Influence of Patient Comorbidities on the Risk of Near-miss Maternal Morbidity or Mortality

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ABSTRACT

Background: Maternal morbidity and mortality are increased in the United States compared with that of other developed countries. The objective of this investigation is to determine the extent to which it is possible to predict which patients will experience near-miss morbidity or mortality.

Methods: The authors defined near-miss morbidity as end-organ injury associated with length of stay greater than the 99th percentile or discharge to a second medical facility, and identified all cases of near-miss morbidity or death from admissions for delivery in the 2003–2006 Nationwide Inpatient Sample. Logistic regression was used to examine the effect of maternal characteristics on rates of near-miss morbidity/mortality.

Results: Approximately 1.3 per 1,000 hospitalizations for delivery was complicated by near-miss morbidity/mortality as defined in this study (95% CI 1.3–1.4). Most of these events (58.3%) occurred in 11.8% of the delivering population—in those women with important medical comorbidities or obstetric complications identified before admission for delivery. The highest rates were noted among women with pulmonary hypertension (98.0 cases per 1,000 deliveries), malignancy (23.4 per 1,000), and systemic lupus erythematosus (21.1 per 1,000).

Conclusions: Risk for near-miss morbidity or mortality is substantially increased among an identifiable subset of pregnant women. To the extent that antepartum multidisciplinary coordination and high-quality intrapartum care improve delivery outcomes for women with significant antepartum medical and obstetric disease, then public health investments to reduce the national burden of delivery-related near-miss morbidity and mortality will have the greatest effect by focusing resources on identifying and serving these high-risk groups.

What We Already Know about This Topic

- Maternal mortality is increasing in the United States, but the risk factors for maternal near-miss morbidity or mortality have not been well defined

What This Article Tells Us That Is New

- Using the 2003–2006 Nationwide Inpatient Sample, approximately 1.3 per 1,000 hospitalizations for delivery was complicated by near-miss morbidity or mortality
- Women with preexisting conditions or antenatal obstetric complications suffer the majority of these events

BOTH the Joint Commission and Amnesty International have recently called attention to the poor record of maternal patient safety in the United States.[1,2] The maternal mortality ratio in the United States has been estimated to be as high as 17 deaths per 100,000 live births, and the rate of annual increase between 1998 and 2008 exceeded that of any other developed country.[3] Multiple studies have suggested that nearly half of all pregnancy-related deaths are preventable with timely delivery of appropriate healthcare services.[4–7] Although many maternal deaths are due to etiologies that are unpredictable, an increasing proportion of maternal deaths are attributed to preexisting disease.[8] Both the extent to which maternal morbidity/mortality is concentrated in high-risk patients and the relative effect of specific preexisting conditions have not been well defined. This information is needed to evaluate the potential effect of public health investments to regionalize maternal health care, specifically to triage high-risk

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patients to regional centers with increased capacity to deliver intensive antepartum and peripartum care.

Even in the largest datasets, studies that focus on maternal mortality alone do not provide sufficient case numbers on which to conduct a detailed analysis of risks associated with preexisting conditions. We therefore chose to expand our analysis to include near-miss maternal morbidity as well as mortality. An obstetric "near-miss" occurs when a pregnant or recently postpartum woman survives a life-threatening event, either by chance or because of high-quality medical care.[6,9] James Drife introduced this concept in 1993 when he called for an expansion of the United Kingdom Confidential Enquiry in Maternal Death to consider "near- miss" events to better elucidate the processes leading to adverse outcomes.[10] Geller *et al.* and Gregory *et al.* incorporated this concept into their continuum of maternal delivery outcomes beginning with "ideal birth," and progressing from some morbidity, to severe morbidity, to near-miss, and finally to maternal death.[6,11]

Definitions of near-miss morbidity have typically relied on either management-based criteria (*e.g.*, intensive care unit admission,[12–18]) or criteria available from chart review but not administrative data.[9,19,20] Recently, the World Health Organization conducted a systematic review of studies of near-miss maternal morbidity and found that end-organ injury was a more specific and epidemiologically sound method to identify near-miss morbidity than were management-based criteria.[21] Moreover, definitions based on chart review have limited utility in analyzing population-level predictors of near-miss maternal morbidity because this outcome is fortunately rare.

In our investigation, we develop an administrative data definition of near-miss maternal morbidity and define the extent to which preexisting maternal medical and obstetric conditions that are identifiable before the time of admission to the labor and delivery suite predict near-miss maternal morbidity or death.

Materials and Methods

Data Source

Data were derived from the Nationwide Inpatient Sample (NIS), an administrative dataset that is maintained by the Agency for Healthcare Research and Quality as part of the Healthcare Cost and Utilization Project. The NIS is constructed to approximate a 20% stratified sample of non-Federal hospitals, and contains information on all acute care admissions from each of the sampled hospitals. Approximately 1,000 hospitals are selected for inclusion each year; sampling is based on five characteristics including ownership (*e.g.*, investor owned, government, not-for-profit), bed size, teaching status, urban (*vs.* rural) location, and geographic region, such that the sample is representative of all hospitalizations in the United States. Multiple data elements are included for each admission including patient age, race, admission source, assigned diagnosis-related group, disposition, and up to 15 diagnoses and procedures recorded using the International Classification of Diseases, Ninth Revision codes (ICD-9 CM).‡

Identification of Hospitalizations for Delivery

We queried all diagnosis, procedure, and diagnosis-related group fields using a modified version of the algorithm described by Kuklina *et al.*[22] to identify all admissions for delivery in the NIS during 2003–2006. Hospitalizations were included if they had a diagnosis code or diagnosis-related groups indicating delivery or procedure codes related to delivery (*e.g.*, forceps, breech extraction, vacuum extraction, version and extraction, manually assisted deliveries, episiotomy, hysterotomy, or cesarean delivery). Hospitalizations were excluded if they had diagnosis codes indicating hydatidiform mole, ectopic pregnancy, other abnormal products of conception, or procedure codes indicating abortion. We excluded hospitalizations in which the age of the patient was missing. The ICD-9 CM and diagnosis-related group codes used in selecting deliveries can be found in appendix 1.

Primary Outcome

Near-miss morbidity or death was the primary outcome of this analysis. We surveyed the literature[23–25] and reviewed the ICD-9 CM manual to compile a list of severe, life-threatening complications representing end-organ injury that were relevant to an obstetric population. We then identified the presence of these complications in our cohort of delivering patients by querying all diagnosis fields using the appropriate ICD-9 CM codes (table 1). The association of each of these complications with in-hospital death or discharge to a medical facility was then confirmed using univariate analysis (data not shown). One or more of each of these complications was present in 82.1% of in-hospital maternal deaths.

We defined near-miss morbidity as the presence of any of the complications listed in table 1 plus either a length of stay corresponding to the 99th percentile for delivery-related hospitalization (*i.e.*, greater than 7 days) or discharge to a facility other than home (*i.e.*, short- term hospital, skilled nursing facility, intermediate care facility, or another type of healthcare facility).

Predictors

From a survey of the published literature[25–33] and clinical plausibility, we compiled a list of maternal medical and obstetric comorbidities that might act as risk factors for near-miss morbidity/mortality. We focused our analysis on preexisting conditions (comorbidities) rather than on complications of delivery and identified the presence of these conditions by querying all diagnosis fields using the ICD-9 CM codes listed in appendix 2.

Missing Data

Disposition after hospital discharge was missing in 213 records; these were assumed to be routine discharges to home, consistent with 97.3% of records. Length of stay was missing

‡ Information on the dataset is available at http://www.hcup-us.ahrq.gov/nisoverview.jsp. Accessed June 1, 2010.

Table 1. Maternal Complications in Patients Classified as Having Near-miss Morbidity/Mortality

Complication	ICD-9 CM Codes	N = 4,550	(%)
Acute heart failure	415.0, 427.5, 428.1, 428.21, 428.31, 428.41, 997.1, 669.4x, 428.23, 428.33, 428.43	880	(19.3)
Acute renal failure	584.x, 669.3x	568	(12.5)
Acute liver disease	570, 646.7x, 674.8x	948	(20.8)
Acute myocardial infarction	410.x	42	(0.9)
Acute respiratory distress syndrome	518.81, 518.82, 518.84, 518.5x, 799.1x	923	(20.3)
Aspiration pneumonitis	507.0, 997.3	268	(5.9)
Disseminated intravascular coagulation/ coagulopathy	666.3x, 286.6, 286.7, 286.9, 287.4	981	(21.6)
Coma	780.01, 780.03, 572.2, 250.2x, 250.3x, 251.0	39	(0.9)
Delerium	293.x	28	(0.6)
Major blood product reactions	999.5–999.8x	34	(0.7)
Panhypopituitary syndrome	253.2	*	—
Puerperal cerebrovascular disorders	671.5x, 674.0x, 430–432, 436, 997.01, 997.02, 433.01, 433.11, 433.21, 433.31, 433.81, 433.91, 434.01, 434.11, 434.91, 325, 348.1, 348.3x, 348.5, 437.1, 437.2, 437.6, 346.6x	408	(9.0)
Pulmonary edema	518.4x, 428.1x	233	(5.1)
Pulmonary embolism	673.x, 415.1x	369	(8.1)
Sepsis	038.x, 995.91, 995.92	570	(12.5)
Severe anesthesia complications	668.0–668.2x, 995.86	128	(2.8)
Shock	669.1, 785.5x, 998.0x, 995.4x, 995.0x, 995.94, 999.4	307	(6.7)
Status asthmaticus	493.01, 493.11, 493.21, 493.91	21	(0.5)
Status epilepticus	345.3	11	(0.2)

* Cell not shown because cell size less than or equal to 10.

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

in 61 records; these were assumed to be less than 7 days, which is true of 99% of hospitalizations. Eleven states in 2003–2004 and nine states in 2005–2006 did not record or publically release data on patient race; race was coded as "Missing" when this data element was not available.

Statistical Analysis

Bivariate analysis was initially completed with the entire dataset to detect an association between near-miss morbidity/mortality and the maternal characteristics shown in table 2. Conditions that afflict 10 or fewer patients are not reported in accordance with the NIS Data Use Agreement, designed to prevent identification of individuals. Chronic congestive heart failure and history of pulmonary embolism were excluded from further analysis because the total number of patients was less than or equal to 10 in the delivering cohort. Categoric variables were compared using the chi-square test. The patient demographics and the preexisting condition variables shown in table 2 were then tested for collinearity. The variance inflation scores ranged from 1.0 to 1.25, with a mean of 1.03, and the maximum condition index was 3.78 and all variables were retained in subsequent analysis.

The dataset was then randomly split into an estimation dataset (70%) and a validation dataset (30%). Logistic regression analysis was then performed on the estimation dataset to identify independent predictors of near-miss morbidity/mortality. Initially all of the variables were included in the model. After the first step of model selection, variables with limited statistical significance ($P > 0.1$) or clinical significance (OR >0.9 and <1.1) were excluded and the model was refit. We did not consider interaction terms in the model. The model was tested for discrimination in both the estimation and validation dataset by calculating the area under the receiver operating curve.

Variable selection and univariate statistics were completed using SPSS version 17.0 (SPSS, Chicago, IL). Multivariate analysis was completed in Stata version 10.0, (Stata, College Station, TX).

Results

Of the 3,463,327 maternal hospital admissions for delivery in the NIS for the years 2003–2006, we identified 4,550 hospitalizations (0.13%) that were complicated by a near-miss morbidity/mortality event. Of these, 3,996 patients (87.9%) remained in the hospital longer than 7 days, 775 (17.0%) were discharged or transferred to a medical facility, and 226 (5.8%) died during the delivery-hospitalization.

The most common complications, each occurring in approximately 20% of these patients, were disseminated intravascular coagulation/coagulopathy, acute liver disease, acute respiratory distress syndrome, and acute heart failure (table 1). One or more of these complications was present in 68.4% (n = 3,112) of the patients.

Table 2. Rates of Maternal Demographic Characteristics and Comorbidities in Patients with and without Near-miss Morbidity/Mortality

	Patients with Near-miss Morbidity/Mortality		Patients without Near-miss Morbidity/Mortality		
	N = 4,550	(%)	N = 3,458,777	(%)	*P* Value
Age	—	—	—	—	<0.001
<20	456	(10.0)	357,629	(10.3)	—
20–34	2,944	(64.7)	2,602,993	(75.3)	—
35–39	843	(18.5)	405,218	(11.7)	—
≥40	307	(6.7)	92,937	(2.7)	—
Race	—	—	—	—	<0.001
White	1,424	(31.3)	1,329,645	(38.4)	—
Black	933	(20.5)	318,719	(9.2)	—
Hispanic	739	(16.2)	651,804	(18.8)	—
Asian or Pacific Islander	160	(3.5)	117,828	(3.4)	—
Native American	31	(0.7)	14,290	(0.4)	—
Other	162	(3.6)	121,103	(3.5)	—
Missing	1,101	(24.2)	905,388	(26.2)	—
Conditions	—	—	—	—	—
Malignancy	31	(0.7)	1,292	(0.0)	<0.001
Pulmonary hypertension	45	(1.0)	414	(0.0)	<0.001
Placenta previa	224	(4.9)	17,939	(0.5)	<0.001
Sickle cell disease	64	(1.4)	4,071	(0.1)	<0.001
Hypertensive disorder of pregnancy	1,577	(34.7)	236,141	(6.8)	<0.001
Chronic renal disease	128	(2.8)	6,521	(0.2)	<0.001
Preexisting hypertension	465	(10.2)	51,178	(1.5)	<0.001
Chronic ischemic heart disease	*	—	395	(0.0)	<0.001
Congenital heart disease	32	(0.7)	2,569	(0.1)	<0.001
Systemic lupus erythematosus	63	(1.4)	2,929	(0.1)	<0.001
Hypercoagulable state	44	(1.0)	4,574	(0.1)	<0.001
Human immunodeficiency virus	12	(0.3)	789	(0.0)	<0.001
Multiple gestation	448	(9.8)	60,717	(1.8)	<0.001
Drug abuse	168	(3.7)	39,788	(1.2)	<0.001
Valvular disease	138	(3.0)	22,759	(0.7)	<0.001
Asthma	194	(4.3)	74,430	(2.2)	<0.001
Diabetes mellitus	480	(10.5)	191,455	(5.5)	<0.001
Obesity	108	(2.4)	40,658	(1.2)	<0.001
Cystic fibrosis	*	—	170	(0.0)	<0.001
History of organ transplant	*	—	341	(0.0)	<0.001
Previous cesarean delivery	716	(15.7)	494,228	(14.3)	0.005
Spine abnormalities	*	—	3,752	(0.1)	0.977
Tobacco abuse	123	(2.7)	115,851	(3.3)	0.015

* Cell not shown because cell size less than or equal to 10.

Table 2 shows the rates of various maternal demographic characteristics and comorbidities in the delivering cohort and the univariate association with near-miss morbidity/mortality. Women older than 34 yr and non-Hispanic black women are disproportionately represented among patients with near-miss morbidity/mortality. In addition, all tested conditions were significantly associated with this outcome, with the exception of spine abnormalities. Among women with near-miss morbidity/mortality, the most common comorbidities are hypertensive disorders of pregnancy (34.7%), previous cesarean delivery (15.7%), diabetes mellitus (10.5%), preexisting hypertension (10.2%), and multiple gestation (9.8%).

The rate of near-miss morbidity/mortality per 1,000 hospitalizations is increased with age older than 34 yr and nonwhite race (table 3). Near-miss morbidity or mortality complicates close to 10% of deliveries in women with pulmonary hypertension and 2% or more deliveries in women with malignancy or systemic lupus erythematosus. This rate exceeds 1% for women with placenta previa, sickle cell disease, chronic renal disease, congenital heart disease, and human immunodeficiency virus.

All preexisting conditions listed in table 3 are independently associated with near-miss morbidity/mortality, with the exception of obesity and previous cesarean delivery.

Discrimination of the final logistic regression model was assessed in the estimation and validation samples by calculating the area under the receiver operating characteristic curve; this value was 0.79 and 0.78, respectively.

Table 4 lists the discrimination characteristics for various thresholds to identify high-risk patients. An adjusted OR threshold of 3 has a sensitivity of 58.3%, meaning that most

Table 3. Rates and Adjusted Odds Ratios for Near-miss Morbidity/Mortality by Maternal Characteristics and Comorbidities

	Rate of Near-miss Morbidity/Mortality per 1,000 Deliveries†	95% CI	Adjusted Odds Ratio‡	95% CI	*P* Value
Age	—	—	—	—	—
<20 (3)	1.3	1.1–1.2	1.07	0.95–1.21	0.255
20–34	1.1	1.2–1.4	Ref	—	—
35–39(2)	2.1	1.9–2.2	1.60	1.45–1.75	<0.001
≥40(4)	3.3	2.9–3.7	2.08	1.81–2.40	<0.001
Race	—	—	—	—	—
White	1.1	1.0–1.1	Ref	—	—
Black	2.9	2.7–3.1	2.40	2.17–2.66	<0.001
Hispanic	1.1	1.1–1.2	1.25	1.12–1.39	<0.001
Asian or Pacific Islander	1.4	1.1–1.6	1.37	1.13–1.67	0.002
Native American	2.2	1.4–2.9	1.76	1.12–2.76	0.014
Other	1.3	1.1–1.5	1.34	1.10–1.64	0.004
Missing	1.2	1.1–1.3	1.19	1.09–1.31	<0.001
Conditions	—	—	—	—	—
Malignancy	23.4	15.3–31.6	18.37	12.16–27.76	<0.001
Pulmonary hypertension	98.0	70.8–125.2	12.00	7.61–18.91	<0.001
Placenta previa	12.3	10.7–13.9	10.02	8.51–11.81	<0.001
Sickle cell disease	15.5	11.7–19.2	6.95	5.08–9.52	<0.001
Hypertensive disorders of pregnancy	6.6	6.3–7.0	6.58	6.10–7.09	<0.001
Chronic renal disease	19.3	15.9–22.6	6.56	5.14–8.36	<0.001
Preexisting hypertension	9.0	8.2–9.8	5.87	5.20–6.64	<0.001
Chronic ischemic heart disease	*	*	5.48	2.48–12.08	<0.001
Congenital heart disease	12.3	8.1–16.5	5.45	3.42–8.70	<0.001
Systemic lupus erythematosus	21.1	15.9–26.2	5.39	3.86–7.54	<0.001
Hypercoagulable state	9.5	6.7–12.3	5.37	3.74–7.72	<0.001
Human immunodeficiency virus	15	6.6–23.4	4.89	2.16–11.10	<0.001
Multiple gestation	7.3	6.6–8.0	4.01	3.56–4.53	<0.001
Drug abuse	4.2	3.6–4.8	3.26	2.70–3.94	<0.001
Valvular disease	6.0	5.0–7.0	2.99	2.40–3.73	<0.001
Asthma	2.6	2.2–3.0	1.58	1.33–1.87	<0.001
Diabetes mellitus	2.5	2.3–2.7	1.18	1.05–1.33	0.005
Obesity	2.6	2.1–3.1	—	—	NS
Previous cesarean delivery	1.4	1.3–1.6	—	—	NS
Tobacco abuse	1.1	0.9–1.2	0.70	0.56–0.87	0.001
Overall	1.3	1.3–1.4	—	—	—

* Cell not shown because the event rate is based on a cell size less than or equal to 10. † Event rates were calculated using the entire data set. ‡ Adjusted odds ratios were calculated from the final logistic regression model for the estimation data set.

of all near-miss maternal morbidity or mortality events occurred in 11.8% of the delivering population—in those women who had least 1 of 15 conditions listed in table 3 with an adjusted OR of 3 or greater. Decreasing the adjusted OR threshold to 2 increases sensitivity to 69.4%, and encompasses an additional 10.2% of delivering women who were either ≥40 yr of age or of non-Hispanic black race, with no identifiable coexisting disease with an adjusted OR of 3 or greater. The remaining 78% of the delivering population did not have any of the identified risk factors with an adjusted OR of 2 or greater; these women experienced 30.6% of all near-miss maternal morbidity/mortality events, but individual risk was just 0.05% during each hospitalization for delivery.

Discussion

Using the largest hospital discharge dataset available in the United States, we found that 1 in 760 hospitalizations for delivery is complicated by near-miss morbidity or mortality. We sought to determine the extent to which near-miss morbidity/mortality is concentrated in high-risk patients and found that most of these events occur in patients with high-risk conditions generally identifiable at the time of admission to the labor floor. This suggests a potential opportunity to improve maternal outcomes by triaging high-risk women to delivery centers with increased capacity to deliver intensive antepartum and peripartum care.

Previous population-level analyses have documented increased risk for severe maternal morbidity or mortality among those parturients admitted with malignancy,[32] pulmonary hypertension,[25] placenta previa,[34–36] sickle cell disease,[28,30,33] hypertensive disorders of pregnancy,[31,37] chronic renal disease,[25] preexisting hypertension,[25,29,31] chronic ischemic heart disease,[25,28,30] congenital heart disease,[25,38] systemic lupus erythematosus,[25,27,28,30] hypercoagulable

Table 4. Discrimination Characteristics for Independent Risk Factor Thresholds to Predict a Composite of Near-miss Morbidity or Mortality

Adjusted Odds Ratio*	Sensitivity (%)	Specificity (%)	Positive Predictive Value (%)	1–Negative Predictive Value† (%)	Proportion of the Delivering Population‡ (%)
12	1.7	>99.9	4.27	0.13	0.05
10	6.5	99.4	1.49	0.12	0.6
6	42.9	92.4	0.73	0.08	7.7
5	51.5	90.7	0.73	0.07	9.3
4	56.4	89.3	0.69	0.06	10.8
3	58.3	88.3	0.65	0.06	11.8
2	69.4	78.1	0.41	0.05	22.0

* Column 1 refers to the adjusted odds ratio for maternal characteristics and comorbidities listed in table 3. Sensitivity, specificity, and positive predictive value apply to the population of women whose greatest risk factor has an adjusted odds ratio equal to or greater than the corresponding value listed in column 1. † 1-Negative predictive value is the risk of near-miss morbidity or mortality for the population of women whose greatest risk factor has an adjusted odds ratio less than the corresponding value listed in column 1. ‡ Proportion of the delivering population whose greatest risk factor has an adjusted odds ratio equal to or greater than the corresponding value listed in column 1.

state,[28–30] human immunodeficiency virus,[39,40] multiple gestation,[41–46] valvular heart disease,[25,28,30,38] and diabetes mellitus.[25,28,29] We used multivariate analysis to define the independent risk of near-miss morbidity/mortality associated with each of these conditions. High rates of substance abuse have been noted in inquiries of maternal death,[47] and our analysis confirms a fourfold increased rate of near-miss morbidity/mortality among these women. Likewise, deaths attributed to asthma have been consistently identified by maternal mortality surveillance efforts,[47] and asthma has been associated with other adverse obstetric outcomes including preeclampsia, chorioamnionitis, antepartum and postpartum hemorrhage, and cesarean delivery.[48–51] Our study confirms an epidemiologic link between asthma and near-miss maternal morbidity or mortality.

In contrast with previous studies, neither obesity nor previous cesarean delivery predicted a near-miss maternal morbidity/mortality event in our multivariate analysis. Event rates were increased at least twofold among obese women; however, multivariate analysis suggests that coexisting medical disease rather than obesity *per se* drives this relationship. Approximately 15% of the sample had a previous cesarean delivery, and while risk was increased approximately 10% in this group, the sample size was insufficient to confirm or refute an independent relationship in multivariate analysis. Nevertheless, previous cesarean delivery does increase risk for abnormal placentation,[35,36,52] and placenta previa was a strong independent risk factor for near-miss morbidity/mortality.

Although smoking has been shown to increase a number of specific maternal risks, including myocardial infarction[29] and stroke,[28] women who smoked had a slightly reduced risk of near-miss morbidity/mortality in the current study. Tobacco abuse has been shown to correlate with intrauterine growth restriction resulting in small head circumference for gestational age[53] and with preterm birth, both of which may decrease probability of cesarean delivery and the increased risk of maternal complications that accompany it. In addition, smoking has been associated with reduced rates of preeclampsia in women younger than 30 yr without preexisting hypertension.[54,55]

Risk is increased among nonwhite women, but particularly among non-Hispanic black women. Multivariate adjustment for maternal age and preexisting conditions does little to attenuate this increase in risk. Although black race has been shown to predict a number of adverse maternal outcomes, including pregnancy-related death,[8,37,56] the mechanism for this disparity is unknown and may involve maternal behavioral patterns, genetic predispositions, social circumstances, environmental exposures, and suboptimal medical care.[57,58]

Advancing maternal age is strongly associated with near-miss morbidity/mortality, consistent with previous reports.[56,59,60] Compared with women age 20–34 yr, risk is increased twofold for women between 35 and 39 yr, and threefold for women aged 40 yr and older. Adjustment for all preexisting conditions considered in this analysis explains approximately 16% and 31% of this increased risk, respectively.

On the continuum of maternal delivery outcomes, near-miss lies between severe obstetric morbidity and maternal death.[6] The delivery-related mortality rate in our study was 6.5 per 100,000 hospitalizations for delivery, comparable with rates recently reported elsewhere.[5,61] This ratio is less than half of the maternal mortality ratio, which includes all deaths during any point in pregnancy or within 42 days of the end of pregnancy, and substantially less than the pregnancy-related maternal mortality ratio, which includes all deaths during any point in pregnancy or up to a full year after the termination of pregnancy.[58]

Severe obstetric morbidity includes a broader category of women who suffered major complications with delivery that were not necessarily associated with critical illness (*e.g.*, blood transfusion). Previous analyses of population-level administrative data in the United States and Canada have used ICD-9 CM codes to identify those delivery-related hospital-

izations that resulted in severe obstetric morbidity, and have reported incidences between 4.4 and 8.1 per 1,000 deliveries.[23–25] Combining ICD-9 CM codes with a requirement for prolonged length of stay decreases the number of identified cases, presumably by improving specificity.[23] Prolonged length of stay greater than the 90th percentile (*i.e.*, length of stay more than 3 days) or discharge to a second health care facility has been used to enhance specificity to identify true cases with severe obstetric morbidity.[23,24]

Our current work builds on existing definitions of severe obstetric morbidity to capture near-miss maternal morbidity by requiring an ICD-9 CM code that designates end-organ injury, and by pairing this requirement with either a prolonged length of stay greater than the 99th percentile or discharge to a second medical facility. This new definition allowed us to query a dataset with close to 3.5 million hospitalization records, to identify a composite outcome of near-miss maternal morbidity or mortality, and to evaluate a long list of patient characteristics and comorbidities in a single multivariate model to predict these adverse outcomes as a whole.

Based on recent surveillance in the United States and the United Kingdom, complications of preexisting medical conditions appear to be the fastest rising category of maternal death.[8,62] Our analysis confirms this observation; close to 60% of near-miss maternal morbidity or mortality events are concentrated in approximately 10% of women with medical or obstetric conditions known at the time of admission to the labor and delivery unit. As such, targeted regionalization, specifically, triaging high-risk patients to regional centers with increased capacity to deliver intensive antepartum and peripartum care, may be a viable public health strategy to improve maternal delivery outcomes in the United States.

Similarly, The American Congress of Obstetricians and Gynecologists and the National Institutes of Health have called for regional networks structured around referral centers that provide a safe environment for women to undertake a trial of labor after cesarean delivery.[63] Centers with resources to support these trials of labor could be the same centers with enhanced capacity to care for women with significant preexisting disease. Services in these regional centers may already or could be expanded to include antepartum consultations to maternal-fetal medicine specialists, anesthesiologists, cardiologists, and other specialists as needed, multidisciplinary coordination to optimize the delivery plan, around-the-clock dedicated in-house obstetric and anesthesia and intensive care services, an on-site blood bank for women with conditions that increase risk for hemorrhage, and interventional radiology. Delivery in a regional center with a multidisciplinary care team has recently been shown to reduce morbidity among women with placenta accreta[64] and morbidity and mortality among women who underwent peripartum hysterectomy.[65]

The list of high-risk conditions in table 3 and the risk thresholds in table 4 could be used as a triage tool for individual facilities. For example, nonhospital birth centers and small delivery centers with limited capacity to provide around-the-clock services might use thresholds to decide on their level of acceptable risk, and consequently the characteristics of the pregnant population they are safely able to serve. Obstetric health care providers working within the targeted regional centers could also use this tool, in this case to identify those patients who may benefit from closer antenatal scrutiny and referrals for multidisciplinary antepartum consultation and coordination.

Despite the significant potential applications, several limitations are inherent in this analysis. We were unable to confirm the severity of conditions by using medical records. The conditions listed in table 3 were considered to be preexisting, but the data are cross-sectional, and a present-on-admission flag is not available to confirm antepartum diagnosis. Specific ICD-9 CM codes do not exist for many conditions of interest, including placenta accreta and antepartum cesarean delivery. In addition, the NIS has insufficient power to evaluate certain rare conditions, such as cystic fibrosis and chronic congestive heart failure. Existing codes may not reliably be applied if the consequences for billing are minor, and therefore common conditions such as obesity are typically not well coded.

In conclusion, we found that risk for near-miss maternal morbidity or mortality is substantially increased among a subset of pregnant women who can be identified before admission for delivery. Existing clinical studies suggest that for many of these conditions, antepartum multidisciplinary coordination and careful delivery planning and implementation can improve outcomes for these high-risk patients. Future investigations are needed to define the extent of hospital-level variation in near-miss maternal morbidity/mortality and the potential effect of targeted regionalization to triage high-risk patients to facilities with the capacity to provide high acuity antepartum and peripartum care.

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Appendix 1. Definition of Delivery-related Admission

	Codes
Inclusion criteria	—
ICD-9 CM diagnosis codes	—
Outcome of delivery	V27.x
Normal delivery	650.x
ICD-9 CM procedure codes	—
Forceps, vacuum, and breech extraction	72.x
Internal and combined version and extraction	73.22
Other manually-assisted deliveries	73.59
Episiotomy	73.6
Cesarean delivery	74.0–74.2, 74.4, 74.9
Diagnosis-related groups	—
Diagnosis-related groups indicating complicated and uncomplicated vaginal and cesarean delivery	370–375
Exclusion criteria	—
ICD-9 CM diagnosis codes	—
Ectopic or molar pregnancy	630.x-633.x
Pregnancy with abortive outcome	634.x-639.x
ICD-9 CM procedure codes	—
Abortion	69.01, 69.51, 75.0

ICD-9 = International Statistical Classification of Diseases and Related Health Problems (version 9).

Appendix 2. ICD-9 CM Definitions for Comorbid Conditions

	ICD-9 Definition
Malignancy	140.x-208.x
Pulmonary hypertension	416.0x, 416.8x, 416.9x
Placenta previa	641.0x, 641.1x
Sickle cell disease	282.4x, 282.6x
Hypertensive disorder of pregnancy	642.3x-642.6x, 642.9x
Chronic renal disease	581.x-583.x, 585.x, 587.x, 588.x, 646.2x
Preexisting hypertension	401.x-405.x, 642.0x-642.2x, 642.7x
Chronic ischemic heart disease	412.x-414.x
Congenital heart disease	745.0x-747.4x, 648.5x
Systemic lupus erythematosus	710.0x
Hypercoagulable state	289.81, 289.82
Human immunodeficiency virus	042.x
Multiple gestation	V27.2-V27.7, 651.x
Drug abuse	304.x, 305.0x, 305.2x-305.9x, 648.3x
Valvular disease	394.x-397.x, 424.x
Asthma	493.x
Diabetes mellitus	250.x, 648.0x, 648.8x
Obesity	278.0x
Cystic fibrosis	277.0x
History of organ transplant	V42.x
Chronic congestive heart failure	428.22, 428.23, 428.32, 428.33, 428.42, 428.43
History of deep vein thrombosis, pulmonary embolism	V12.51
Previous cesarean delivery	654.2x
Spine abnormalities	737.3x-737.4x, 741.x
Tobacco abuse	305.1x

ICD-9 = International Statistical Classification of Diseases and Related Health Problems (version 9).