April 9, 2021

Dear members of the Professional Experience Committee,

I am submitting my Culminating Experience project titled "Delivery Complications and Postpartum Hospital Use in California" in partial fulfillment of the Masters of Public Health degree in the generalist concentration.

My culminating experience project is a research project maternal health, delivery complications, and healthcare utilization. The project analyzes characteristics associated with delivery complications and postpartum hospital use for a cohort of approximately 348,000 women in California using administrative data.

This work synthesizes my clinical experience, chosen MPH competencies, and larger career goals. In my clinical practice I am a family medicine physician with experience in obstetrics. Currently I am a public health and general preventive medicine resident at Cook County Health/NU Feinberg, with an interest in maternal-child health. This project allowed me to delve deeper into obstetric outcomes during delivery and in the postpartum period. I am interested in the medical co-morbidities and socioeconomic factors that contribute to adverse pregnancy outcomes. The skills and knowledge I would learn in this project would help me with my goal as a physician with expertise in maternal child health.

Competency	Detail How The Competency Was Synthesized In Your Project (may be through project activity, written product, and/or presentation
1 describe behavioral, social, and cultural factors that contribute to the health and well-being of communities	In my review of the literature for this project, I found that maternal mortality and morbidity outcomes in the United States are worsening.
12 apply demographic, epidemiologic and anthropologic methods to assess health disparities at local and global levels	My results showed that being non-Hispanic Black, or from high poverty ZIP codes or having Medicaid coverage, were significant risk factors for postpartum hospital use.
10 formulate and apply plans for data cleaning and management using statistical analysis software	I obtained data from the state of California, and prepared the data for analysis, including creating new variables, creating dummy variables for regression analysis.

20 calculate epidemiological measures of association between risk factors and disease	I applied statistical tests including Chi-square test to determine the association of postpartum hospital utilization and maternal characteristics, and including multivariable regression analysis to estimate the likelihood of postpartum hospital utilization.
18 analyze data employing computer-based statistical analysis package	I used STATA for data cleaning and analysis. Through this experience I improved my skills in coding.

Sincerely,

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Delivery Complications and Postpartum Hospital Use in California

Submitted in fulfillment of the requirements for the MPH

Chen Wang, MD

Abstract

Introduction

Research on maternal birth outcomes rarely includes postpartum complications with longitudinally linked patient data. We analyze characteristics associated with delivery complications and postpartum hospital use for women in California.

Methods

This population-based cohort study is based on California hospital discharge data. International Classification of Diseases 10th Revision codes were used to categorize the incidence of severe maternal morbidity (SMM) and other, route-specific delivery complications as well as preexisting and pregnancy-related conditions and principal diagnoses for postpartum hospital visits. Postpartum hospital use is a composite outcome defined as Emergency Department (ED) visits or hospital readmissions within 90 days of delivery discharge. Multivariable Poisson regression analyses were used to estimate the association of patient-level and hospital-level characteristics with the likelihood of postpartum hospital use.

Results

In 2017, there were 457,498 delivery admissions in California-licensed hospitals of which we analyzed 348,828 index deliveries with linked patient data. Among linked deliveries, 34,825 (10.0%) had an inpatient admission (4,206, 1.2%) or an ED visit (30,371, 9.2%) within 90 days of delivery discharge. Delivery complications included a 1.7% SMM rate, 7.9% rate of vaginal delivery complications, 10.0% of rate of cesarean delivery complications, and 2.9% frequency of long lengths of stay, all of which were significantly associated with postpartum hospital use. In addition, preexisting and pregnancy-related conditions, undergoing cesarean delivery, being less

than 18 years old, non-Hispanic Black, or from high poverty ZIP codes or having Medicaid coverage, were also significant risk factors for postpartum hospital use.

Discussion

One in ten women had a hospital visit within 90 days postpartum. Improving postpartum care is an urgent public health priority.

Key Words

Severe maternal morbidity, postpartum, quality of care, readmission, emergency department use

Introduction

The postpartum period is a critical time when pregnancy-related and chronic comorbidities can dramatically affect a woman's health (American College of Obstetricians and Gynecologists, 2018a). Most pregnancy-related deaths occur postpartum and maternal morbidity has increased (Callaghan et al., 2012; Davis, 2019; MacDorman et al., 2016). The prevalence of chronic disease and advanced maternal age among pregnant women is increasing (Admon et al., 2017; Martin et al., 2019) and both are associated with adverse obstetric outcomes (American College of Obstetricians and Gynecologists, 2018a; Callaghan et al., 2012). The standard postpartum care model is moving away from a single six-week visit to multiple visits between 3 to 12-weeks postpartum (American College of Obstetricians and Gynecologists, 2018a). But receipt of postpartum care, particularly for those with chronic or pregnancy-specific conditions, or socioeconomic barriers to care, remains suboptimal (Bennett et al., 2014; Kilfoyle et al., 2017). One marker for deficits in postpartum care is the incidence of emergency department (ED) visits and readmissions after delivery, many of which are potentially preventable with better access to obstetric and primary care. Better understanding postpartum hospital use can inform efforts to improve care transitions during this critical time (American College of Obstetricians and Gynecologists, 2018b).

Yet, few population-based studies examine postpartum hospital use. Most studies have been limited by the availability of longitudinal, patient-linked state hospital discharge data, with most states unable to provide data on individual patients' hospital use over time. Most studies of postpartum complications have therefore been based on single institutions or limited to populations defined by specific medical conditions or insurance statuses (Brousseau et al., 2018;

Clark et al., 2010; Cunningham et al., 2017; Ehrenthal et al., 2017; Fein et al., 2019; Harris et al., 2015; Harvey et al., 2018; Sheen et al., 2019). There are two notable exceptions: Batra et al. analyzed postpartum ED use in California births from 2009-2011. The study found that 8.3% of delivery admissions had a subsequent ED visit within 90 days of delivery discharge (Batra et al., 2017). Second, Clapp et al. analyzed postpartum readmissions in New York, California, and Florida from 2004-2011 and found readmission rates of 1.7 to 2.2% across the three states (Clapp et al., 2016).

This study builds on prior research by using linked data from 2017 births in California. We aim to use a contemporary, comprehensive cohort of all-payor, longitudinally linked data to better elucidate postpartum hospital utilization in California. We provide an updated estimate of ED and readmission rates, provide an updated and more extensive range of patient and hospital characteristics potentially associated with postpartum hospital use. In addition, we aim to address the association of 90-day postpartum hospital use with the incidence of severe maternal morbidity (SMM) measured at the delivery admission, as well as more common route-specific delivery complications.

Methods

This is a retrospective cohort study analyzing women with hospital discharges after a live birth in California in 2017. We first present analyses of the incidence of delivery complications and associations of both complications and postpartum hospital use with patient and hospital factors. We then model the likelihood of any postpartum hospital use using both patient characteristics, including delivery complications and hospital delivery volume.

Data source

Patient-level data were obtained from the California Office of Statewide Health Planning and Development Patient Discharge Data set and Emergency Department Data set, which include data from all state-licensed hospitals in California. This study was approved by the State of California Committee for the Protection of Human Subjects and was ruled exempt by the university's Institutional Review Board.

Diagnosis-related groups and International Classification of Disease 10th revision (ICD-10) diagnosis and procedure codes were used to identify individuals who had vaginal and cesarean deliveries. To analyze unique patients, after a chronologically first delivery any additional births to the same woman in the 2017 calendar year were excluded from analysis. The index delivery discharge and subsequent ED and inpatient discharge files were merged using the record linkage number assigned by the California Office of Statewide Health Planning and Development. The record linkage number is derived from the patient's Social Security Number. Delivery admissions which did not have a record linkage number and were excluded from the analysis.

Delivery Complications

Delivery admission outcomes were categorized by ICD-10 coded SMM, as defined by the Centers for Disease Control and Prevention (2019). SMM are also described in non-mutually exclusive groups based on definitions used by Grobman et al. (2006) In addition, ICD-10 codes were used to identify delivery route-specific complications derived from the Asch et al. coding (2009). These complication codes were derived from a sample of nearly five million deliveries from 107 obstetrics and gynecology residency programs, using ICD-9 coding. A crosswalk has since been developed to adapt them from ICD-9 to ICD-10 coding (Huennekens et al., 2020; Roy

et al., 2019). Asch et al. complications were initially grouped into hemorrhagic, infectious, and thrombotic diagnoses during the delivery hospitalization, severe obstetric lacerations (third- or fourth-degree perineal lacerations, cervical laceration, and anal sphincter tear not associated with third-degree laceration) for women who underwent vaginal delivery and operative complications for women who underwent cesarean delivery. Since then the American College of Obstetricians and Gynecologists has recommended against using obstetric lacerations as a quality metric, therefore we excluded lacerations in the definition of vaginal delivery complications (American College of Obstetricians and Gynecologists, 2015). Long delivery hospitalization length of stay, a potentially important proxy for uncoded delivery complications, was defined as greater than four days for vaginal delivery and greater than five days for cesarean delivery.

Maternal Demographic and Clinical Characteristics

Maternal sociodemographic and clinical characteristics included maternal age, grouped as ≤18, 19-24, 25-29, 30-34, 35-39, and ≥40 years of age at time of delivery. Self-reported race and ethnicity were characterized as non-Hispanic White, non-Hispanic Black, Hispanic (subdivided by English- versus Spanish- speaking), Asian or Pacific Islander, or other/unknown race and ethnicity. Insurance status was categorized as private/commercial, Medicaid, or other (including self-pay, other government programs, other indigent programs, Medicare disability, and unknown). We coded whether delivery admissions occurred on weekends versus weekdays. Patient residence ZIP codes in California were matched to ZIP Code Tabulation Areas (ZCTAs) using American Community Survey 2018 five-year census data to identify the percentage of families living in each zip code who were at or below 125% of the federal poverty level. Patients were then categorized as living in ZCTAs with <5%, 5-9.99%, 10-19.99%, 20% or more

residents in or near poverty, or as non-California residents (for whom poverty designation was unknown).

Clinical characteristics assessed included both pre-existing and pregnancy-related conditions. Pre-existing chronic conditions (pregestational diabetes, chronic hypertension, moderate/severe or acute asthma, pulmonary hypertension, cardiac disease, chronic renal disease, gastrointestinal disease, neuromuscular disease, hyperthyroidism, connective tissue or autoimmune disease, bleeding disorder, bariatric surgery, or HIV/AIDS), substance use disorder, mental illness, morbid obesity and pregnancy-related conditions (gestational diabetes mellitus, gestational hypertension, preeclampsia/eclampsia, preterm delivery, multiple gestation, previous cesarean delivery) were identified from up to 24 ICD-10 codes following the methods of Leonard et al. (2020). Appendix A shows ICD-10 codes used to categorize delivery complications and preexisting or pregnancy-related conditions.

Hospital-Delivery Volume

. Annual delivery hospital birth volume was divided by quartiles. First quartile hospitals had fewer than 972 deliveries per year, second quartile hospitals had 972-1650 deliveries per year, third quartile hospitals had 1650-2453 deliveries per year, and fourth quartile had 2454 or more per year.

Postpartum Hospital Use

We chose 90-day postpartum period for analysis because it approximates the length of the fourth trimester, a concept that extends the period of postpartum medical care and monitoring to 12 weeks after delivery (American College of Obstetricians and Gynecologists, 2018a). Postpartum hospital use is a composite outcome defined as inpatient admissions or ED visits for

any reason within 90 days of the delivery discharge date. We used principal diagnosis codes to identify the most common diagnoses at the postpartum inpatient admissions or ED visits.

Statistical Analysis

Chi-square tests were used to determine associations between delivery complications and postpartum hospital use with maternal sociodemographic characteristics, clinical conditions, and hospital characteristics. Multivariable Poisson regression analyses estimated the likelihood of postpartum hospital use controlling for patient and hospital-level characteristics, with standard errors adjusted for clustering of admissions within hospitals. The Poisson incidence rate ratio (IRR) was used because it provides a better approximation of relative risk for low prevalence outcomes than logistic regression(Zou, 2004). Analyses used STATA version 15, College Station, TX.

Results

Delivery Complications and Postpartum Hospital Use

There were a total of 457,498 delivery admissions in 2017. Of these, there were 92,709 deliveries (21%) which did not have a record linkage number and were excluded from the analysis. Appendix B provides a comparison of those excluded by lack of record linkage number to those included in the study. From the remaining linked delivery admissions, 15,681 were second births to the same individual. After excluding all second deliveries within 2017 there were 348,828 unique women included in the analysis, consisting of 242,606 vaginal deliveries (69.5%) and 106,222 cesarean deliveries (30.5%) at 246 California hospitals. About one-third (33.7%) of births were to those identifying as Non-Hispanic White, and 41.5% to those who

were Hispanic. Private/commercial insurances were the payor for slightly more than half of births (55.7%), and Medicaid was the payor for less than half of births (41.1%).

There were 12 maternal deaths during delivery admissions. The overall rate of SMM was 1.7%, with SMM rates of 1.1% for individuals who had vaginal deliveries and 3.2% for individuals who had cesarean deliveries. Excluding deliveries with SMM solely based on a transfusion code, the rate of non-transfusion SMM was 0.8% (0.7% for vaginal deliveries versus 2.0% for cesarean deliveries. Route-specific non-SMM complications were much more frequent, 7.9% for those who had vaginal deliveries and 10.0% for those who had cesarean deliveries.

In total, 40,873 ED visits and 4,508 admissions consisting of 30,371 hospital days occurred within 90 days of a delivery discharge. A total of 34,825 women had either an inpatient admission (1.2%) or an ED visit (9.2%) in those 90 days, with 10.0% of all women having any 90-day hospital use. There were 4,546 women (1.5%) who had either a 90-day readmission or three or more ED visits. As shown in Figure 1, majority of postpartum hospital use took place within 10 days of delivery discharge and continued throughout the 90 days follow up period. [Figure 1]

Table 1 describes the etiologies of SMM. [Table 1] Of the 6,003 women with at least one ICD-10 code consistent with SMM, nearly two-thirds (62.6%) involved blood product transfusions and 26.3% had complications of hypertensive disorders of pregnancy. Route-specific complications were primarily attributed to hemorrhagic and infectious diagnoses for individuals with both vaginal and cesarean deliveries.

The most common principal diagnoses at postpartum hospital encounters are presented in Table 2 [Table 2]. At the postpartum ED visits the most common principal diagnosis was “other

complications of the puerperium” (7.7%) followed by urinary tract infections (7.0%), and mastitis (3.7%). At postpartum admissions, the most common admission diagnosis were hypertensive disorders of pregnancy (19.1%). The ten most prevalent diagnoses represented 36.8% percent of diagnoses at postpartum emergency department visits, and 66.1% of diagnoses at postpartum admissions.

Associations between Maternal and Hospital Characteristics and Delivery Complications and Postpartum Hospital Use

Bivariate associations between the incidence of each type of delivery complication and postpartum hospital use within each demographic, clinical and hospital subgroup are presented in Table 3 [Table 3]. The highest rates of SMM were seen among individuals who identify as non-Hispanic Black, women at the each extreme of age, and women with comorbid conditions, hypertensive disorders of pregnancy, or multiple gestation. Higher rates of both vaginal and cesarean delivery route-specific complications were documented for individuals ages 18 and younger, those identifying as Asian, and who were privately insured. Higher rates of route-specific complication were seen in individuals living in more affluent areas and with delivery admissions at higher volume hospitals. By far the highest route-specific complication rates were for individuals with pre-existing comorbidities and pregnancy related conditions. Over 11% of women with long length of stay had documented SMM, and over 27% of women with long length of stay had documented route-specific complications. Among delivery admissions, 1.6% of vaginal deliveries and 5.9% of cesarean deliveries were complicated by long length of stay. Weekend admission was significantly associated with increased cesarean delivery complications, but not with SMM or vaginal delivery complications.

Postpartum hospital use [Table 3] was much higher among younger women and those identifying as non-Hispanic Black, and in particular, women covered by Medicaid. There was a distinct poverty level gradient showing higher postpartum hospital use among women living in poorer areas. Women with preexisting comorbidities, obstetric conditions, or long lengths of stay had the highest postpartum hospital use. The highest delivery volume hospitals had the lowest rates of postpartum hospital use.

Multivariable Models for Likelihood of Postpartum Hospital Use

Regression estimates of the likelihood of any 90-day hospital use are presented in Table 4 [Table 4]. Long length of delivery stay, SMM, or having a route-specific complication conferred between 7% and 22% higher risk. Undergoing cesarean delivery conferred a 32% higher risk of postpartum hospital use. As compared to the reference age of 19-24, younger women had a higher likelihood of 90-day hospital use and older women a lower likelihood. Women who identify as non-Hispanic Black were 31% more likely than those who identify as non-Hispanic White to have postpartum hospital use, and women on Medicaid were 74% more likely than privately-insured women. Having a substance use disorder or mental illness conferred between 41% to 43% percent higher risk of 90-day hospital use. Women with preexisting comorbidities were 27% more likely to have postpartum hospital use and every pregnancy-related condition conferred significantly higher risk. As compared to women living in the most affluent area, the likelihood of postpartum hospital use was significantly higher for women living in ZCTAs where the proportion of families in or near poverty was 10% or greater. Weekend delivery admission and hospital delivery volume were not significantly associated with increased postpartum hospital use.

Discussion

Risk Factors for Postpartum Hospital Use

This study found that one in ten of the 348,828 women with a first 2017 delivery in California had a postpartum ED visit or hospital readmission within 90 days of delivery admission. We found that the demographic and clinical risk factors associated with delivery complications were also associated with the likelihood of postpartum hospital use. Associations with delivery complications and postpartum hospital use were particularly strong for young women, women who underwent cesarean delivery, and those with mental illness or substance use disorder, morbid obesity, preterm birth, hypertensive disorders of pregnancy, or multiple gestations. Having a cesarean delivery itself independently conferred significant postpartum hospital use risk. While patients with Medicaid generally had similar or lower delivery complications than privately insured women, Medicaid coverage was the strongest independent risk factor for postpartum hospital use. Similarly, while individuals who identified as non-Hispanic Black had much higher rates of SMM, they did not have higher route-specific complications yet had an over 30% higher rate of postpartum hospital use independent of insurance status.

Are Route-specific Complications Biased Against Hospitals Who Use More ICD-10 Codes?

Higher postpartum hospital use was also correlated with lower hospital delivery volume, as shown in Table 3. However, our finding of lower route-specific complication rates for lower delivery volume hospitals, as well as for Medicaid patients and those from higher ZCTA poverty areas, seems counter-intuitive. This reverse social gradient of more affluent, better insured patients having higher route-specific complication rates is reinforced when we look at Appendix

B comparisons between excluded patients without Social Security Numbers and patients in our analytic sample. These comparisons reveal lower route-specific complication rates for excluded deliveries, which were much more likely to be Medicaid patients from higher poverty areas.

One potential factor, previously described in studies of ICD-10 coded delivery complications, is the large variation in what has been termed hospital medical record coding intensity (Grobman et al., 2006). This refers to the association between the number of ICD codes a hospital routinely uses for *uncomplicated* deliveries and the significantly higher likelihood of finding complication codes at high coding intensity hospitals. In our sample of 246 hospitals, the mean number of ICD-10 codes used by the lowest volume quartile hospitals for *uncomplicated deliveries* was 5.1 while the mean was 6.0 for the highest quartile hospitals, Similarly, Medicaid patients had an average of 5.3 codes versus 5.9 for privately insured, and uncomplicated patients from the highest poverty area had an average 5.3 codes versus 5.8 for the most affluent areas. (data not shown). Thus, some of the inverse social gradient may be related to use of more resource rich hospitals who more aggressively code discharges of more affluent, privately insured patients. These findings raise questions about the validity and reliability of ICD-10 coded route-specific complications.

There were also potentially important age differences between privately insured and Medicaid patients and across ZCTA poverty areas. In the most affluent areas, 36.9 % of the women were age 35 and older, including 7.4% being age 40 years and older. Only 14% of women from the poorest areas were age 35 years and older and only 2.7% were age 40 years and older. The mean age of Medicaid patients was over four years younger than the privately insured (data not shown).

Previous Studies

This study is one of the few population-based studies of postpartum hospital use and is innovative in its use of ICD-10 coded data based on Leonard et al. (2020). Our findings are largely consistent with Batra et al., who found 8.3% of women had at least one ED visit within 90 days postpartum, and had the same clinical risk factors including SMM, cesarean delivery, and antepartum complications. Based on data predating Medicaid expansion in 2014, Batra et al. found even higher risk for Medicaid versus private coverage, with Medicaid patients having 2.3 times the likelihood of a postpartum ED visit. The most prevalent ICD-10 coded diagnoses among all ED visits were similar to the most prevalent ICD-9 coded diagnoses among the first ED visits in the paper by Batra et al. Other studies had found that hypertensive disorders, infection, wound disruption, urinary tract infection, mental illness or substance use disorder were common indications for postpartum hospital use (Brousseau et al., 2018; Clapp et al., 2016; Harvey et al., 2018).

Unlike Batra et al., which grouped ICD-9 preexisting comorbidities and pregnancy-related conditions as a single variable, our study disaggregated the numerous pre-existing and pregnancy-related clinical risk factors and included the full range of ICD-10 coded conditions used by Leonard et al. in their analysis of risk factors for SMM (2020). This allowed us to differentiate risk posed by specific conditions such as mental illness, substance use disorder, morbid obesity, preterm delivery, hypertensive disorders, and diabetes. We also analyzed risk from route-specific delivery complications, more granular age groups including women over 40, and hospital characteristics. We also show the importance of long length of delivery stay as a

postpartum hospital use risk factor potentially capturing additional complicated delivery admissions not identified just from ICD-10 complication codes.

In the Clapp et al. three-state study of births from 2004-2011, the readmission rate was significantly higher for those who identified as non-Hispanic Black, those with Medicaid, and those who underwent cesarean delivery or had preexisting and pregnancy-related conditions, especially hypertension. Individuals with psychiatric illness, substance use, or seizure disorder were more than twice as likely to be readmitted. We did not find mental illness as a top principal admission diagnosis although it was highly associated with postpartum hospital use, similar to work by Clapp et al. We found that sepsis ranked as the third most common indication for admission, while it was less common in the three-state study (Clapp et al., 2016). Our study looked at the primary diagnoses at all admissions, while Clapp et al. looked at both principal and associated diagnoses, which may account for differences in the findings.

Approaches to Improving Postpartum Care

Postpartum outpatient care is often poorly attended, with disparities based on insurance status, race and ethnicity, age (Wilcox et al., 2016). Improving postpartum care requires interventions in many areas, such as quality improvement, access to care. Quality improvement initiatives led by statewide perinatal collaboratives target causes of common complications (Lee King et al., 2020). The California Maternal Quality Care Collaborative has demonstrated reduced rates of cesarean deliveries, more timely treatment of preeclampsia and improved patient education (Main et al., 2018). Care navigation programs have demonstrated improved attendance of postpartum medical visits for women with Medicaid (Yee et al., 2017).

Policy and payment reforms can also support improved postpartum care. Legislation extending Medicaid from 60 days to one-year postpartum is being enacted. In California, women with mental health diagnoses are currently eligible for the extension ("AB-577 Health care coverage: maternal mental health," 2019). The American Recovery Act of 2021 allows all states the option for the extension ("American Rescue Plan Act "). Reimbursement policies that support postpartum care as a team-based care process (e.g., including home visits, postpartum visits starting within 3 weeks postpartum and ongoing as needed) rather than a single visit would also help. Medicaid extension, navigator programs, and quality improvement initiatives would have upfront cost, but are investments at a critical time and are likely to pay future dividends in improved health outcomes and decreased healthcare spending (Eckert, 2020).

Limitations

Perhaps the most important weakness was exclusion of about one-fifth (92,709, 21%) of births due to missing Social Security numbers, and so did not have a record linkage number to link to postpartum hospital use. Excluded individuals differed in that they were more likely to identify as Spanish-speaking Hispanic, or Asian/Pacific Islander, with Medicaid coverage (59.2% among excluded deliveries compared to 41.1% in the analytic sample) and having fewer preexisting comorbidities. As shown in Appendix B, the excluded patients were much more likely to be living in higher poverty areas. To the extent that foreign-born California residents lack access to comprehensive primary care, we would expect that their postpartum hospital use would be significantly higher. We were unable to ascertain actual attendance at outpatient visits. This study uses clinical data based on ICD-10 coding, which imperfectly captured patient characteristics such as obesity, prior cesarean births, or gestational age. However, hospital

administrative data on deliveries has been shown to better capture antepartum complications than birth certificate data (Lydon-Rochelle et al., 2005). Another limitation was the small sample of American Indian/Alaskan Native women (0.5%), so their data were analyzed in combination with other ethnic groups.

Implications for Practice and/or Policy

Our study used a population-based sample to determine the extent to which the trends of increasing SMM are reflected in postpartum hospital use. We found that the demographic and clinical risk factors associated with delivery complications were also associated with postpartum ED use and hospital admission. Improvements in postpartum care and access to care are essential to improving overall maternal health and address the marked inequities in the US healthcare system.

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Table 1
Etiology of Severe Maternal Morbidity and Other Obstetric Complications
348,828 Women with Deliveries in California, 2017

	Percent Prevalence Among Complicated Deliveries[a]
Severe Maternal Morbidity[b] (n=6,003)	
Transfusions	62.6
Hypertensive disorders of pregnancy[c]	26.3
Infectious[d]	11.6
Non-hypertensive cardiopulmonary[e]	8.3
Other[f]	6.1
Vaginal Delivery Complications (n=19,258)	
Hemorrhagic	47.0
Infectious	36.3
Thrombotic	0.3
Cesarean Delivery Complications (n=10,604)	
Infectious	57.3
Hemorrhagic	47.4
Operative complications[g]	5.1
Thrombotic	0.5

[a]Column totals are greater than 100 percent because complication categories are not mutually exclusive.

[b]Defined by the Centers for Disease Control and Prevention: acute myocardial infarction, aneurysm, acute renal failure, adult respiratory distress syndrome, amniotic fluid embolism, cardiac arrest/ventricular fibrillation, conversion of cardiac rhythm, disseminated intravascular coagulation, eclampsia, heart failure/arrest during surgery or procedure, puerperal cerebrovascular disorders, pulmonary edema/acute heart failure, severe anesthesia complications, sepsis, shock, sickle cell disease with crisis, air and thrombotic embolism, hysterectomy, temporary tracheostomy, ventilation, blood products transfusion

[c]Includes ICD-10 codes for acute renal failure, acute pulmonary edema or acute heart failure, puerperal cerebrovascular disorders, aneurysm, disseminated intravascular coagulation, eclampsia, acute myocardial infarction, cardiac arrest or ventricular fibrillation, heart failure or arrest during procedure or surgery, and conversion of cardiac rhythm.

[d]Includes ICD-10 codes for sepsis.

[e]Includes ICD-10 codes for shock, acute respiratory distress syndrome, mechanical ventilation, temporary tracheostomy, air and thrombotic embolism, and amniotic fluid embolism.

[f]Includes ICD-10 codes for hysterectomy, severe anesthesia complications, and sickle cell disease with crisis.

[g]Includes ICD-10 codes for postprocedural or surgical site infection, accidental puncture or laceration of adjacent structures, retained foreign body and related complications, and postprocedural intestinal obstruction.

Table 2
Most Common Principal Diagnoses at Postpartum Hospital Visits within 90 Days of Delivery Discharge, 2017

Postpartum Emergency Department Visit n=40,873	n (%)	Postpartum Inpatient Admission n=4,508	n (%)
Other complications of the puerperium	3,160 (7.7)	Hypertensive disorders[a]	860 (19.1)
Urinary tract infections	2,880 (7.0)	Cholecystitis	447 (10.0)
Mastitis	1,528 (3.7)	Sepsis	330 (7.3)
Postpartum hemorrhage and retained products of conception	1,508 (3.7)	Endometritis	309 (6.9)
Cholelithiasis without cholecystitis	1,267 (3.1)	Other disease of the digestive system	260 (5.8)
Abdominal pain, unspecified etiology	1,147 (2.8)	Surgical wound infection or disruption	259 (5.7)
Surgical wound infection or disruption	1,031 (2.5)	Postpartum hemorrhage and retained products of conception	174 (3.9)
Headache, unspecified	878 (2.1)	Other postpartum complications	131 (2.9)
Abnormal uterine and vaginal bleeding	846 (2.1)	Pancreatitis	116 (2.6)
Chest pain, unspecified etiology	802 (2.0)	Mastitis	94 (2.1)
All other diagnoses	25,826 (63.2)	All other diagnoses	1,528 (33.9)

[a]Includes hypertension, preeclampsia, eclampsia

Table 3
Incidence of Delivery Complications and Postpartum Hospital Use by Clinical and Sociodemographic Characteristics, n=348,828 Women with Deliveries in California 2017

	Baseline characteristics	Delivery complications			Postpartum hospital use
	Percent all deliveries (n=348,828)	Percent severe maternal morbidity[a] (n=348,828)	Percent vaginal delivery complication[b] (n=242,606)	Percent cesarean delivery complication[c] (n=106,222)	Percent postpartum emergency visit or inpatient admission (n=348,828)
All deliveries	100	1.7	7.9	10.0	10.0
Sociodemographic characteristics					
Age (years)					
≤18	1.9	2.3	8.8	14.6	17.2
19-24	19.0	1.8	8.2	10.6	14.5
25-29	26.9	1.5	7.5	9.5	10.5
30-34	30.1	1.7	8.0	10.0	8.0
35-39	17.8	1.9	8.0	9.7	7.4
≥40	4.3	2.7	8.5	10.7	8.5
Race/Ethnicity					
Non-Hispanic White	33.7	1.4	7.1	8.6	8.7
Non-Hispanic Black	6.4	2.7	7.5	10.2	16.3
Hispanic, English-speaking	36.1	1.8	7.8	9.9	11.8
Hispanic, Spanish-speaking	5.4	1.7	7.2	9.1	9.4
Asian/Pacific Islander	13.7	1.8	11.1	14.3	6.0
Other/Unknown	4.8	1.7	7.2	9.4	9.0
Insurance					
Private	55.7	1.6	9.1	11.3	6.8
Medicaid	41.1	1.9	6.5	8.2	14.2
Other	3.2	1.9	7.4	9.9	10.5

ZIP Code Tabulation Areas Percent of Families at or below 125% Poverty[d]					
<5%	9.2	1.6	10.0	11.6	6.6
5-9.99%	24.4	1.6	8.9	11.1	7.8
10-19.99%	32.6	1.6	7.8	9.9	10.3
>20%	32.9	1.7	6.8	8.8	12.2
Out of state	0.9	1.9	7.6	9.9	12.9
Clinical characteristics					
Preexisting comorbidities[e]	17.0	4.3	11.9	13.8	12.9
Specific preexisting comorbidities					
Anemia	11.6	5.0	14.6	15.6	11.8
BMI>40	4.8	2.4	11.0	10.8	16.2
Mental illness	5.8	2.7	11.8	13.2	15.0
Substance use disorder	2.2	4.2	10.5	12.5	21.1
Obstetric-related conditions					
Gestational diabetes	9.2	1.9	10.8	10.1	10.6
Gestational hypertension	4.4	2.7	15.3	13.8	12.9
Long delivery length of stay[f]	2.9	11.3	27.7	27.5	15.6
Multiple gestation	1.5	6.4	20.1	13.7	12.9
Preeclampsia and eclampsia	5.1	6.3	19.7	15.9	14.9
Preterm delivery	7.9	4.8	10.6	13.1	14.2
Previous cesarean delivery	4.5	4.3	13.7	10.0	13.6
Weekend admission	21.9	1.7	8.1	13.4	9.7
Hospital characteristics					
Delivery volume (deliveries/year)					
Quartile 1 (<972)	21.5	1.9	6.3	7.8	11.1
Quartile 2 (972-1649)	28.6	1.7	6.9	8.4	10.3
Quartile 3 (1650-2454)	24.6	1.8	9.7	12.3	9.6
Quartile 4 (>2454)	25.3	1.5	8.8	11.5	9.1

All comparisons significant at $p < 0.001$ except for the following: weekend admission for severe maternal morbidity, vaginal delivery complication, postpartum hospital use, gestational diabetes for severe maternal morbidity, previous cesarean delivery for cesarean delivery complications.

[a]Defined by the Centers for Disease Control and Prevention: acute myocardial infarction, aneurysm, acute renal failure, adult respiratory distress syndrome, amniotic fluid embolism, cardiac arrest/ventricular fibrillation, conversion of cardiac rhythm, disseminated intravascular coagulation, eclampsia, heart failure/arrest during surgery or procedure, puerperal cerebrovascular disorders, pulmonary edema/acute heart failure, severe anesthesia complications, sepsis, shock, sickle cell disease with crisis, air and thrombotic embolism, hysterectomy, temporary tracheostomy, ventilation, and blood products transfusion.

[b]Vaginal delivery complications include hemorrhagic, infectious, and thrombotic diagnoses associated with hospitalization for childbirth.

[c]Cesarean delivery complications include hemorrhagic, infectious, and thrombotic diagnoses and operative complications associated with hospitalization for childbirth.

[d]Patient ZIP codes were matched to ZIP Code Tabulation Areas using American Community Survey 2018 five-year census data to identify the percentage of families living in each ZIP code who were at or below 125% the federal poverty level.

[e]Includes diabetes, hypertension, moderate/severe or acute asthma, pulmonary hypertension, cardiac disease, chronic renal disease, gastrointestinal disease, neuromuscular disease, hyperthyroidism, connective tissue or autoimmune disease, bleeding disorder, bariatric surgery, or HIV/AIDS.

[f]Defined as >4 days for vaginal delivery or >5 days for cesarean delivery.

Table 4
Incidence Rate Ratios (IRR) Assessing Factors Associated with Postpartum Hospital Use, 2017

	Emergency department visit or admission n= 34,825
Characteristics	All deliveries n=348,828
	IRR (95% CI)
Sociodemographic characteristics	
Age (years)	
≤18	1.15 (1.09-1.22)
19-24	Reference
25-29	0.80 (0.78-0.83)
30-34	0.70 (0.68-0.72)
35-39	0.66 (0.64-0.68)
≥40	0.72 (0.68-0.76)
Race/ethnicity	
Non-Hispanic white	Reference
Non-Hispanic Black	1.31 (1.27-1.36)
Hispanic English-speaking	1.06 (1.04-1.09)
Hispanic Spanish-speaking	0.82 (0.78-0.86)
Asian	0.78 (0.75-0.82)
Other/Unknown	0.94 (0.89-0.99)
Insurance	
Private	Reference
Medicaid	1.74 (1.70-1.78)
Other	1.41 (1.33-1.49)
ZIP Code Tabulation Areas Percent of Families in Poverty[a]	
<5%	Reference
5-9.99%	1.01 (0.96-1.06)
10-19.99%	1.10 (1.05-1.15)
>20%	1.10 (1.05-1.16)
Out of state	1.23 (1.12-1.36)
Complications and Severe Maternal Morbidity	
Vaginal delivery complications[b]	1.19 (1.14-1.25)
Cesarean delivery complications[c]	1.10 (1.04-1.16)
Severe Maternal Morbidity[d]	1.22 (1.15-1.28)
Clinical characteristics	
Mode of delivery	

Vaginal delivery	Reference
Cesarean delivery	1.32 (1.29-1.35)
Preexisting comorbidities[e]	1.27 (1.24-1.30)
Specific preexisting comorbidities	
Anemia	1.06 (1.02-1.09)
BMI>40	1.30 (1.25-1.34)
Mental illness	1.43 (1.38-1.48)
Substance use disorder	1.41 (1.35-1.48)
Obstetric conditions	
Gestational diabetes	1.11 (1.07-1.15)
Gestational hypertension	1.20 (1.15-1.25)
Long delivery length of stay[f]	1.07 (1.02-1.13)
Multiple gestation	1.04 (0.97-1.12)
Preeclampsia and eclampsia	1.16 (1.11-1.20)
Preterm delivery	1.22 (1.18-1.26)
Previous cesarean delivery	1.09 (1.05-1.14)
Weekend admission	1.00 (0.98-1.02)
Hospital characteristics	
Hospital delivery volume (deliveries/year)	
Quartile 1 (<972)	Reference
Quartile 2 (972-1649)	0.97 (0.94-0.99)
Quartile 3 (1650-2454)	0.93 (0.91-0.96)
Quartile 4 (>2454)	0.93 (0.90-0.96)

CI = confidence interval

[a]Patient zip codes were matched to Zip Code Tabulation Areas using American Community Survey 2018 five-year census data to identify the percentage of families living in each zip code who were at or below 125% the federal poverty level.

[b]Vaginal delivery complications include hemorrhagic, infectious, and thrombotic diagnoses associated with hospitalization for childbirth.

[c]Cesarean delivery complications include hemorrhagic, infectious, and thrombotic diagnoses and operative complications associated with hospitalization for childbirth.

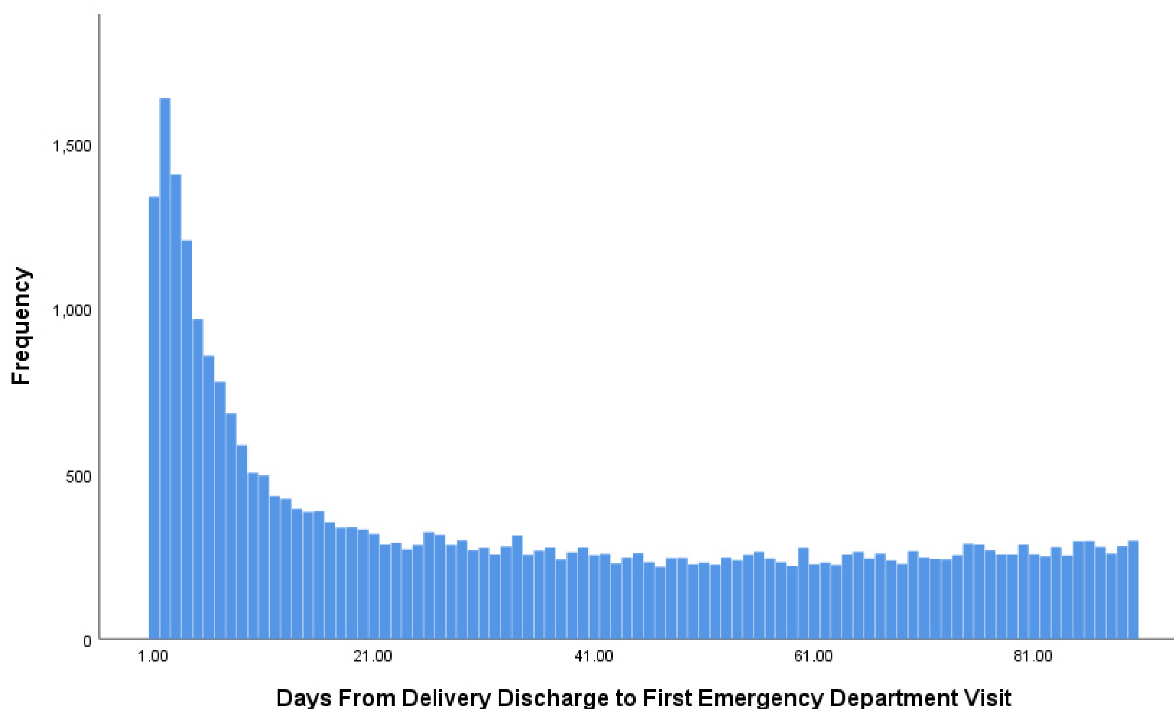
[d]Defined by the Centers for Disease Control and Prevention: acute myocardial infarction, aneurysm, acute renal failure, adult respiratory distress syndrome, amniotic fluid embolism, cardiac arrest/ventricular fibrillation, conversion of cardiac rhythm, disseminated intravascular coagulation, eclampsia, heart failure/arrest during surgery or procedure, puerperal cerebrovascular disorders, pulmonary edema/acute heart failure, severe anesthesia complications, sepsis, shock, sickle cell disease with crisis, air and thrombotic embolism, hysterectomy, temporary tracheostomy, ventilation, and blood products transfusion.

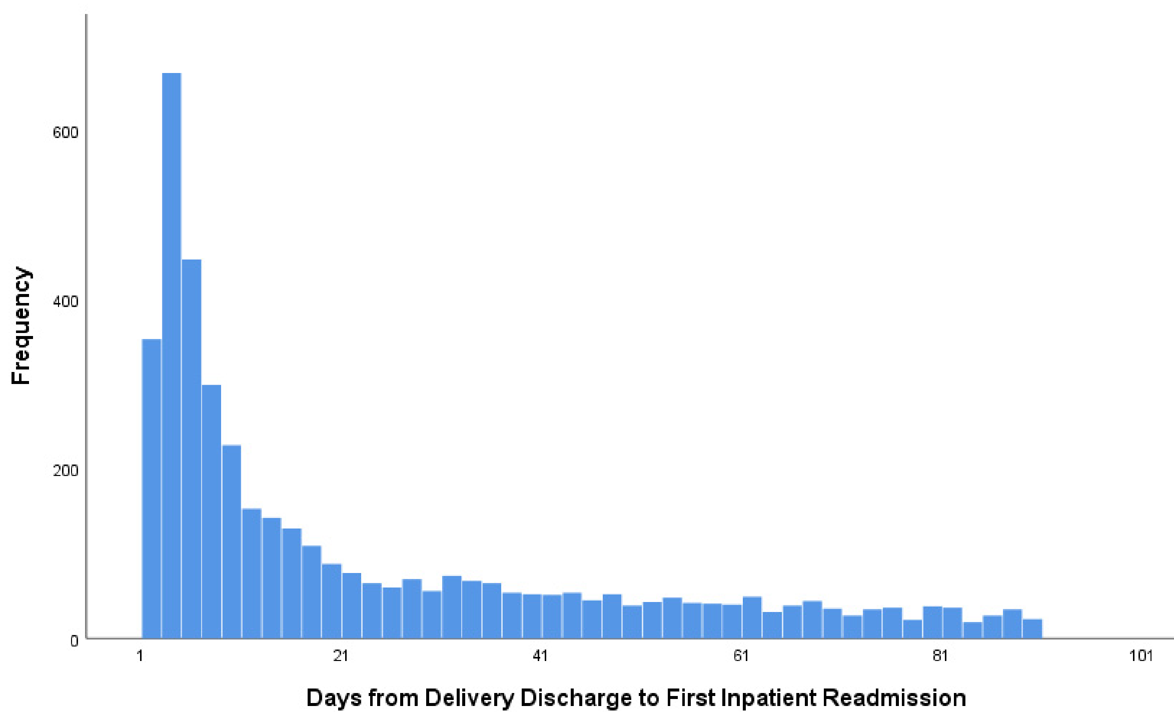
[e]Includes diabetes, hypertension, moderate/severe or acute asthma, pulmonary hypertension, cardiac disease, chronic renal disease, gastrointestinal disease, neuromuscular disease,

thyrotoxicosis, connective tissue or autoimmune disease, bleeding disorder, bariatric surgery, or HIV/AIDS.

[f]Defined as >4 days vaginal delivery or >5 days cesarean delivery.

Figure 1. Days from delivery discharge to first hospital use





Appendix A Codes Used to Identify Severe Maternal Morbidity Indicators, Delivery Complications, Maternal Clinical Conditions During Delivery and Postpartum Hospital Visits

Indicator	**MS-DRG Codes**
Vaginal delivery	774, 775, 767, 768
Cesarean section	765, 766

Severe Maternal Morbidity	**ICD-10 Codes**
Acute myocardial infarction	121.x, 122.x
Aneurysm	171.xx, 179.0
Acute renal failure	N17.x, O90.4
Adult respiratory distress syndrome	J80, J95.1, J95.2, J95.3, J95.82x, J96.0x, J96.2x R09.2
Amniotic fluid embolism	O88.1x
Cardiac arrest/ventricular fibrillation	I46, I46.2, I46.8, I46.9, I49.0, I49.01, I49.02 I46.x, I49.0x
Conversion of cardiac rhythm	5A2204Z, 5A12012
Disseminated intravascular coagulation	D65, D68.8, D68.9, O72.3
Eclampsia	O15. X
Heart failure/arrest during surgery or procedure	I97.12x, I97.13x, I97.710, I97.711
Puerperal cerebrovascular disorders	I60.xx- I68.xx, O22.51, O22.52, O22.53, I97.81x, I97.82x, O87.3
Pulmonary edema/Acute heart failure	J81.0, I50.1, I50.20, I50.21, I50.23, I50.30, I50.31, I50.33, I50.40, I50.41, I50.43, I50.9
Severe anesthesia complications	O74.0, O74.1, O74.2, O74.3, O89.0, O89.01, O89.09, O89.1, O89.2
Sepsis	O85, O86.04, T80.211, T81.4XXA, T81.44xx, R65.20, A40.x, A41.x, A32.7
Shock	O75.1, R57, R57.0, R57.1, R57.8, R57.9, R65.21, T78.2XXA, T88.2XXA, T88.6XXA, T81.10XA, T81.11XA, T81.19XA
Sickle cell disease with crisis	D57.0x, D57.21x, D57.41x, D57.81x
Air and thrombotic embolism	I26.x, O88.0x, O88.2x, O88.3x, O88.8x
Hysterectomy	0UT90ZZ, 0UT94ZZ, 0UT97ZZ, 0UT98ZZ, 0UT9FZZ
Temporary tracheostomy	0B110Z4, 0B110F4, 0B113Z4, 0B113F4, 0B114Z4, 0B114F4
Ventilation	5A1935Z, 5A1945Z, 5A1955Z
Transfusion	30233 Peripheral vein, percutaneous (7th digit: x=1: nonautologous) 30240 Central Vein, open (7th digit: x=1: nonautologous) 30243 Central Vein, percutaneous (7th digit: x=1: nonautologous, x=0: autologous) + Hx (whole blood), Kx (frozen plasma), Lx (fresh Plasma), Mx (plasma cryoprecipitate), Nx (red blood cells), Px (frozen Red cells), Rx (platelets), Tx (fibrinogen)

Asch et al. Route-specific complications	**ICD-10 Codes**

Hemorrhage	O44.xx, O46.xxx, O67.x, O72.x, N99.6x, N99.82x, L76.02, L76.22, M96.811, M96.831
Infection	O41.10xx, O41.12xx, O41.14xx, O75.3, O86.0x, O86.1x, O86.2x, O86.8x, T81.4xXA
Operative Complication	O75.4, O86.0x, N99.7x, G97.49, I97.52, L76.12, L76.22, M96.821, T81.4xXA, T81.5xA, T88.8XXA, K91.3x
Thrombosis	O87.1, O87.3, O88.2xx

Clinical conditions	**ICD-10 Codes**
Preexisting comorbidities:	
Asthma, acute or moderate/severe	O99.5, J45.21, J45.22, J45.31, J45.32, J45.4, J45.5, J45.901, J45.902
Bariatric surgery	O99.84
Bleeding disorder	D66-D69
Cardiac disease	I05-I09, I11-I13, I15, I16, I20, I25, I127.8, I30-I41, I144-I49, I50.22, I50.23, I50.32, I50.33, I50.42, I50.43, I50.812, I50.813, O99.41, O99.42, Q20-24
Chronic renal disease	I12, I13, N03-N05, N07, N08, N11.1, N11.8, N11.9, N18, N25.0, N25.1, N25.81, N25.89, N25.9, N26.9, O26.83, Q20-Q24
Connective tissue or autoimmune disease	M30-M36
Diabetes	E08-E13, O24.0x, O24.1x, O24.3x, O24.8x, O24.82
Gastrointestinal disease	K0-K95, O99.6, O26.6
HIV/AIDS	O98.7, B20, Z21
Hypertension	I10, I11, O10.xx, O11.x
Hyperthyroidism	E05
Neuromuscular disease	O99.35, G40, G70
Pulmonary hypertension	I27.0, I27.2
Specific preexisting comorbidities:	
Anemia	O99.01, O99.01, O99.02, O99.109, D50.x, D55.x, D56.x, D57.1, D57.20, D57.3, D57.40, D57.80, D55, D56, D58.x, D59.x
BMI≥40	Z68.4
Mental illness	F20-F50, F53, O90.6, O99.34, R45.8, T14.91, X78.9
Substance use disorder	F10-F19, T40.0-T40.4, T40.6, O99.31, O99.32
Obstetric conditions:	
Gestational hypertension	O13.x
Gestational diabetes	O24.4x
Multiple gestation	O30.x, O31.x, Z37.2-Z37.7
Preeclampsia	O11.x, O14.x
Preterm delivery	O60.1, Z3A.20-36
Prior cesarean delivery	O34.2x, Z98.891

Appendix B Clinical and Sociodemographic Characteristics of deliveries with record linkage numbers and deliveries without record delivery numbers, 441,537 deliveries, 2017

	Unique deliveries with record linkage number (%) n=348,828	Deliveries without record linkage number (%) n=92,709
Age (years)		
≤18	1.9	3.4
19-24	19.2	15.0
25-29	26.9	25.2
30-34	30.1	31.3
35-39	17.8	19.8
≥40	4.4	5.4
Race/Ethnicity		
Non-Hispanic white	33.7	11.3
Non-Hispanic Black	6.4	1.8
Hispanic English-speaking	36.1	19.5
Hispanic Spanish-speaking	5.4	38.8
Asian or Pacific Islander	13.7	22.8
Other or Unknown	4.8	5.8
Insurance status		
Private	55.7	23.5
Medicaid	41.1	59.2
Other	3.2	17.2
ZIP Code Tabulation Areas Percent of Families at or below 125% Poverty[a]		
<5%	9.2	12.6
5-9.99%	24.4	28.6
10-19.99%	32.6	33.3
>20%	32.9	26.9
Out of state	0.9	1.3
Severe Maternal Morbidity[b]	1.7	1.5
Vaginal delivery complication[c]	7.9	6.3
Cesarean delivery complication[d]	10.0	7.6
Clinical characteristics		
Mode of delivery		
Vaginal	69.6	67.3
Cesarean	30.5	32.7
Preexisting comorbidities[e]	17.5	10.3
Specific preexisting comorbidities		
Anemia	11.6	7.8
BMI>40	4.8	2.2
Mental illness	5.8	1.7
Substance use disorder	2.2	0.7

Obstetric conditions		
Gestational diabetes	9.2	11.1
Gestational hypertension	4.4	3.0
Long length of delivery stay[f]	2.9	3.0
Multiple gestation	1.5	1.4
Preeclampsia and eclampsia	5.1	4.5
Preterm delivery	7.8	8.2
Previous cesarean delivery	4.5	4.9

All p values <0.001 except for multiple gestation

[a]Patient ZIP codes were matched to Zip Code Tabulation Areas using American Community Survey 2018 five-year census data to identify the percentage of families living in each zip code who were at or below 125% the federal poverty level.

[b]Defined by the Centers for Disease Control and Prevention: acute myocardial infarction, aneurysm, acute renal failure, adult respiratory distress syndrome, amniotic fluid embolism, cardiac arrest/ventricular fibrillation, conversion of cardiac rhythm, disseminated intravascular coagulation, eclampsia, heart failure/arrest during surgery or procedure, puerperal cerebrovascular disorders, pulmonary edema/acute heart failure, severe anesthesia complications, sepsis, shock, sickle cell disease with crisis, air and thrombotic embolism, hysterectomy, temporary tracheostomy, ventilation, blood products transfusion

[b]Vaginal delivery complications include hemorrhagic, infectious, and thrombotic diagnoses associated with hospitalization for childbirth.

[c]Cesarean delivery complications include hemorrhagic, infectious, and thrombotic diagnoses and operative complications associated with hospitalization for childbirth.

[e]Includes diabetes, hypertension, moderate/severe or acute asthma, pulmonary hypertension, cardiac disease, chronic renal disease, gastrointestinal disease, neuromuscular disease, hyperthyroidism, connective tissue or autoimmune disease, bleeding disorder, bariatric surgery, or HIV/AIDS

[f]Defined as >4 days for vaginal delivery or >5 days for cesarean delivery