (12.5)	31.9
Pregestational diabetes	624,153 (0.9)	40,209 (1.8)	8.1
Chronic hypertension	937,086 (1.3)	69,704 (3.1)	12.3
Multiple gestation	1,266,253 (1.8)	47,775 (2.2)	2.6
Prior cesarean delivery	10,432,679 (14.7)	373,359 (16.8)	5.7
Hospital factors			
Hospital location			33.4

(*continued*)

Table 1. Characteristics of the Study Population by Presence or Absence of Asthma (Weighted Data)[*] (*continued*)

Characteristic	No Asthma	Asthma	Absolute SMD (%)
Rural	7,985,064 (11.3)	166,128 (7.5)	
Urban nonteaching	26,877,048 (37.9)	596,559 (26.9)	
Urban teaching	35,804,133 (50.5)	1,453,426 (65.4)	
Missing	221,901 (0.3)	5,530 (0.3)	
Region			19.3
Northeast	11,390,328 (16.1)	478,096 (21.5)	
Midwest	15,026,699 (21.2)	535,334 (24.1)	
South	26,957,671 (38.0)	706,967 (31.8)	
West	17,513,449 (24.7)	501,246 (22.6)	

SMD, standardized mean difference.

Data are n (%) unless otherwise specified.

[*] This table demonstrates weighted data to estimate all deliveries in the population.

[†] Maternal race included Asian and Pacific Islander, Native American, and women of other races as defined by the Nationwide Inpatient Sample. This grouping was made to facilitate adjusted analyses for relatively rare outcomes.

asthma was more progressively ascertained over the course of the study.

The findings from this analysis demonstrated that asthma is associated with a constellation of risk factors for adverse pregnancy outcomes, including chronic hypertension and obesity. This study and other recent studies[2] have found larger risk estimates for adverse pregnancy outcomes associated with asthma than older data that show smaller effects.[27] The finding of asthma being more common in the setting of other demographic factors associated with increased maternal risk, including receipt of public insurance, lowest ZIP code income quartile, and being of non-Hispanic Black race, underscores the importance of optimal management of this modifiable condition. An analysis of longitudinal payer data evaluating asthma control based on short-acting β-agonist dispensations and exacerbations found poorly controlled asthma to be associated with increased risk of preterm birth and neonatal intensive care unit admissions, suggesting that improved care may improve neonatal outcomes.[28] Tracking asthma care quality through pharmacy billing data, comparing days covered of inhaled corticosteroids compared with receipt of short-acting β-agonists, may be an important target for improving maternal quality of care.

In addition to modest, yet well characterized, risks for several adverse pregnancy outcomes, this study also found asthma was associated with increased risk for venous thromboembolism. Despite the findings from this study and a prior National Inpatient Sample analysis, asthma is not considered a major risk factor for venous thromboembolism and is not included in even the most comprehensive obstetric venous thromboembolism risk stratification scoring systems.[29] Other studies in nonobstetric patients have demonstrated increased risk for venous thromboembolism among patients with asthma with risk highest among patients with frequent exacerbations and hospitalizations.[30–32] Studies have demonstrated that asthma is associated with increased prothrombotic factors and endothelial dysfunction leading to atherothrombosis and pulmonary embolism.[30] Although attributable risk for venous thromboembolism among deliveries with asthma is low, further investigation is indicated to determine to what degree asthma is a meaningful risk factor for this complication.

There are several important limitations to consider when interpreting this study. First, this study was performed analyzing only administrative hospital discharge data. This database does not include data on other health care utilization, and we are not able to assess outpatient management, prescription of asthma medications, hospital and emergency encounters, and other data related to asthma severity and control. Asthma may have been underreported; asthma prevalence in pregnant women at delivery was considerably lower than asthma prevalence in the general U.S. population. Differential coding of more severe cases could lead to risk associated with asthma being overestimated. Second, this study design does not allow for causal inferences. It is likely that comorbid conditions associated with asthma, such as obesity, were underascertained and that, for some adverse outcomes, asthma may be a "risk marker" to a greater degree than a risk factor. In the regression models, estimates associated with asthma diagnoses generally decreased in magnitude with risk adjustment. Furthermore, for some variables, such as race, the proportion of unknown patients is differential between patients

Table 2. Unadjusted and Adjusted Risk for Pregnancy Complications in the Setting of Asthma (Weighted Data)*

Adverse Outcomes	OR (95% CI)	aOR (95% CI)[†]
Severe maternal morbidity	1.76 (1.70–1.82)	1.50 (1.45–1.55)
Preeclampsia and gestational hypertension	1.60 (1.58–1.63)	1.29 (1.26–1.30)
Preterm delivery	1.29 (1.26–1.31)	1.27 (1.25–1.29)
Postpartum hemorrhage	1.27 (1.24–1.30)	1.21 (1.19–1.24)
Cesarean delivery	1.31 (1.29–1.33)	1.16 (1.15–1.18)
Gestational diabetes	1.34 (1.32–1.36)	1.20 (1.18–1.21)
Venous thromboembolism	2.08 (1.92–2.26)	1.79 (1.65–1.95)
Maternal death[‡]	2.09(1.54–2.83)	n/a

OR, odds ratio; aOR, adjusted odds ratio; n/a, not applicable.
* Estimates in the table demonstrate risk in the presence compared with the absence of asthma using weighted data.
[†] The adjusted models include all of the demographic, obstetric, and medical factors in Table 1, including year of delivery, maternal race, maternal age, payer, ZIP code income quartile, obesity, pregestational diabetes, chronic hypertension, singleton compared with multiple gestation, prior cesarean delivery, and obesity, with the exception of the model for gestational diabetes, which excluded women with pregestational diabetes from the analysis.
[‡] Adjusted analysis was not performed for maternal death, given the low number of outcomes

with asthma and patients without asthma. Given differentials in missing data, as well as likely underascertainment for important risk factors (such as obesity), there is potential for both statistical bias and imprecision of the point estimates that could be refined with ascertainment of higher quality research data.

Third, we are not able to compare billing data with clinical records to validate diagnoses. It is possible that to some degree greater capture of asthma diagnoses occurred over the study period, particularly if asthma was tied to increased reimbursements. The finding that the composite of severe respiratory complications decreased precipitously relative to asthma diagnoses and was stable on a population basis supports that more mild cases of asthma may have been ascertained later in the study period or that asthma treatment among pregnant women improved over time. It is possible that childhood and adolescent diagnoses of asthma may

be more likely to be carried through to adulthood if electronic medical record documentation is used. However, the trends in this study are compatible with the findings of other large analyses. National data from the CDC not restricted to the obstetric population have demonstrated temporal trends in decreased hospitalizations, asthma attacks, and deaths, albeit not as precipitous as the decreased risk for severe respiratory complications over the study period in our analysis.[33] Another large study using data from the 2001 to 2016 National Health and Nutrition Examination Survey similarly demonstrated an increase in asthma prevalence among reproductive aged women.[34] Furthermore, among deliveries with asthma the proportion of adverse outcomes other than the respiratory morbidity composite increased proportionately over the study period. To better characterize diagnosis validity and to determine the proportion of patients with asthma

Table 3. Outcomes by Presence or Absence of Asthma (Weighted Data)

Adverse Outcomes	No Asthma	Asthma
Severe maternal morbidity*	475,305 (0.7%)	25,844 (1.2%)
Preeclampsia and gestational hypertension	5,369,759 (7.6%)	257,870 (11.6%)
Preterm delivery	4,633,016 (6.5%)	183,033 (8.2%)
Postpartum hemorrhage	2,099,765 (3.0%)	82,732 (3.7%)
Cesarean delivery	21,751,235 (30.7%)	814,075 (36.6%)
Gestational diabetes	4,042,857 (5.7%)	166,103 (7.6%)
Venous thromboembolism	45,574 (0.1%)	2,952 (0.1%)
Maternal death	3,373 (0.0%)	224 (0.0%)

Data are n (%).
* Severe maternal morbidity was based on a composite from the Centers for Disease Control and Prevention excluding transfusion.
Data from Centers for Disease Control and Prevention. How does CDC identify severe maternal morbidity? Accessed October 20, 2021. https://www.cdc.gov/reproductivehealth/maternalinfanthealth/smm/severe-morbidity-ICD.htm
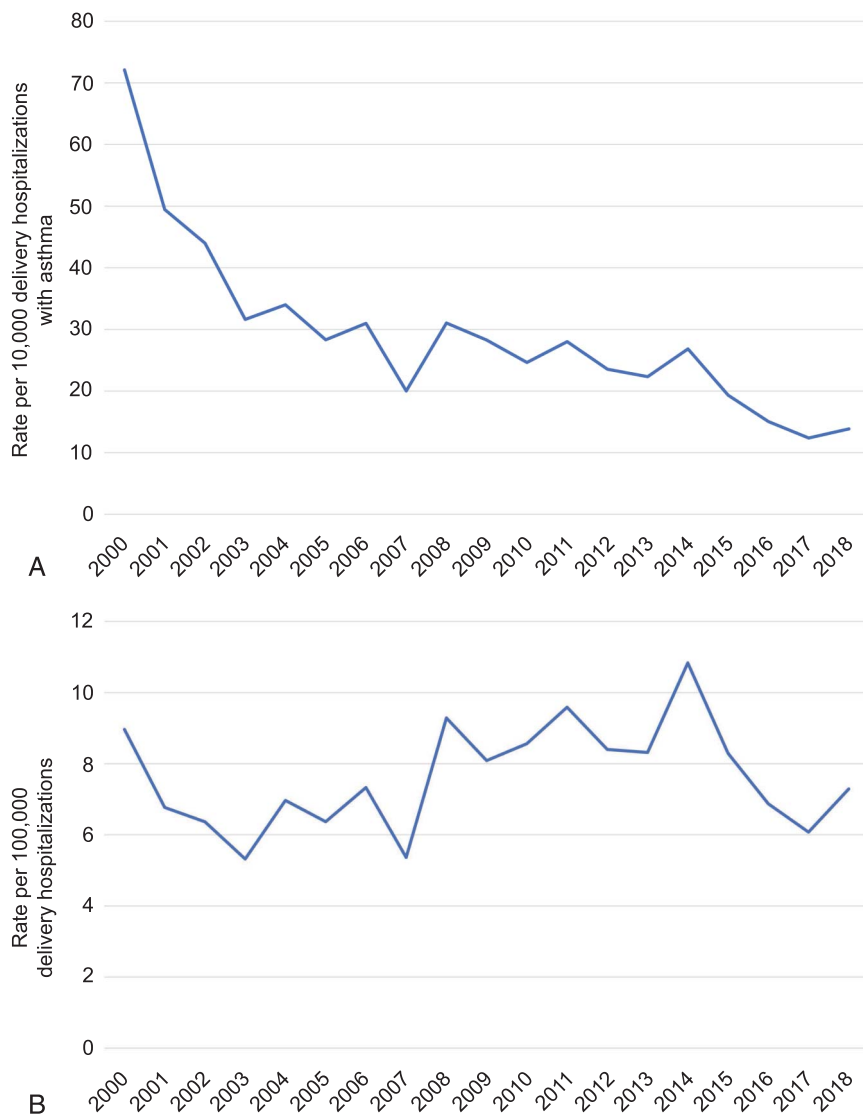
Fig. 3. A. Rate of severe respiratory complication composite per 10,000 delivery hospitalizations with asthma by year. **B.** Rate of severe respiratory complication composite in the setting of asthma per 100,000 delivery hospitalizations by year. The severe respiratory complication composite includes diagnosis or procedure codes for any one or more of the following: status asthmaticus, ventilation, temporary tracheostomy, and adult respiratory distress syndrome.

Friedman. Delivery Hospitalizations and Asthma. Obstet Gynecol 2021.

diagnoses receiving medical management, future analyses can be performed with payer data sets.

Fourth, the transition from ICD-9-CM to ICD-10-CM codes may result in some discontinuities. After the switch to ICD-10-CM in 2015, the number of codes increased from around 18,000 to more than 140,000.[35] The ICD-10-CM includes five times more diagnostic codes and 19 times more procedural codes than in ICD-9.[35] The ICD-10-CM includes greater detail about disease severity and complexity, allowing for more precise identification of specific conditions, and, as a result, there may not be precise equivalence between ICD-9-CM and ICD-10-CM codes. However, for the majority of diagnoses included in this study there were direct conversions between ICD-9-CM and ICD-10-CM, and we attempted to mitigate

potential errors by translating codes via General Equivalence Mappings.

The main strengths of the study include that we were able to analyze a population that is nationally representative, that we were powered to assess associations between asthma and rare outcomes, that we analyzed a broad range of comorbid risk factors and adverse outcomes, and that the study occurred over a 19-year period.

In summary, this study found that asthma was associated with a broad range of adverse outcomes during delivery hospitalization even when adjusting for known risk factors, that asthma was more common among those with comorbid conditions, and that the prevalence of asthma increased greatly over the study period. These findings suggest that asthma may

represent an increasingly important medical condition among high-risk pregnant women and an important focus for optimizing care.

REFERENCES

1. Van Zutphen AR, Bell EM, Browne ML, Lin S, Lin AE, Druschel CM, et al. Maternal asthma medication use during pregnancy and risk of congenital heart defects. Birth Defects Res A Clin Mol Teratol 2015;103:951–61. doi: 10.1002/bdra.23437

2. Baghlaf H, Spence AR, Czuzoj-Shulman N, Abenhaim HA. Pregnancy outcomes among women with asthma. J Matern Fetal Neonatal Med 2019;32:1325–31. doi: 10.1080/14767058.2017.1404982

3. Murphy VE, Namazy JA, Powell H, Schatz M, Chambers C, Attia J, et al. A meta-analysis of adverse perinatal outcomes in women with asthma. BJOG 2011;118:1314–23. doi: 10.1111/j.1471-0528.2011.03055.x

4. Perlow JH, Montgomery D, Morgan MA, Towers CV, Porto M. Severity of asthma and perinatal outcome. Am J Obstet Gynecol 1992;167:963–7. doi: 10.1016/s0002-9378(12)80020-2

5. Cohen JM, Bateman BT, Huybrechts KF, Mogun H, Yland J, Schatz M, et al. Poorly controlled asthma during pregnancy Remains common in the United States. J Allergy Clin Immunol Pract 2019;7:2672–80.e10. doi: 10.1016/j.jaip.2019.05.043

6. Andrews AL, Brinton DL, Simpson KN, Simpson AN. A longitudinal examination of the asthma medication ratio in children with Medicaid. J Asthma 2020;57:1083–91. doi: 10.1080/02770903.2019.1640727

7. Klebanoff MA, Snowden JM. Historical (retrospective) cohort studies and other epidemiologic study designs in perinatal research. Am J Obstet Gynecol 2018;219:447–50. doi: 10.1016/j.ajog.2018.08.044

8. Healthcare Cost and Utilization Project. Overview of the National (Nationwide) Inpatient Sample (NIS). Accessed February 20, 2021. https://www.hcup-us.ahrq.gov/nisoverview.jsp

9. Healthcare Cost and Utilization Project. Trend weights for HCUP NIS data. Accessed March 20, 2021. https://www.hcup-us.ahrq.gov/db/nation/nis/trendwghts.jsp

10. Healthcare Cost and Utilization Project. NIS description of data elements. Accessed February 20, 2021. https://www.hcup-us.ahrq.gov/db/vars/dxn/nisnote.jsp

11. Centers for Medicare & Medicaid Services. ICD-10. Accessed March 20, 2021. https://www.cms.gov/Medicare/Coding/ICD10/

12. Kinlaw A. Easy_ICD9-to-10_GEMs_mapping. Accessed May 31, 2021. https://github.com/alankinlaw/Easy_ICD9-to-10_GEMs_mapping

13. Centers for Disease Control and Prevention. Severe maternal morbidity in the United States. Accessed February 20, 2021. https://www.cdc.gov/reproductivehealth/maternalinfanthealth/severematernalmorbidity.html

14. Main EK, Abreo A, McNulty J, Gilbert W, McNally C, Poeltler D, et al. Measuring severe maternal morbidity: validation of potential measures. Am J Obstet Gynecol 2016;214:643.e1–10. doi: 10.1016/j.ajog.2015.11.004

15. Kuklina EV, Whiteman MK, Hillis SD, Jamieson DJ, Meikle SF, Posner SF, et al An enhanced method for identifying obstetric deliveries: implications for estimating maternal morbidity. Matern Child Health J 2008;12:469–77. doi: 10.1007/s10995-007-0256-6

16. Clapp MA, James KE, Friedman AM. Identification of delivery encounters using International Classification of Diseases, Tenth Revision, Diagnosis and Procedure Codes. Obstet Gynecol 2020;136:765–7. doi: 10.1097/AOG.0000000000004099

17. Bateman BT, Mhyre JM, Hernandez-Diaz S, Huybrechts KF, Fischer MA, Creanga AA, et al. Development of a comorbidity index for use in obstetric patients. Obstet Gynecol 2013;122:957–65. doi: 10.1097/AOG.0b013e3182a603bb

18. National Cancer Institute. Joinpoint trend analysis software. Accessed March 20, 2021. https://surveillance.cancer.gov/joinpoint/

19. Barrio G, Pulido J, Bravo MJ, Lardelli-Claret P, Jiménez-Mejías E, de la Fuente L. An example of the usefulness of joinpoint trend analysis for assessing changes in traffic safety policies. Accid Anal Prev 2015;75:292–7. doi: 10.1016/j.aap.2014.12.010

20. National Cancer Institute. APC/AAPC/Tau confidence intervals. Accessed April 1, 2021. https://surveillance.cancer.gov/help/joinpoint/setting-parameters/method-and-parameters-tab/apc-aapc-tau-confidence-intervals

21. Kim HJ, Fay MP, Feuer EJ, Midthune DN. Permutation tests for joinpoint regression with applications to cancer rates. Stat Med 2000;19:335–51. doi: 10.1002/(sici)1097-0258(20000215)19:3<335::aid-sim336>3.0.co;2-z

22. Faraone SV. Interpreting estimates of treatment effects: implications for managed care. P T 2008;33:700–11.

23. Equator Network. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement: guidelines for reporting observational studies. Accessed March 28, 2021. https://www.equator-network.org/reporting-guidelines/strobe/

24. The National Center for Health Statistics. Asthma. Accessed May 1, 2021. https://www.cdc.gov/nchs/fastats/asthma.htm

25. Uphoff E, Cabieses B, Pinart M, Valdés M, Antó JM, Wright J. A systematic review of socioeconomic position in relation to asthma and allergic diseases. Eur Respir J 2015;46:364–74. doi: 10.1183/09031936.00114514

26. Asthma and Allergy Foundation of America. Asthma disparities in America: a roadmap to reducing burden on racial and ethnic minorities. Accessed May 1, 2021. https://www.aafa.org/asthma-disparities-burden-on-minorities.aspx#pdf

27. Tata LJ, Lewis SA, McKeever TM, Smith CJ, Doyle P, Smeeth L, et al. A comprehensive analysis of adverse obstetric and pediatric complications in women with asthma. Am J Respir Crit Care Med 2007;175:991–7. doi: 10.1164/rccm.200611-1641OC

28. Yland JJ, Bateman BT, Huybrechts KF, Brill G, Schatz MX, Wurst KE, et al. Perinatal outcomes associated with maternal asthma and its severity and control during pregnancy. J Allergy Clin Immunol Pract 2020;8:1928–37.e3. doi: 10.1016/j.jaip.2020.01.016

29. Royal College of Obstetricians and Gynaecologists. Reducing the risk of venous thromboembolism during pregnancy and the puerperium. Green-top Guideline No. 37a. RCOG; 2015.

30. Chung WS, Lin CL, Ho FM, Li RY, Sung FC, Kao CH, et al. Asthma increases pulmonary thromboembolism risk: a nationwide population cohort study. Eur Respir J 2014;43:801–7. doi: 10.1183/09031936.00043313

31. Konstantinides SV. Asthma and pulmonary embolism: bringing airways and vessels closer together. Eur Respir J 2014;43:694–6. doi: 10.1183/09031936.00009414

32. Gu WJ, Liu JC. Asthma and risk of pulmonary thromboembolism. Eur Respir J 2014;43:1534–5. doi: 10.1183/09031936.00157813

33. Centers for Disease Control and Prevention. Asthma data visualizations. Accessed March 27, 2021. https://www.cdc.gov/asthma/data-visualizations/default.htm

34. Flores KF, Bandoli G, Chambers CD, Schatz M, Palmsten K. Asthma prevalence among women aged 18 to 44 in the United States: national health and nutrition examination survey 2001-2016. J Asthma 2020;57:693–702. doi: 10.1080/02770903.2019.1602874

35. Centers for Disease Control and Prevention. International Classification of Diseases, (ICD-10-CM/PCS) transition – background. Accessed June 22, 2021. https://www.cdc.gov/nchs/icd/icd10cm_pcs_background.htm

Standards for Different Types of Articles

Responsible reporting of research studies, which includes a complete, transparent, accurate, and timely account of what was done and what was found during a research study, is an integral part of good research and publication practice and not an optional extra. *Obstetrics & Gynecology* supports initiatives aimed at improving the reporting of health research. We ask authors to use the following guidelines when drafting their manuscripts:

1. CONSORT (Consolidated Standards of Reporting Trials) standards for reporting randomized trials
2. STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines for the reporting of observational studies
3. PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines for meta-analyses and systematic reviews of randomized controlled trials
4. PRISMA for harms (Preferred Reporting Items for Systematic reviews and Meta-Analyses) guidelines reporting harms in systematic reviews, whether harms are a primary or secondary outcome
5. STARD (Standards for Reporting of Diagnostic Accuracy) standards for reporting studies of diagnostic accuracy
6. MOOSE (Meta-analysis of Observational Studies in Epidemiology) guidelines for meta-analyses and systematic reviews of observational studies
7. CHEERS (Consolidated Health Economic Evaluation Reporting Standards) guidelines for reporting economic evaluations of health interventions
8. SQUIRE 2.0 (Standards for Quality Improvement Reporting Excellence) guidelines for reporting on quality improvement in health care
9. CHERRIES (Checklist for Reporting Results of Internet E-Surveys) guidelines for web-based surveys
10. RECORD (Reporting of Studies Conducted Using Observational Routinely-Collected Health Data) guidelines for reporting International Classification of Diseases and Current Procedural Terminology codes

Investigators should be thoroughly familiar with these sets of standards and follow these guidelines in articles submitted for publication.

Links to these guidelines are available at http://ong.editorialmanager.com

rev 8/2020