Rates and indications of cesarean delivery in the preterm population

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ABSTRACT

Cesarean delivery is associated with increased maternal morbidity, but rates are increasing in the United States. Many national strategies have been implemented in an attempt to decrease the cesarean delivery rate; however, these strategies are typically aimed toward full term pregnancies. Cesarean delivery rates and the operative indications for cesarean have not been previously reported for preterm patients. We therefore aimed to examine the relationship between preterm delivery and cesarean delivery by reviewing hospital rates in the state of Massachusetts in a hospital-level analysis, and by examining patient characteristics from a sample of patients from one tertiary care center in Massachusetts.

This was a retrospective analysis of all 45 Massachusetts delivery hospitals in 2014, and of all deliveries that occurred at a tertiary care center from 2009-2015 to evaluate the relationship of preterm delivery with cesarean delivery. A large range in rates for preterm delivery (1.9% to 27.8%), all cesarean delivery (19.7% to 46.7%), and primary cesarean delivery (11.1% to 33.6%) was noted for Massachusetts hospitals. From our hospital-level study, after multivariable adjustment for hospital characteristics with a linear regression model, we found a 5% increase in hospital preterm delivery rate was associated with a 2.8% increase in hospital cesarean rate ($p=0.01$), and a 2.6% increase in primary cesarean rates ($p<0.01$). In our patient-level tertiary care center study, there were 6994 total deliveries, with 1864 (26.7%) preterm births, 2929 (41.9%) total cesareans, and 1822 (26.1%) primary cesareans. Results of a multivariable logistic regression indicated that preterm birth status was associated with approximately two times higher odds of cesarean delivery ($OR_{adj}=1.92$, 95% CI 1.71-2.17, $p<0.001$) and primary cesarean

delivery (OR_{adj}=2.03, 95% CI 1.77-2.32, p<0.001). An increase of 5 weeks in gestational age was associated with 33% lower odds of both total and primary cesarean delivery (OR_{adj}= 0.67, 95% CI 0.62-0.73, p<0.001). Repeat cesarean delivery was the most common indication for cesarean overall in both term and preterm patients. Overall, clinically indicated cesarean deliveries made up the majority of all cesarean and primary cesarean preterm deliveries (75.2% and 88.1%, respectively), and truly elective cesareans accounted for 0.01% of preterm deliveries.

Preterm delivery is significantly associated with increased risk of cesarean delivery using both hospital and individual patient level data, even after adjusting for other cesarean risk factors. Notably, the majority of preterm cesareans were performed for clinically indicated reasons, and the most common indications for preterm cesarean are not amenable to a trial of labor. Thus, preterm delivery is a significant risk factor for cesarean delivery, and the majority of preterm cesareans may be unavoidable.

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Accreditation Council for Graduate Medical Education (ACGME)

Advanced maternal age (AMA)

External cephalic version (ECV)

Confidence interval (CI)

Parity (Para)

Hypertension (HTN)

Diabetes (DM)

Body mass index (BMI)

INTRODUCTION:

Cesarean delivery in the United States

Cesarean delivery is the most commonly performed inpatient surgical procedure in the United States (1-3), and can prevent maternal and/or fetal morbidity and mortality in certain clinical scenarios (1-4). However, cesarean delivery has been shown to be associated with a three-fold increase in severe maternal morbidity, in addition to increased complications in future pregnancies, when compared to vaginal deliveries (3,4). Notably, the national cesarean rate has rapidly increased, rising from 23.0% in 1989 to 32.2% in 2011 (4,5). In light of these maternal risks, the rapid rise in cesarean delivery rates – without improvement in neonatal outcomes over the same era – has raised concern about the potential for overuse of cesarean delivery in unindicated or elective circumstances (1-4). High variation in cesarean rates across the country also suggests that differences in personal physician practice, rather than medical necessity, are a significant driver of cesarean delivery rates (2,3).

In terms of maternal risk, cesarean delivery is considered major abdominal surgery, and when compared to vaginal delivery, has been associated with increased severe morbidity (postpartum bleeding, genital tract injury, wound disruption, infection, requirement of hysterectomy at time of delivery, anesthetic complications, shock, cardiac arrest, acute renal failure, venous thromboembolism, assisted ventilation, amniotic fluid embolism) and maternal mortality (13.3 vs 3.3 per 100,000) (4). Additionally, 90% of women who have had one cesarean will undergo cesarean for all future pregnancies (3,4). These risks thus extend to every subsequent childbirth for the woman, in addition to accruing the known complications of repeated abdominal surgery: worsening surgical

scar tissue in the pelvic organs and increased risk for surgical trauma in subsequent cesareans or non-obstetrical pelvic surgery (3). Furthermore, the uterine scar that results from cesarean delivery can interfere with subsequent placentation of future pregnancies (3,4). The risk of placental previa, where the placenta abnormally implants in the lower uterine segment and covers cervical opening, increases 3-fold after 3 cesareans (4). Additionally, the risk of abnormal placentation into the myometrium of the uterine scar, known as placental accreta, increases to almost 40% with placental previa after 3 cesareans. Placental previa and accreta are associated with severe morbidity, including life-threatening maternal hemorrhage, need for massive transfusion and intensive care unit admission, and neonatal morbidity from preterm and/emergent delivery (4). Thus, the primary cesarean delivery, defined as a woman's first cesarean delivery, draws particular attention due to its impact on future pregnancies (3,4).

The rapid rise of cesarean delivery in the United States has caused concern among health professionals (1-4). The Joint Commission included the cesarean rate as one of five measures in its Perinatal Care Measure set in 2007, which was endorsed by the National Quality Forum in 2008 (6,7). Additionally, hospital cesarean rates are published by both private and public organizations as a method of accountability for health care providers, and patients are encouraged to use these data in deciding where to seek obstetrical care (6-8). Healthy People 2010 set a target for low-risk cesarean delivery at 15%, and when this target was unachievable, set a target of 23.9% for Healthy People 2020 (3,9,10).

To address the cesarean rate, a recent national workshop examined the indications behind primary cesarean delivery in order to develop strategies to decrease the cesarean

rate (3). The indication for cesarean delivery – typically recorded in the medical record immediate following delivery by the delivering physician – specifically address the clinical reason that a cesarean was performed over allowing for vaginal delivery. (i.e. breech presentation, non-reassuring fetal status, maternal and fetal contraindications to labor) (3,4,6,7). They identified the most common indications for cesarean: failed induction, arrest of labor, malpresentation; to address these indications, the workshop recommended discouraging elective induction of labor, encouraging operative vaginal delivery and external cephalic version in malpresentation, and redefining the normal labor curve to allow longer times for cervical dilation and head descent among the main strategies (3,4). The workshop concluded that most indications for cesarean are dependent on clinical interpretation by the clinician, and that "there are very few absolute indications for cesarean" (3).

Preterm delivery

Preterm delivery occurs either due to spontaneous and unstoppable preterm labor, or due to maternal and/or fetal complications necessitating urgent and early delivery (11-13). When spontaneous labor occurs prior to 34 weeks, tocolytics are given suppress uterine contractions in attempt to stop the labor; however, these interventions have not been shown to be effective for a prolonged duration (11). Thus, despite hospitalization and treatment, spontaneous preterm labor results in preterm delivery 50% of the time (11). Indicated, iatrogenic preterm delivery for maternal benefit include worsening hypertensive disorders, poorly controlled diabetes, abnormal placentation (such as previa or accreta), prior uterine surgery, obstetrical hemorrhage, or chorioamnionitis; the

maternal risk of continuing pregnancy in those clinical scenarios is considered to outweigh the fetal benefit of continued gestation into term (13). Fetal indications for preterm delivery are typically for the prevention of stillbirth, and this is seen in clinical scenarios where grave placental dysfunction or fetal distress is suspected (13). Spontaneous and indicated preterm deliveries present with unique clinical challenges for peripartum management, and are considered "high risk pregnancy" by definition (11-14).

Preterm birth and cesarean delivery

Studies specifically focused on the relationship between preterm delivery status and cesarean outcomes are lacking. Previous literature has largely focused on cesarean rates and associated maternal and obstetrical risk factors in the general obstetrical or low-risk term populations (14-19) without focus on the risks and indications unique to preterm deliveries. One previous international study has suggested that the cesarean rate is higher in the extremely preterm (26-31 weeks) population (2). Several studies aimed at optimizing risk adjustment for comparing cesarean rates across hospitals have identified preterm delivery as a risk factor for cesarean delivery, although this association has not been consistently observed (14-16). Additionally, another study determined that race and ethnicity did not appear to be associated with risk of cesarean in periviable (23-24 weeks gestational age) deliveries; rather, risk was driven by medical morbidity (26). Several studies aimed at optimizing risk adjustment for comparing cesarean rates across hospitals have identified preterm delivery as a risk factor for cesarean delivery, although this association has not been consistently observed (14-16).

In the previous literature, specific cesarean indications have been stratified into three hierarchical classes: 1) clinically indicated, where vaginal delivery is contraindicated for maternal or fetal well-being 2) mixed, where adequate information was unavailable or cesarean was an acceptable option per national guidelines, and 3) truly elective, where a cesarean was performed for non-medically indicated reasons (21-22). As it is crucial to understand why cesarean sections are performed in order to formulate strategies to decrease the rate, especially in cesareans performed for mixed or truly elective reasons, these indications offer valuable insight to the study of cesarean rates (3,4). Overall, however, few studies on the indications for cesarean delivery have been performed (21-25), and those studies do not stratify results by gestational age, or focus solely on the term population.

Motivated by the fact that 1) our institution delivers the largest percentage of preterm patients in our state (27), 2) our institution's cesarean delivery rate is one of the highest in our state (27), and 3) the indications for cesarean may differ significantly between term and preterm patients, rendering the usual strategies to decrease cesarean rates ineffective, we aimed to study the association between preterm birth status and cesarean delivery. Using hospital-level data from all delivering hospitals within the state of Massachusetts, we sought to explore the relationship between a hospital's preterm birth rate and a hospital's cesarean rate. Additionally, using patient-level data from our institution, we examined the relationship between preterm birth and cesarean delivery for individual patients, and analyzed the differences in indication for cesarean between term and preterm delivery groups.

METHODS AND MATERIALS:

Ethics statement

This study was approved by the Tufts Institutional Review Board (#11217).

Study population and data collection

Massachusetts hospital birth data

This was a retrospective cohort study of all delivering hospitals in the state of Massachusetts for the 2014 calendar year. Hospital delivery statistics were obtained from data reported to the Massachusetts Department of Public Health (28). Birth centers that do not perform cesarean deliveries were excluded from our study. Hospital-specific data for total number of beds, percent of patients with public payer insurance, case mix index, and readmission rate in 2014 was obtained from the Center for Health Information and Analysis (29). Urbanicity was determined by the hospital city as categorized by the National Center for Health Statistics (30), and the geographic region was categorized by the hospital city according to the Massachusetts Executive Office of Health and Human Services (31). Hospitals associated with an Accreditation Council for Graduate Medical Education (ACGME) - credentialed Obstetrics and Gynecology residency were identified via the ACGME website (32).

Single tertiary care center data from our institution

This was a retrospective cohort study of patients who were delivered at Tufts Medical Center between January 1, 2009 and December 31, 2015. Eligible patients were those with a singleton or twin pregnancy that resulted in a livebirth at 23 weeks 0 days or later. Patients with intrauterine fetal demise, triplets or higher-order multiples, or delivery

for termination of pregnancy were excluded. Since 2009, clinical and demographic data on all deliveries have been captured in an electronic medical record-generated database, including demographic factors, comorbidities, obstetrical and medical history, the delivery course/outcome, and if performed, the indication(s) for cesarean delivery. The database was reviewed for completeness for patients meeting study inclusion criteria, and any missing information was extracted from paper records and other inpatient electronic medical records where possible.

Statistical Analysis

Massachusetts hospital data analysis

Simple and multivariable linear regression analysis were used to study the primary outcome of hospital rate of cesarean delivery (defined as number of total cesarean deliveries divided by number of total deliveries), with hospital rate of preterm birth (defined as number of deliveries at less than 37 weeks 0 days of gestation divided by number of total deliveries) as the primary independent variable of interest. We additionally studied the rate of primary cesarean delivery rate (defined as number of primary cesarean deliveries divided by number of total deliveries) as a secondary outcome. Hospital characteristics of interest were selected *a priori* based on known association with preterm birth and/or cesarean delivery, and covariates for our final models were selected from those candidates via a backwards selection process. A non-weighted linear regression analysis was used in order to prevent skewing of our results to favor high-volume centers. However, sensitivity analyses were performed separately with a log-transformed preterm delivery rate and a weighted linear regression (by hospital

delivery number) to determine if controlling for unequal variances would impact our results.

Single institution data analysis

The primary independent variable of interest was preterm (<37weeks 0 days) vs. term delivery (≥37 weeks 0 days) and the primary dependent variable of interest was delivery type (cesarean vs vaginal delivery). Twin deliveries that resulted in a double delivery (vaginal followed by cesarean delivery) were counted as a cesarean delivery. Patient background characteristics and preterm status were compared between the patients with cesarean vs. vaginal delivery using a t-test for continuous outcomes and chi-squared test for categorical outcomes. To identify factors associated with delivery timing, patient background demographic and clinical characteristics were also compared between the preterm and term delivery groups using a t-test for continuous outcomes and chi-squared test for categorical outcomes. Multivariable logistic regression was used to estimate an adjusted odds ratio for cesarean delivery with preterm birth as the primary variable. Potential confounding variables were determined based on a priori clinical knowledge of factors likely to be associated with either preterm status or cesarean risk. To build a multivariable model, covariates that were calculated to have a univariable relationship with the outcome of $p < 0.1$ were entered into a backwards selection process that removed variables until the AIC was minimized. A secondary analysis was performed using gestational age at delivery as a continuous predictor variable, instead of the dichotomized age at 37 weeks.

To further study the reasoning behind cesarean delivery in term and preterm patients, we compared the recorded cesarean delivery indications between the term and preterm groups. The research team (JK, AP, CM) reviewed all indications for cesarean delivery recorded over 1 year at our tertiary care center to identify 14 categories of clinical indications (Appendix, Table 5.1). The operative notes for patients in our study cohort who underwent cesarean delivery were then reviewed by all three research team members and categorized according to this schema. Discrepancies between team members were resolved after discussion together. Patients were coded with multiple cesarean delivery indications if the operative note reflected them. These main categories were then divided accordingly into three mutually-exclusive hierarchical classes of indications (clinically indicated, mixed, truly elective) as used in previous studies (21,22) (Appendix, Table 5.1). In patients who had multiple indications that belonged to different hierarchical classes, the highest ranking class was used by the following scheme: clinically indicated > mixed > truly elective. The 14 individual categories of indications and the 3 hierarchical classes of indications were compared between preterm and term groups using the chi-squared test.

A two-sided alpha of 0.05 was used throughout to determine statistical significance. A power analysis and a sensitivity analysis on our predicted sample size was performed prior to starting the study to ensure an adequate sample size to detect meaningful clinical effect size, and determined that we had 80% power to detect a 4% difference in cesarean delivery rates (Appendix, Power Calculation, Table 5.2). All statistical tests were performed in R (33).

RESULTS

Massachusetts hospital-level characteristics

Forty-five hospitals were included in our study. Two birth centers that do not deliver preterm patients or perform cesarean delivery were excluded (234 deliveries total). Included hospitals and characteristics are outlined in the Appendix, Table 5.3. There was large variation in preterm delivery rates across institutions, from 2% to 28% (our institution). Additionally, there was wide variation in in overall (20% to 47%) and primary cesarean delivery rates (11% to 34%). Scatter plots of hospital preterm delivery rate and hospital cesarean rate are shown in Figure 3.1 and Figure 3.2. Residual plots and histograms are included in the Appendix, Figure 5.1 and Figure 5.2. Log-transformation of the preterm delivery rate demonstrated better homoscedasticity, but did not did not demonstrate better fit, and thus was not used. Additionally, a weighted linear regression (by total hospital delivery number) for both overall and primary cesarean deliveries did not improve our model's fit, and showed similar results, thus was also not used (Appendix, Table 5.4). The highest case-mix index of 1.57 belonged to our institution, the tertiary care center used in the patient-level analysis. All levels of urbanicity (large metro, large fringe metro, medium metro, small metro, micropolitan, noncore) and all geographic regions of Massachusetts (Boston, Northeast, Metro West, Southeast, Central, Western) were represented in our hospital cities. Eleven out of 45 hospitals (24%) were associated with an ACGME accredited Obstetrics and Gynecology residency program.

Hospital preterm birth rate and cesarean delivery rate

Hospital preterm birth rate was positively associated with total hospital cesarean delivery rate, and this relationship remained significant after multivariable adjustment (Table 3.1: 2.8% increase in hospital cesarean delivery rate for every 5% increase in preterm birth rate, p=0.01). This model explained 43% of the variance in the overall cesarean delivery rate (p<0.01). Primary cesarean delivery rates were also significantly associated with increasing hospital preterm birth rate after multivariable linear regression, with a 2.6% increase in hospital primary cesarean rate for every 5% increase in hospital preterm birth rate (p<0.01, Table 3.2). This final model accounted for 47% of the variance in the preterm birth rate (p<0.01). Most measured hospital characteristics were not statistically significantly associated with overall or primary hospital cesarean delivery rate, except for total beds for primary cesarean delivery rates, and geographic location for both primary and all cesarean delivery rates. No significant collinearity was identified for continuous variables (Appendix, Table 5.5).

Patient-level factors associated with Pre-term vs. Term delivery

In the patient-level analysis of our institution, there were 6,994 total deliveries, with 2929 cesarean sections (41.9%) and 4065 vaginal deliveries (58.1%) over the 6-year study period. Overall, the preterm cesarean rate (56%) was significantly higher than the term cesarean rate (37%) (Table 3.3, p<0.01). Compared to patients who delivered term, preterm patients were more likely to be African American and Hispanic, and less likely to be Asian (p<0.01). Preterm patients were more likely primigravid (p<0.01) and nulliparous (p<0.01). Preterm patients were more likely to have a twin gestation than patients delivering to term (18.1% vs 1.7%, p<0.01).

Patient-level factors associated with cesarean delivery

Compared to patients who delivered vaginally, patients who underwent cesarean delivery (both total and primary) were statistically significantly more likely to be of AMA, to be African American, Hispanic, or Other race, to be primigravid and nulliparous, to have maternal diabetes and hypertension, to have a higher BMI and to have a twin gestation (Table 3.3).

Preterm delivery and odds of cesarean delivery

After adjusting for maternal age, race, parity, diabetes, hypertension, BMI, and twin gestation, preterm birth was significantly associated with a nearly two-fold increased odds of all cesarean delivery (OR=1.92, CI 1.71-2.17, $p<0.001$, Table 3.4). When we only include primary cesarean deliveries in our multivariate logistic regression model, preterm birth was still significantly associated with a two-fold increased adjusted odds of primary cesarean delivery (OR=2.03, CI 1.77-2.32, $p<0.01$, Table 3.5). Collinearity was notable between gravity and parity, and thus only parity was used in our analysis (Appendix, Table 5.6). Tests for the linearity assumption of continuous variables are shown in Appendix Figure 5.3. Additionally, every week increase in gestational age was associated with an 8% decreased odds of both overall cesarean delivery and primary cesarean delivery (OR 0.92, 95% CI 0.91-0.94, $p < 0.01$, Table 3.6). This equates to a 33% lower odds of cesarean delivery for every 5-week increase and 55% lower odds for every 10-week increase in gestational age.

Indications for cesarean in the term and the preterm population

For term patients, the most common indications for cesarean delivery were repeat cesarean delivery (40%), failure to progress (30%), and fetal intolerance to labor (16%, Table 3.7, Figure 3.3). For preterm patients, the most common indications for cesarean delivery were malpresentation (40%), repeat cesarean delivery (34%), and non-reassuring fetal status without labor (27%, Table 3.7, Figure 3.3). When we only include primary cesarean deliveries in our analysis, the most common indication for term patients were failure to progress, malpresentation, and fetal intolerance to labor (47%, 24%, 19%, respectively, Table 3.7, Figure 3.4), and for preterm patients were malpresentation, non-reassuring fetal status without labor, and severe preeclampsia distant from delivery (47%, 30%, 13% respectively).

Hierarchical classes of cesarean indications also differed between term and preterm patients. The majority of preterm overall cesareans (75.2%) and preterm primary cesareans (88.1%) fell under the clinically indicated hierarchical class, as compared to 38% and 52% of term overall cesareans and term primary cesareans, respectively (Table 3.8, $p<0.01$ for all cesarean and primary cesarean).

Table 3.1: Univariable and multivariable analysis of risk factors for hospital rate of all cesarean delivery

	Univariable analysis (N=45)				Multivariable analysis (N=45)			
Variable	**Beta**	**Standard error**	**R^2**	**p-value***	**Adjusted beta****	**Adjusted standard error**	**Adjusted p-value**	**95% CI**
Preterm birth rate (%) 5% increase	0.34 1.72	0.16	0.10	0.03	0.55 2.75	0.21	0.01	0.13-0.97
Total Beds (per 1000)	0.01	0.04	0.001	0.84				
Public Payer (per 10%)	-0.01	0.01	0.01	0.43				
Case mix index	0.05	0.04	0.04	0.12				
Readmission rate (per 10%)	-0.02	0.05	0.05	0.66				
Urbanicity			0.23	0.06				
Large metro	Ref	Ref						
Large fringe metro	0.003	0.02						
Medium metro	-0.05	0.03						
Small metro	-0.05	0.03						
Micropolitan	-0.06	0.04						
Noncore	-0.004	0.05						
Geography			0.33	0.007			<0.01	
Boston	0.07	0.02			0.01	0.03		-0.06-0.08
Northeast	0.08	0.03			0.08	0.03		0.03-0.13
Metro West	0.05	0.03			0.06	0.03		0.01-0.11
Southeast	0.08	0.03			0.08	0.02		0.03-0.13
Central	Ref	Ref			Ref	Ref		Ref
Western	0.01	0.03			0.02	0.03		-0.03-0.07
ACGME Residency	0.004	0.02	0.001	0.83				

* Global p-value

** Multivariable linear regression analysis was used, with hospital rate of preterm birth as the primary variable and hospital rate of all cesarean delivery as the primary outcome, adjusted for % preterm birth and geography per backward selection model, R squared = 0.43, F-statistic = 4.84, p=0.0009

Table 3.2: Univariable and multivariable analysis of risk factors for hospital rate of primary cesarean delivery

	Univariate Analysis (N=45)				Multivariable Analysis (N=45)			
Variable	**Beta**	**Standard error**	**R^2**	**p-value***	**Adjusted beta****	**Adjusted standard error**	**Adjusted p-value**	**95% CI**
Preterm Birth rate (%) 5% increase	0.40 1.99	0.12	0.21	0.002	0.52 2.59	0.17	0.004	0.17-0.86
Total Beds (per 1000)	0.02	0.03	0.01	0.84	-0.04	0.03	0.15	-0.10-0.02
Public Payer (per 10%)	-0.01	0.01	0.01	0.46				
Case mix index	0.001	0.001	0.03	0.25				
Readmission rate (per 10%)	-0.04	0.04	0.0002	0.92				
Urbanicity			0.23	0.13				
Large metro	Ref	Ref						
Large fringe metro	-0.02	0.02						
Medium metro	-0.06	0.02						
Small metro	-0.06	0.02						
Micropolitan	-0.06	0.03						
Noncore	-0.04	0.04						
Geography			0.32	0.007			0.02	
Boston	0.08	0.02			0.04	0.03		-0.01-0.10
Northeast	0.06	0.02			0.06	0.02		0.02-0.11
Metro West	0.04	0.02			0.05	0.02		0.01-0.09
Southeast	0.06	0.02			0.06	0.02		0.02-0.10
Central	Ref	Ref			Ref	Ref		Ref
Western	0.02	0.02			0.03	0.02		-0.01-0.07
ACGME Residency	0.02	0.02	0.03	0.22				

* Global p-value

**Multivariable linear regression analysis was used, with hospital rate of preterm birth as the primary variable and hospital rate of primary cesarean delivery as the primary outcome, adjusted for total beds and geography per backward selection model, R squared = 0.47, F statistic = 4.62, p=0.0009

Table 3.3. Demographic and clinical characteristics of patients delivering at Tufts Medical Center, 2009-2015 (n=6994)

Background and Delivery Characteristic	Preterm [N=1864] (%)	Term [N=5130] (%)	p-value*	Vaginal [N=4065] (%)	All cesarean [N=2929] (%)	p-value* for all cesarean (compared to vaginal)	Primary cesarean [N=1822] (%)	p-value* for primary cesarean (compared to vaginal)
Preterm Delivery	1864 (100)	0		818 (20.1)	1046 (35.7)	<0.01	687 (37.7)	<0.01
Cesarean Delivery	1046 (56.1)	1883 (36.7)	<0.01	0	2929 (100)		1822 (100)	
Age, in years								
Mean (SD)	30.1 (6.2)	30.6 (5.7)	<0.01	29.9 (5.8)	31.3 (5.7)	<0.01	30.8 (5.8)	<0.01
AMA (%)	474 (25.4)	1301 (25.4)	0.68	894 (22.0)	881 (30.1)	<0.01	485 (26.6)	<0.01
Race (%)			<0.01			<0.01		<0.01
White	737 (39.5)	2382 (46.4)		1925 (47.4)	1396 (47.7)		858 (47.1)	
African-American	384 (20.6)	793 (15.5)		586 (14.4)	481 (16.4)		294 (16.1)	
Asian	280 (15.0)	1314 (25.6)		1025 (25.2)	504 (17.2)		317 (17.4)	
Hispanic	313 (16.8)	542 (10.6)		485 (11.9)	464 (15.8)		299 (16.4)	
Other	65 (3.5)	59 (1.2)		8 (0.2)	67 (2.3)		41 (2.3)	
Unknown	85 (4.5)	40 (0.8)		36 (0.9)	17 (0.6)		13 (0.7)	
Gravidarity			<0.01			0.15		<0.01
Mean (SD)	2.6 (1.7)	2.6 (1.6)		2.6 (1.6)	2.6 (1.6)		2.4 (1.5)	
1 (%)	597 (32.0)	1364 (26.6)		1148 (28.2)	813 (27.8)		581 (31.9)	
2 (%)	495 (26.6)	1691 (33.0)		1241 (30.5)	945 (32.3)		595 (32.7)	
3 (%)	312 (16.7)	956 (18.6)		773 (19.0)	495 (16.8)		291 (17.4)	
4 (%)	215 (11.5)	563 (11.0)		441 (10.8)	337 (11.5)		175 (16.4)	
≥5 (%)	245 (13.1)	556 (10.8)		462 (11.4)	339 (11.6)		180 (2.3)	
Parity			<0.01			<0.01		<0.01
Mean (SD)	1.4 (1.3)	1.4 (1.2)		1.5 (1.2)	1.4 (1.2)		1.3 (1.1)	
0 (%)	465 (24.9)	1085 (21.2)		860 (21.1)	690 (23.6)		736 (40.4)	
1 (%)	694 (37.2)	1950 (38.0)		1502 (36.9)	1142 (39.0)		480 (26.3)	
2 (%)	405 (21.7)	1310 (25.5)		1059 (26.1)	656 (22.4)		380 (20.9)	
3 (%)	181 (9.7)	502 (9.8)		386 (9.5)	297 (10.1)		154 (8.5)	
4 (%)	72 (3.9)	194 (3.8)		174 (4.3)	92 (3.1)		45 (2.5)	
≥5 (%)	47 (2.5)	89 (1.7)		84 (2.1)	52 (1.8)		27 (1.5)	
Maternal diabetes (%)	159 (8.5)	357 (7.0)	0.03	198 (4.9)	318 (10.9)	<0.01	199 (10.9)	<0.01
Maternal hypertension (%)	190 (10.2)	494 (9.6)	0.49	340 (8.3)	344 (11.7)	<0.01	221 (12.1)	<0.01
BMI			<0.01			<0.01		<0.01
Mean (SD)	31.6 (7.4)	31.1 (7.1)		30.2 (6.7)	32.6 (7.6)		32.6 (7.6)	
<30 (%)	878 (47.1)	2691 (52.5)		2324 (57.2)	1245 (42.5)		764 (41.9)	
30-39 (%)	782 (42.0)	1949 (38.0)		1427 (35.1)	1304 (44.5)		819 (45.0)	
≥40 (%)	204 (10.9)	490 (9.6)		314 (7.2)	380 (13.0)		239 (13.1)	
Twin gestation (%)	337 (18.1)	86 (1.7)	<0.01	128 (3.1)	295 (10.1)	<0.01	189 (10.4)	<0.01

SD: standard deviation
BMI: body mass index
*Gravidarity, parity, and BMI were used as categorical variables

Table 3.4: Univariable and multivariable analysis of patient risk factors for cesarean delivery

Background Characteristic	Univariate Analysis (N=6994)			Multivariable Analysis (N=6994)		
	OR	95% CI	p-value*	Adjusted OR**	95% CI	p-value*
Preterm	2.21	1.98-2.46	<0.001	1.92	1.71-2.17	<0.001
Age	1.04	1.03-1.05	<0.001	1.06	1.05-1.07	<0.001
AMA	1.48	1.32-1.67	<0.001			
Race			<0.001			<0.001
White	Ref	Ref		Ref	Ref	
African-American	1.13	0.98-1.30		1.21	1.05-1.41	
Asian	0.68	0.60-0.77		0.86	0.75-0.98	
Hispanic	1.32	1.14-1.52		1.39	1.19-1.63	
Other	11.5	5.88-26.15		14.32	7.18-32.76	
Unknown	5.65	0.36-1.15		0.62	0.33-1.13	
Gravidarity			0.15			
1	Ref	Ref				
2	1.08	0.95-1.22				
3	0.90	0.78-1.04				
4	1.09	0.91-1.28				
≥5	1.04	0.88-1.22				
Parity			<0.001			<0.001
0	Ref	Ref		Ref	Ref	
1	0.95	0.84-1.08		0.93	0.81-1.06	
2	0.77	0.67-0.89		0.69	0.60-0.80	
3	0.96	0.80-1.15		0.78	0.64-0.95	
4	0.66	0.50-0.86		0.47	0.35-0.62	
≥5	0.77	0.53-1.10		0.50	0.34-0.73	
Maternal diabetes	2.38	1.98-2.86	<0.001	2.01	1.66-2.45	<0.001
Maternal hypertension	1.41	1.21-1.66	<0.001	1.15	0.99-1.36	0.08
BMI			<0.001			<0.001
<30	Ref	Ref		Ref	Ref	
30-39	1.71	1.54-1.89		1.58	1.41-1.76	
≥40	2.26	1.92-2.66		1.99	1.66-2.38	
Twin gestation	3.44	2.79-4.28	<0.001	2.25	1.79-2.83	<0.001

GA: gestational age
AMA: advanced maternal age
BMI: body mass index
OR: odds ratio
*Gravidarity, parity, and BMI were used as categorical variables
**Using preterm as a binary predictor and adjusted for age, race, BMI, Parity, diabetes, hypertension, and twin gestation.

Table 3.5: Univariable and multivariable analysis of patient risk factors for primary cesarean delivery

Background Characteristic	Univariable Analysis (N=5887)			Multivariable Analysis (N=5887)		
	OR	95% CI	p-value*	Adjusted OR**	95% CI	p-value*
Preterm	2.39	2.12-2.70	<0.001	2.03	1.77-2.32	<0.001
Age	1.03	1.02-1.04	<0.001	1.05	1.04-1.06	<0.001
AMA	1.33	1.16-1.53	<0.001			
Race			<0.001			<0.001
White	Ref	Ref		Ref	Ref	
African-American	1.13	0.96-1.32		1.21	1.01-1.44	
Asian	0.69	0.60-0.81		0.91	0.77-1.07	
Hispanic	1.38	1.17-1.63		1.49	1.24-1.78	
Other	11.50	5.67-25.55		18.87	9.02-44.54	
Unknown	0.81	0.41-1.50		0.65	0.32-1.24	
Gravida			<0.001			
1	Ref	Ref				
2	0.95	0.82-1.09				
3	0.74	0.63-0.88				
4	0.78	0.64-0.96				
≥5	0.77	0.63-0.94				
Para			<0.001			<0.001
0	Ref	Ref		Ref	Ref	
1	0.37	0.32-0.43		0.36	0.31-0.42	
2	0.42	0.36-0.49		0.38	0.32-0.44	
3	0.47	0.38-0.57		0.38	0.30-0.48	
4	0.30	0.21-0.42		0.22	0.15-0.32	
≥5	0.38	0.24-0.58		0.25	0.16-0.30	
Maternal diabetes	2.30	1.95-2.94	<0.001	2.01	1.61-2.51	<0.001
Maternal hypertension	1.44	1.21-1.72	<0.001	1.21	1.01-1.45	0.04
BMI			<0.001			<0.001
<30	Ref	Ref		Ref	Ref	
30-39	1.75	1.55-1.97		1.64	1.44-1.87	
≥40	2.32	1.92-2.79		1.95	1.58-2.40	
Twin gestation	3.56	2.83-4.50	<0.001	2.05	1.59-2.65	<0.001

GA: gestational age
AMA: advanced maternal age
BMI: body mass index
OR: odds ratio
*Gravidarity, parity, and BMI were used as categorical variables
**Using preterm as a binary predictor and adjusted for age, race, BMI, Parity, diabetes, hypertension, and twin gestation.

Table 3.6: Multivariable analysis of gestational age and other risk factors for cesarean deliveries

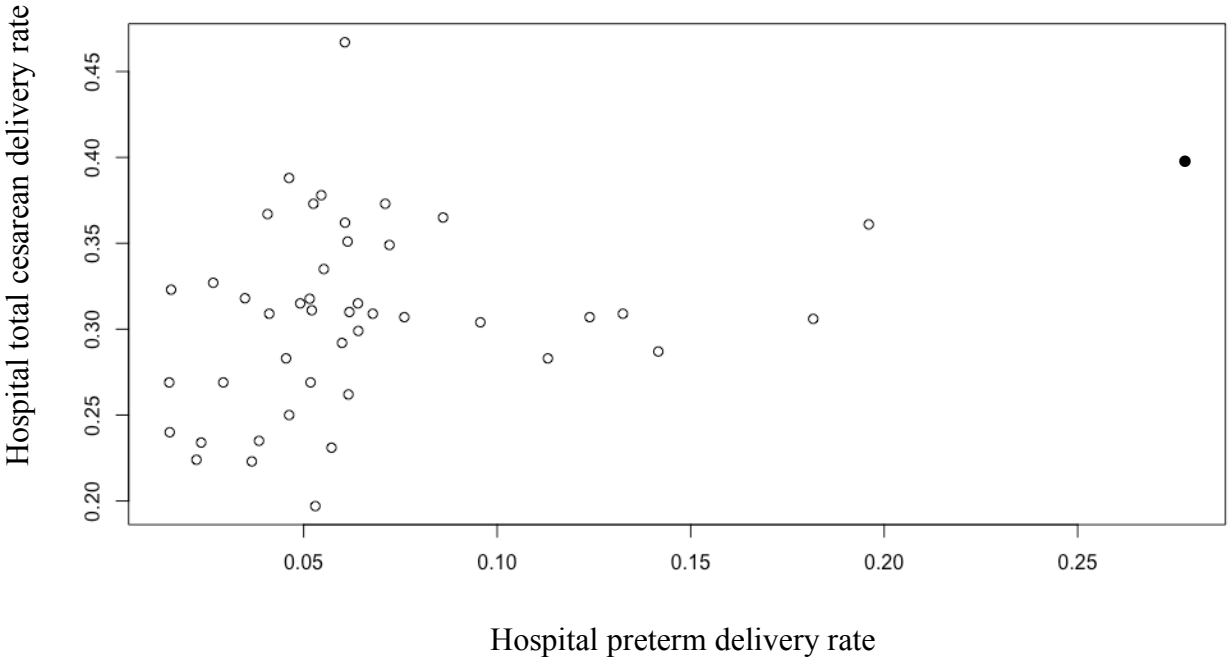
Background Characteristic	All cesarean delivery (N=6994)			Primary cesarean delivery (N=5887)		
	Adjusted OR*	95% CI	p-value	Adjusted OR*	95% CI	p-value
GA, weeks	0.92	0.91-0.94	<0.001	0.92	0.91-0.94	<0.001
Increase of 5 weeks	0.67	0.62-0.73		0.67	0.62-0.73	
Increase of 10 weeks	0.45	0.38-0.53		0.45	0.39-0.53	
Age	1.06	1.05-1.07	<0.001	1.05	1.04-1.06	<0.001
Race			<0.001			<0.001
White	Ref	Ref		Ref	Ref	
African-American	1.21	1.05-1.41		1.20	1.00-1.42	
Asian	0.83	0.73-0.95		0.90	0.77-1.06	
Hispanic	1.40	1.20-1.64		1.49	1.24-1.79	
Other	14.08	7.08-		18.52	8.87-43.64	
Unknown	0.64	32.14		0.65	0.32-1.24	
		0.34-1.14				
Parity			<0.001			<0.001
0	Ref	Ref		Ref	Ref	
1	0.93	0.81-1.06		0.36	0.31-0.42	
2	0.69	0.60-0.80		0.38	0.32-0.44	
3	0.78	0.65-0.95		0.38	0.30-0.48	
4	0.46	0.35-0.62		0.22	0.15-0.31	
≥5	0.51	0.35-0.75		0.25	0.15-0.39	
Maternal diabetes	2.07	1.71-2.52	<0.001	2.04	1.64-2.56	<0.001
Maternal hypertension	1.17	1.00-1.38	0.05	1.21	1.01-1.45	0.04
BMI			<0.001			<0.001
<30	Ref	Ref		Ref	Ref	
30-39	1.45	1.31-1.62		1.65	1.45-1.88	
≥40	1.78	1.48-2.12		1.96	1.59-2.41	
Twin gestation	2.38	1.90-2.99	<0.001	2.25	1.75-2.90	<0.001

*Adjusted for age, race, Parity (categorical), diabetes, hypertension, BMI (categorical), and twin gestation. Likelihood ratio with model that includes only intercept p <0.001.

Table 3.7. Comparison of indications for cesarean delivery								
Indication for cesarean delivery	**All Cesarean delivery (N=2929)**				**Primary Cesarean Delivery (N=1822)**			
	Term (N=1883) (%)	**Preterm (N=1046) (%)**	**Total**	**p-value**	**Term (N=1135) (%)**	**Preterm (N=687) (%)**	**Total**	**p-value**
Repeat cesarean delivery	748 (39.7)	359 (34.3)	1107	0.004	0 (0.0)	0 (0.0)	0	--
Failure to progress/failed induction	563 (29.9)	41 (3.9)	604	<0.001	529 (46.6)	39 (5.7)	568	<0.001
Fetal intolerance to labor	302 (16.0)	87 (8.3)	389	<0.001	270 (23.8)	76 (11.1)	346	<0.001
Malpresentation	274 (14.6)	416 (39.8)	690	<0.001	217 (19.1)	320 (46.6)	537	<0.001
Non-reassuring fetal surveillance (without labor)	71 (3.8)	282 (27.0)	353	<0.001	58 (5.1)	205 (29.8)	263	<0.001
Maternal contraindication to labor	69 (3.7)	46 (4.4)	115	0.38	50 (4.4)	29 (36.7)	79	0.95
Infection, distant from delivery	51 (2.7)	14 (1.3)	65	0.02	50 (4.4)	10 (1.5)	60	0.001
Elective, with suspected macrosomia	45 (2.4)	0 (0.0)	45	--	38 (3.3)	0 (0.0)	38	--
Primary cesarean by maternal request	21 (1.1)	8 (0.8)	29	0.47	21 (1.9)	8 (1.2)	29	0.35
Placenta previa	18 (1.0)	79 (7.6)	97	<0.001	10 (0.9)	52 (7.6)	62	<0.001
Fetal contraindication to labor	18 (1.0)	12 (1.1)	30	0.76	16 (1.4)	10 (1.5)	26	1.00
Elective, with history of dystocia or 4th degree	13 (0.7)	4 (3.8)	17	0.43	13 (1.1)	4 (0.6)	17	0.34
Severe preeclampsia, distant from delivery	9 (0.5)	124 (11.9)	133	<0.001	9 (0.8)	90 (13.1)	99	<0.001
Cord prolapse	5 (0.3)	14 (1.3)	19	0.001	5 (0.4)	13 (1.9)	18	0.005

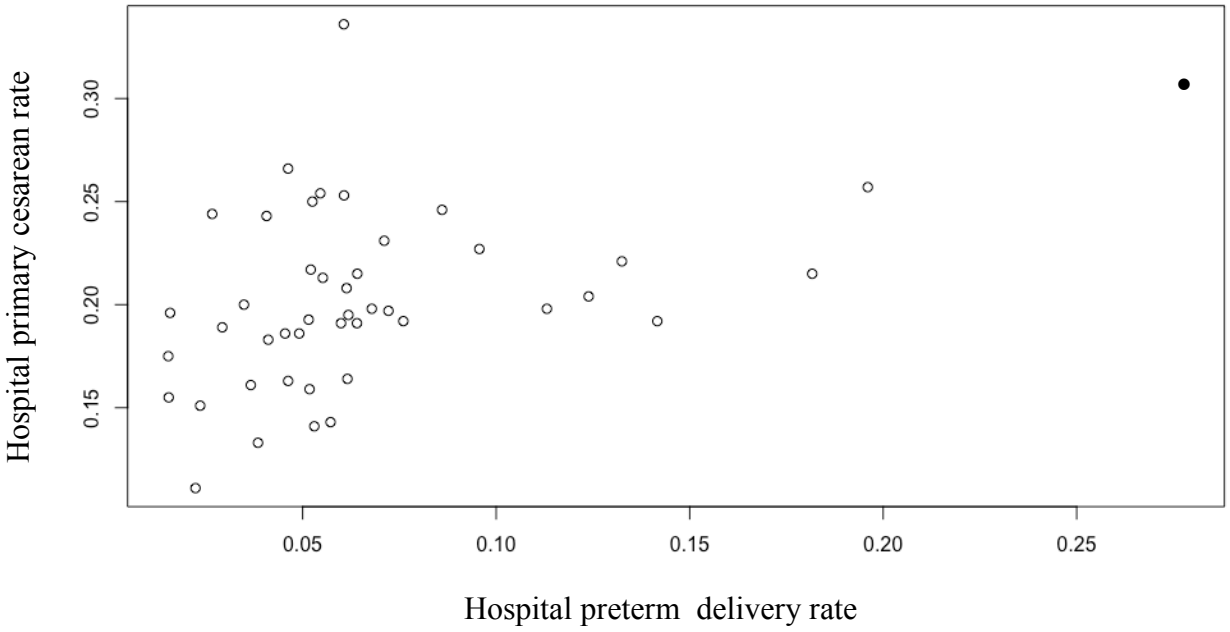
Table 3.8: Hierarchical classes of cesarean delivery indications for preterm delivery						
Class of Indication	**All cesarean (N=2929)**			**Primary cesarean (N=1822)**		
	Term (N=1883) (%)	**Preterm (N=1046) (%)**	**p-value**	**Term (N=1135) (%)**	**Preterm (N=687) (%)**	**p-value**
Clinically Indicated	715 (38.0)	787 (75.2)	<0.001	590 (52.0)	605 (88.1)	<0.001
Mixed	1147 (60.9)	252 (24.1)		524 (46.2)	75 (10.9)	
Truly elective	21 (1.1)	7 (0.6)		21 (1.9)	7 (1.0)	

Figure 3.1. Scatter plot of all cesarean delivery rate and preterm delivery rate.



- Our institution, which was used for patient-level data analysis

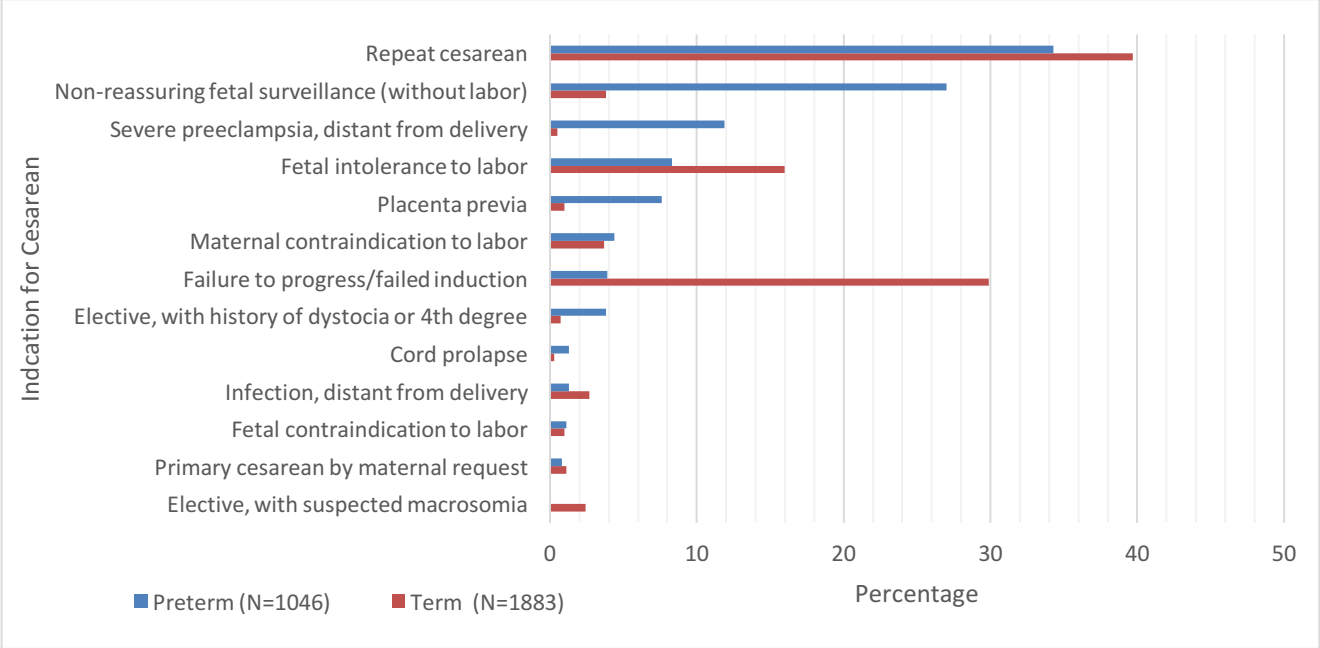
Figure 3.2. Scatter plot of primary cesarean delivery rate and preterm delivery rate.



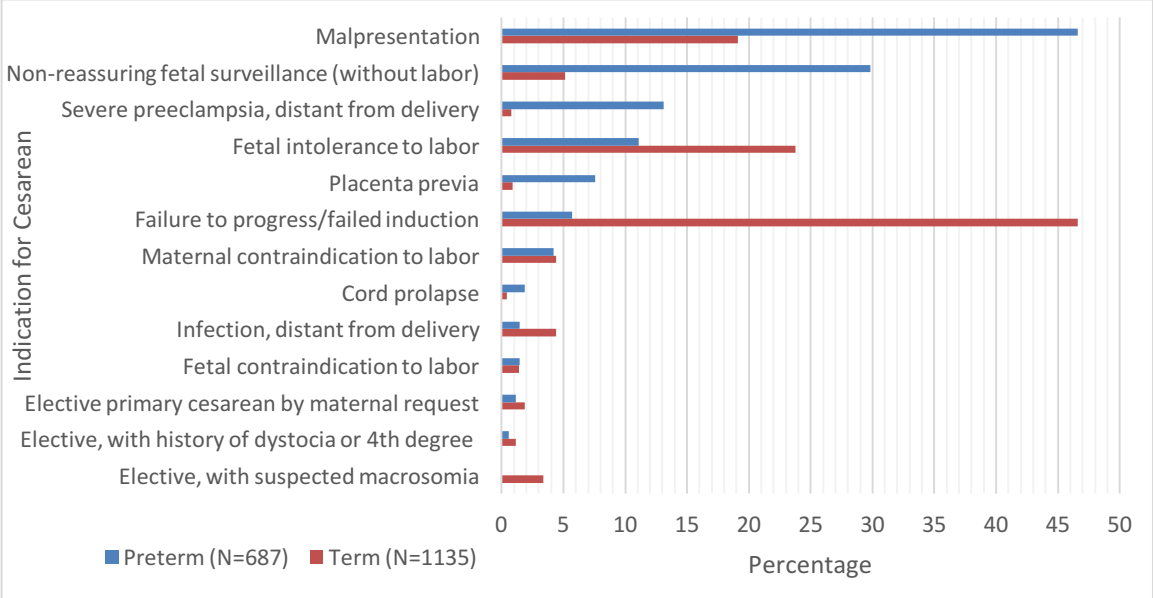
- Our institution, which was used for patient-level data analysis

Figure 3.3. Comparison of indications for (A) all and (B) primary cesarean delivery in term and preterm patients.

A. Indications for all cesarean deliveries between term and preterm patients



B. Indications for primary cesarean deliveries between term and preterm patients



DISCUSSION

In our analysis of hospital-level and individual patient-level data, preterm birth status was significantly associated with the risk of both overall and primary cesarean delivery, even after accounting for possible confounders. Additionally, the vast majority of indications for cesarean among preterm patients are clinically indicated (>75%), and elective cesarean delivery was exceedingly rare in both preterm and term patients (<1%), suggesting that the increased risk for cesarean delivery in the preterm population may be unavoidable.

Hospital rates of cesarean delivery are positively associated with rates of preterm delivery

Using state-wide data over one year, a 5% increase in preterm birth rate was associated with a 2.8% and 2.6% increase in overall and primary cesarean delivery rates, within the range of preterm births included in our study. The clinical impact of this association is significant, especially as we consider that there is up to a 14-fold difference between hospital preterm delivery rates – and that more than 80% of hospitals deliver preterm patients less than 10% of the time. This large difference is likely due to preferential transfer of preterm patients with acute morbidity to hospitals with higher levels of care and available neonatal intensive care specialists and facilities. Interestingly, factors that have been previously shown to influence cesarean delivery rates, such as a hospital's case-mix index, percent of public payer insurance, and the presence of an ACGME residency (2, 34-37), were not significantly associated with the cesarean delivery rate in our cohort of hospitals. Geographic region has been previously identified

as a factor for cesarean delivery rates (2,37), and the authors have suggested that this is due to areas with a high percentage of ethnic heterogeneity or private-payer patients resulting in higher rates of hospital cesarean section for the term, low-risk population. However, in our multivariable model, percent of public payer insurance accepted by the hospital did not reach significance and was not included in our final model, and geographic differences, though significant, were associated with smaller changes in the cesarean rate than gestational age.

The variation in Massachusetts hospital cesarean delivery rates across institutions is similar to previous studies performed on state- and nation-wide levels, where the rates of hospital cesarean delivery have varied by a factor of ten (2). A narrower primary cesarean rate range was seen and is similar to previously published ranges for the state of Massachusetts (34). Previous studies on cesarean delivery rate variations between hospitals have not been able to fully explain the variation based on clinical covariates, suggesting nonmedical overuse (1-4, 23, 24,34,36). The fact that our model cannot account for more than 50% of the hospital cesarean delivery rate variation still suggests that nonmedical reasons for cesarean delivery may have a significant impact on hospital rates.

Notably, our institution used for patient-level analysis is an outlier in Massachusetts with more than 1 in 4 preterm deliveries, accounting for the highest preterm delivery rate in the state. While our cesarean delivery rate is the second highest in the state, it is not unexpected given the high preterm delivery rate and the relationship of pre-term delivery and cesarean seen in the other hospitals in Massachusetts.

Preterm birth increases risk of cesarean delivery, and may be unavoidable

In our patient-level data analysis, age, race, parity, maternal comorbidities, obesity, and twins all were significantly associated with all cesarean delivery and primary cesarean delivery, which is consistent with previous studies (1-4,21-25,35,38,39). However, the increased odds for all cesarean delivery and primary cesarean delivery in patients who deliver preterm even after adjustment for all these factors is striking. Additionally, the relationship between gestational age and cesarean delivery shows a dose-response pattern (Appendix, Table 5.7). In our specific data set, deliveries prior to 26 weeks were not associated with increased cesarean delivery risk as compared to term births; this may be due to the clinical practice of allowing labor in the extremely premature (<24 weeks) patients for malpresentation, due to the lack of benefit in cesarean delivery to change the poor prognosis. However, overall, the earlier delivery is indicated, the higher the odds for cesarean delivery for all cesarean and primary cesarean deliveries. Further, our examination of indications suggests that the vast majority of both term and preterm cesarean section deliveries are clinically appropriate and necessary, in that vaginal delivery is contraindicated. “Truly elective” cesarean deliveries appropriately represent a very small fraction of our preterm cesarean deliveries, and do not contribute to the overall cesarean delivery rate.

It is striking that the most common indications reported for cesarean delivery in the preterm population are not amenable to a trial of labor. Notably, repeat cesarean delivery is the indication for cesarean for a large percentage of both preterm and term deliveries. Vaginal birth after cesarean (VBAC) is a viable option for appropriate patients; however, VBAC is associated with small but serious risks to maternal and

neonatal well-being, and additionally require immediately available anesthesia staff and operative facilities. For these reasons, VBAC cannot be forced as the sole option for appropriate women nor implemented in all hospitals as a strategy to decrease cesarean delivery rates. Given these limitations, strategies to decrease cesarean delivery rates should focus predominantly on the primary cesarean deliveries, specifically on the "mixed" indication group. However, this cohort only represented 75 preterm cesarean deliveries that occurred at our institution over six years, which suggests a low rate of non-medically indicated preterm cesarean delivery.

Preterm patients are known to be at higher risk for non-vertex fetal presentation, known as malpresentation (3,4,40), which accounted for the highest individual indication for all and primary cesarean delivery in the preterm population and is considered a "clinically indicated" indication for cesarean delivery. Non-vertex fetuses can undergo manual rotation to achieve vertex presentation in a procedure known as external cephalic version (ECV) (3,4,40). In term patients, ECV has been previously shown to increase rate of vertex presentation at time of delivery and subsequently decrease cesarean rates (3,4). For preterm deliveries, a previous Cochrane meta-analysis of ECV that included studies which performed ECV as early as 32 weeks demonstrated that this could increase rates of vertex presentation at delivery; however, ECV increased the rate of iatrogenic preterm delivery due to complications associated with the procedure itself (40). Given the known increased morbidity of preterm neonates, ECV cannot be recommended to preterm patients without a thorough discussion of the risks and benefits. Additionally, preterm patients that necessitate delivery likely have higher association with contraindications to ECV, such as preterm premature rupture of membranes, active labor, and placental

previa. Thus, although ECV is an appropriate strategy for term patients with malpresentation to increase the chance for vaginal delivery, the same strategy will likely be less effective in the preterm population.

Non-reassuring fetal status in the absence of labor, in "clinically indicated" class, was the second most common individual indication for all and primary preterm cesarean delivery. For these patients, undergoing induction of labor and awaiting vaginal delivery is contraindicated due to acutely decompensating fetal status. Typically, these are patients who are undergoing antenatal surveillance due to maternal and/or fetal morbidity for prevention of stillbirth, or present with an obstetrical complaint that determines non-reassuring fetal status during the workup. In contrast, this indication only accounted for 71 term patients over a six-year time period at our institution. For this group, no viable alternative to cesarean delivery is available.

Severe preeclampsia, considered a "mixed" indication, was the third most common individual indication for primary preterm cesarean delivery. A prolonged induction of labor is typically avoided in these patients due to the severity of maternal morbidity associated with ongoing pregnancy. Thus, cesarean delivery has been recommended in women who are less than 28 weeks pregnant, especially if nulliparous with unfavorable cervices, as labor induction is rarely successful in this cohort (41,42). A high rate of preterm cesarean delivery is unsurprising, but further evaluation may help determine if vaginal delivery could be appropriate for more patients in this group by allowing for longer and more aggressive induction of labor.

Strengths and limitations

Our analysis of Massachusetts hospitals is limited to cross-sectional hospital-level data, and thus lacks individual patient data to include into our model. Additionally, our linear regression model is only applicable to the range of preterm deliveries represented in our cohort of Massachusetts hospitals, and the majority of hospitals delivered less than 10% preterm patients, although this is likely also reflective of most delivering hospitals in the United States. However, our institutional data offers valuable insight into the individual decision for cesarean delivery among preterm patients. Our institution is a unique center for obstetrical care and thus for a patient-level analysis, as a large proportion of our deliveries are high risk for a wide spectrum of maternal and fetal reasons, and our preterm delivery rate is high (28). This study includes a large sample size over several years of deliveries at our tertiary care center that can yield results with robust power. However, these patient-level data are restricted to one tertiary care center and may not be generalizable to different care settings, such as a community hospital where the proportion of preterm deliveries is lower. Additionally, the proportion of preterm deliveries at our institution is higher than other tertiary care centers in our state by 15-20% (28). Thus, strategies specifically focusing on the cesarean rate in the preterm group may not have the same impact in other tertiary care centers. However, improved understanding of the relationship between preterm delivery and cesarean will always benefit high-risk obstetrician groups who routinely must deliver their patients preterm for maternal and/or fetal indications.

Future directions

Recognition of significant contributors to cesarean delivery is an integral part of the national conversation on strategies to reduce cesarean deliveries, and specifically identifying the indications for cesarean delivery is necessary in order to develop strategies that are effective. Interventions focused on decreasing preterm birth overall could directly lead to decreasing unavoidable cesarean deliveries. Additionally, the indications behind cesarean delivery preterm patients may not be clinically amenable to the usual strategies to reduce cesarean deliveries. Overall, the co-morbidities associated with increased rate of preterm birth and cesarean delivery reflect trends in the health of the maternal population. Given the non-elective nature of most cesarean delivery in our study, strategies that target increasing BMI, rates of diabetes and hypertension, and provide specialized care for twin pregnancy and advanced maternal age may be the most effective ways to decrease preterm and cesarean delivery risk. Patient-level data on indications for delivery (labor, pre-eclampsia, preterm rupture of membranes) may identify additional opportunities for improvement in care. However, prevention of both spontaneous and iatragenic preterm birth has not been satisfyingly addressed by current available interventions and remains a challenging on-going problem in obstetrical practice.

Our study also suggests that a hospital's preterm delivery rate should be taken into account when interpreting a hospital's cesarean delivery rate. As both national and hospital-level quality improvement groups employ hospital cesarean rates as a measure of quality care that may affect reimbursement, penalties, and hospital rankings, understanding the impact of the preterm delivery rate on the cesarean rate is imperative for accurate interpretation of those rates.

APPENDIX

Table 5.1. Indications for cesarean delivery and corresponding class	
Indication for cesarean delivery	**Class of Indication**
Malpresentation Non-reassuring fetal surveillance (without labor) Fetal intolerance to labor Placenta previa Cord prolapse Maternal contraindication to labor Fetal contraindication to labor	Clinically Indicated
Repeat cesarean delivery Failure to progress/failed induction Severe preeclampsia, distant from delivery Elective, with history of dystocia or 4^{th} degree Elective, with suspected macrosomia Infection, distant from delivery	Mixed
Elective primary cesarean by maternal request	Truly elective

Power calculation

Between January 1, 2009 – December 31, 2015, there were 7,019 deliveries at Tufts Medical Center. We estimated that at least 90% would meet inclusion criteria, giving a sample size of 6,317. The Massachusetts Department of Public Health has previously reported a preterm delivery rate of about 30% at Tufts Medical Center. Thus, we expected a cohort of about 1,895 preterm deliveries and 4,422 term deliveries for analysis. Our estimated sample size allows us 99% power to detect a 15% difference in cesarean section rates between the preterm and term births (conservatively assuming 25% cesarean section rates in the term group, and 40% in the preterm group), with an alpha = 0.05. We also performed a sensitivity analysis *a priori* to test our assumptions about power calculation parameters by varying cesarean delivery rates within the term and preterm population (Appendix Table 5.1). Our database provided at least 80% power to detect a difference of 4% in cesarean delivery rates between the preterm and term groups if preterm cesarean rates range between 20 – 50% and term cesarean rates range between 20-35%, assuming alpha of 0.05.

Table 5.2. Sensitivity analysis for power calculation. Green-coded calculations all have 80% or more power. Red-coded calculations have less than 80% power.

Total Deliveries	Preterm Deliveries	Term Deliveries	Preterm Cesarean Rate	Term Cesarean Rate	Delta for Cesarean Rate	Power	Alpha
6317	1895	4422	0.5	0.35	0.15	1	0.05
6317	1895	4422	0.4	0.35	0.05	0.96	0.05
6317	1895	4422	0.39	0.35	0.04	0.86	0.05
6317	1895	4422	0.38	0.35	0.03	0.62	0.05
6317	1895	4422	0.4	0.3	0.1	1	0.05
6317	1895	4422	0.35	0.3	0.05	0.97	0.05
6317	1895	4422	0.34	0.3	0.04	0.88	0.05
6317	1895	4422	0.33	0.3	0.03	0.65	0.05
6317	1895	4422	0.35	0.25	0.1	1	0.05
6317	1895	4422	0.3	0.25	0.05	0.98	0.05
6317	1895	4422	0.29	0.25	0.04	0.90	0.05
6317	1895	4422	0.28	0.25	0.03	0.70	0.05
6317	1895	4422	0.3	0.2	0.05	1	0.05
6317	1895	4422	0.25	0.2	0.05	0.99	0.05
6317	1895	4422	0.24	0.2	0.04	0.94	0.05
6317	1895	4422	0.23	0.2	0.03	0.76	0.05

Table 5.3. List of Massachusetts hospitals and characteristics used in analysis

Hospital*	Total Deliveries	Preterm Deliveries (%)	All Cesarean (%)	Primary Cesarean (%)	Total Beds	Public Payer %	Case mix index	Readmission Rate %	Urbanicity**	Geographic region***	ACGME Residency****
Anna Jaques Hospital	733	47 (6.4)	219 (29.9)	158 (21.5)	140	59.1	0.75	15.1	2	2	No
Baystate Franklin Medical Center	479	14 (2.9)	129 (26.9)	91 (18.9)	110	69.4	0.76	14.9	5	6	Yes
Baystate Medical Hospital	4189	519 (12.4)	1286 (30.7)	855 (20.4)	767	68.5	1.13	14.7	3	6	Yes
Bershire Medical Center	800	37 (4.6)	200 (25.0)	130 (16.3)	204	70.0	0.92	16.1	4	6	No
Beth Israel - Plymouth	701	42 (6.0)	205 (29.2)	134 (19.1)	172	63.1	0.94	13.2	2	4	No
Beth Israel Deaconess	5027	666 (13.2)	1553 (30.9)	1111 (22.1)	703	56.5	1.28	15.7	1	1	Yes
Beverly Hospital	2274	140 (6.2)	596 (26.2)	373 (16.4)	404	61.9	0.79	16.7	2	2	No
Boston Medical Center	2624	251 (9.6)	798 (30.4)	596 (22.7)	470	77.8	1.1	16.3	1	1	Yes
Brigham and Women's Hospital	4189	761 (18.2)	1282 (30.6)	901 (21.5)	851	51.4	1.51	15.4	1	1	Yes
Brockton Hospital	978	60 (6.1)	343 (35.1)	203 (20.8)	245	72.0	0.86	17.5	2	4	No
Cambridge Hospital	1063	25 (2.4)	249 (23.4)	161 (15.1)	230	74.7	0.76	17.7	2	3	Yes
Cape Cod Hospital	763	58 (7.6)	234 (30.7)	146 (19.2)	269	68.3	1.04	12.0	4	4	No
Cooley Dickinson Hospital	676	18 (2.7)	221 (32.7)	165 (24.4)	93	58.7	0.84	12.8	3	6	No
Emerson Hospital	1181	58 (4.9)	372 (31.5)	220 (18.6)	199	44.9	0.77	12.1	2	3	No
Fairview Hospital	130	2.5 (1.9)	31 (24.0)	20 (15.5)	28	66.2	0.6	18	4	6	No
Falmouth Hospital	457	24 (5.3)	170 (37.3)	114 (25.0)	103	69.1	0.99	13.6	4	4	No
Good Samaritan Medical Center	995	46 (4.6)	386 (38.8)	265 (26.6)	205	68.2	0.83	15.3	2	4	No
Harrington Memorial	269	6 (2.2)	60 (22.4)	30 (11.1)	126	66.1	0.77	12.6	3	5	No
HealthAlliance Hospital	927	48 (5.2)	249 (26.9)	147 (15.9)	83	67.9	0.84	16.4	3	5	No
Heywood Hospital	415	22 (5.3)	82 (19.7)	59 (14.1)	106	64.5	0.81	16.8	3	5	No
Holy Family Hospital and Medical Center	973	59 (6.1)	454 (46.7)	327 (33.6)	189	67.2	0.89	13.6	2	2	No
Holyoke Medical Center	437	25 (5.7)	101 (23.1)	62 (14.3)	107	76.2	0.84	14.8	3	6	No
Lawrence General Hospital	1538	111 (7.2)	537 (34.9)	303 (19.7)	230	73.5	0.77	14.7	2	2	No
Lowell General Hospital	2284	155 (6.8)	706 (30.9)	452 (19.8)	333	64.3	0.85	14.7	2	2	No
Martha's Vineyard Hospital	131	2.5 (1.9)	35 (26.9)	23 (17.5)	31	65.9	0.65	18.1	5	4	No
Massachusetts General Hospital	3899	441 (11.3)	1103 (28.3)	772 (19.8)	1043	56.2	1.41	14.2	1	1	Yes
Melrose Wakefield Hospital	960	53 (5.5)	322 (33.5)	204 (21.3)	207	61.8	0.85	17.4	2	2	No
Mercy Medical Center	1210	55 (4.5)	342(28.3)	225 (18.6)	420	74.2	0.87	14.5	3	6	No
MetroWest Medical Center	802	57 (7.1)	299 (37.3)	185 (23.1)	284	61.5	0.92	15.9	2	3	Yes

Milford Regional Medical Center	973	40 (4.1)	301 (30.9)	178 (18.3)	150	51.9	0.81	16.6	3	5	No
Morton Hospial	379	23 (6.1)	137 (36.2)	96 (25.3)	91	68.4	92	16.4	2	4	No
Mt. Auburn	2787	102 (3.7)	622 (22.3)	449 (16.1)	225	53.8	0.84	12.7	2	3	No
Nantucket Cottage Hospital	127	2.5 (2.0)	41 (32.3)	25 (19.6)	23	44.1	0.62	16.0	6	4	No
Newton Wellesley	4610	285 (6.2)	1429 (31)	899 (19.5)	282	40.3	0.74	11.8	2	3	No
North Adams Regional Hospital	52	2.5 (4.8)	12 (23.5)	7 (13.3)	117	65.0	0.91	12.9	4	6	No
North Shore Medical Center (Salem)	1312	84 (6.4)	413 (31.5)	251 (19.1)	431	70.5	0.91	14.4	2	2	No
Norwood Hospital	488	17 (3.5)	155 (31.8)	98 (20)	177	63.9	0.87	14.5	2	3	No
Saint Vincent Hospital	2035	106 (5.2)	633 (31.1)	442 (21.7)	299	65.6	0.96	15.6	3	3	No
South Shore Hospital	3476	299 (8.6)	1269 (36.5)	855 (24.6)	415	57.5	0.84	14.4	2	4	No
St. Elizabeth's	954	187 (19.6)	344 (36.1)	245 (25.7)	262	65.4	1.11	16.9	1	1	Yes
Sturdy Memorial Hospital	713	29 (4.1)	262 (36.7)	173 (24.3)	149	65.0	0.82	13.0	2	3	No
Tufts Medical Center	1156	321 (27.8)	461 (39.9)	358 (31)	273	60.0	1.57	17.0	1	1	Yes
Umass Memorial Medical Center	3968	562 (14.2)	1139 (28.7)	762 (19.2)	719	64.3	1.26	16.4	3	5	Yes
Winchester Hosptial	1888	103 (5.4)	714 (37.8)	480 (25.4)	229	44.1	0.77	14.4	2	2	No
Southcoast Hospitals (Charlton, St. Luke's, Tobey)	3414	176 (5.2)	1085 (31.8)	658 (19.3)	529	72.6	0.92	16.7	2	4	No

*Cambridge Birth Center, and North Shore Birth Center, with 127 and 107 deliveries, respectively, were not included, as these centers are unable to deliver preterm neonates or perform cesareans.
**As categorized by the National Center for Health Statistics (https://www.cdc.gov/nchs/data/series/sr_02/sr02_166.pdf), 1: Large metro, 2: large fringe metro, 3: medium metro, 4: small metro, 5: micropolitan, 6: noncore
***As categorized by the Massachusetts Executive Office of Health and Human Services (http://www.mass.gov/anf/research-and-tech/it-serv-and-support/application-serv/office-of-geographic-information-massgis/datalayers/regeohhs.html). 1: Boston, 2: Northeast, 3: Metro West, 4: Southeast, 5: Central, 6: Western
*** As identified from the Accreditation Council for Graduate Medical Education (https://apps.acgme.org/ads/Public/Reports/ReportRun?ReportId=1&CurrentYear=2016&SpecialtyId=40&IncludePreAccreditation=false)

Table 5.4. Sensitivity analyses for A) log-transformed preterm delivery rate and B) weighted linear regression by total hospital delivery number, for hospital-level analysis of preterm delivery percentage and cesarean delivery percentage.

A) Log-transformed preterm delivery rate

	All cesarean delivery				**Primary cesarean delivery**			
	Adjusted beta*	95% CI	p-value	R^2	Adjusted beta**	95% CI	p-value	R^2
Preterm birth %	1.08	1.01-1.16	0.02	0.41	1.10	1.03-1.16	0.004	0.47

Using preterm birth rate as a log-transformed variable did not demonstrate better fit compared to untransformed variable for both overall (R^2=0.43) and primary (R^2=0.47) cesarean. Thus, the log-transformed variable was not used.

B) Linear regression, weighted by total hospital delivery number

	All cesarean delivery				**Primary cesarean delivery**			
	Adjusted beta*	95% CI	p-value	R^2	Adjusted beta**	95% CI	p-value	R^2
Preterm birth %	0.46	0.11-0.81	0.01	0.35	0.46	0.19-0.73	0.001	0.43

Weighted linear regression did not demonstrate better fit compared to unweighted analysis for both overall (R^2=0.43) and primary (R^2=0.47) cesarean. Thus, weighted linear regression was not used.

*Multivariable linear with hospital rate of preterm birth as the primary variable and hospital rate of all cesarean delivery as the primary outcome, adjusted for geography

**Multivariable linear with hospital rate of preterm birth as the primary variable and hospital rate of primary cesarean delivery as the primary outcome, adjusted for total beds and geography

Table 5.5. Correlation of variables and variance inflation factor (VIF) of hospital characteristics used for multivariable linear analysis of hospital cesarean delivery rate							
	% Preterm	**Deliveries**	**Total Beds**	**% Public payer**	**Case Mix Index**	**Readmission rate**	**VIF**
% Preterm	1.00	0.45	0.55	-0.08	-0.01	0.17	5.30
Deliveries	0.45	1.00	0.84	-0.29	-0.12	-0.09	4.93
Total beds	0.55	0.84	1.00	-0.07	-0.12	0.005	7.25
% Public payer	-0.08	-0.29	-0.07	1.00	0.09	0.29	1.36
Case mix index	-0.01	-0.12	-0.12	0.09	1.00	0.11	7.88
Readmission rate	0.17	-0.09	0.005	0.29	0.11	1.00	1.26

Table 5.6. Correlation of variables and variance inflation factor (VIF) of patient variables used in multivariable logistic regression analysis of cesarean delivery at our institution									
	Preterm	**Age**	**Race**	**Para**	**DM**	**HTN**	**BMI**	**Twins**	**VIF**
Preterm	1.00	-0.04	0.01	-0.04	0.02	0.002	0.04	0.30	1.06
Age	-0.04	1.00	-0.11	0.25	0.05	0.07	-0.01	0.03	1.07
Race	0.01	-0.11	1.00	0.016	-0.005	0.003	-0.03	-0.04	1.02
Para	-0.04	0.25	0.02	1.00	-0.02	0.01	0.04	-0.07	10.3
DM	0.02	0.05	-0.005	0.02	1.00	0.05	0.17	0.01	1.01
HTN	0.002	0.07	0.003	0.01	0.05	1.00	0.13	0.009	1.02
BMI	0.04	-0.01	-0.03	0.04	0.17	0.13	1.00	0.03	1.01
Twins	0.30	0.03	-0.04	-0.07	0.01	0.009	0.03	1.00	1.04

Table 5.7: Univariable and multivariable analysis of categorical gestational age for primary cesarean delivery

	Gestational age (weeks.days)	Univariable Analysis			Multivariable Analysis		
		OR	95% CI	p-value*	Adjusted OR**	95% CI	p-value*
All cesarean delivery (N=6994)	**< 26.0**	1.20	0.79-1.79	<0.001	0.97	0.62-1.48	<0.001
	26.0 – 29.6	4.22	3.18-5.63		3.45	2.55-4.70	
	30.0 – 33.6	3.11	2.56-3.80		2.63	2.12-3.27	
	34.0 – 36.6	1.93	1.64-2.28		1.69	1.41-2.01	
	>37.0	Ref	Ref		Ref	Ref	
Primary cesarean delivery (N=5887)	**< 26.0**	1.20	0.79-1.79	<0.001	0.97	0.62-1.48	<0.001
	26.0 – 29.6	4.22	3.18-5.63		3.45	2.55-4.70	
	30.0 – 33.6	3.11	2.56-3.80		2.63	2.12-3.27	
	34.0 – 36.6	1.93	1.64-2.28		1.69	1.41-2.01	
	>37.0	Ref	Ref		Ref	Ref	

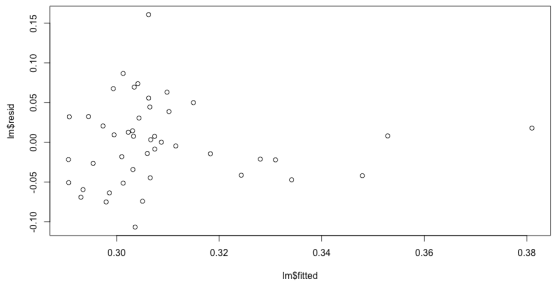
*Categorical p-value

**Using gestational age used as a categorical predictor and adjusted for age, race, BMI (categorical), Parity (categorical), diabetes, hypertension, and twin gestation.

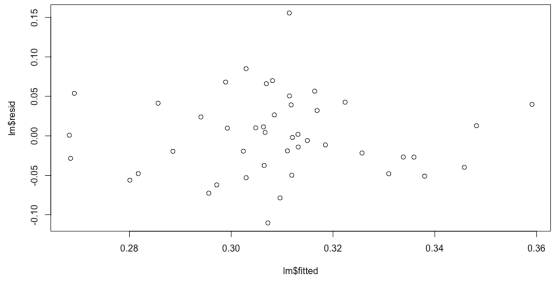
Figure 5.1. Residual plot and histograms of (A) all hospital cesarean rate and (B) primary cesarean rate vs preterm delivery rate. A sensitivity analysis was performed with a log-transformed preterm delivery rate variable in an attempt to improve homoscedasticity (residual plot shown in A2 and B3); the results did not differ from our primary analysis and thus the log-transformed variable was not used.

A: All hospital cesarean rate residual plot (1), after log transformation (2), and histogram of log-transformed variable

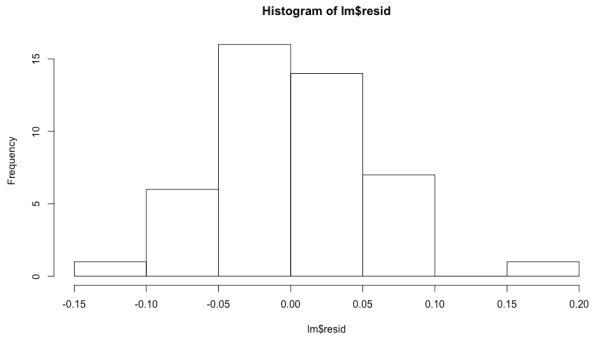
1.



2.

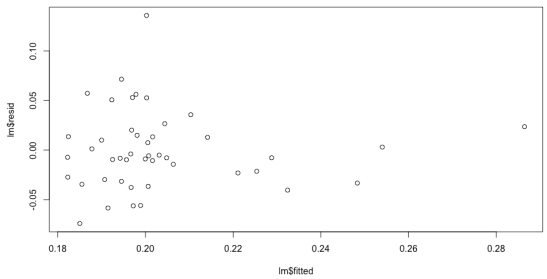


3.

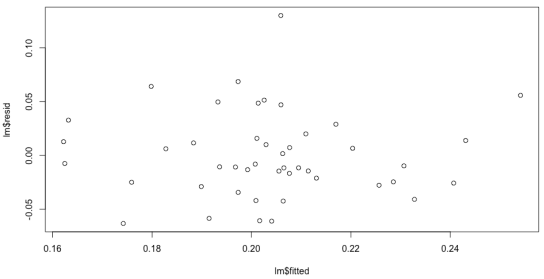


B: Primary hospital cesarean rate residual plot (1), after log transformation (2), and histogram of log-transformed variable

1.



2.



3.

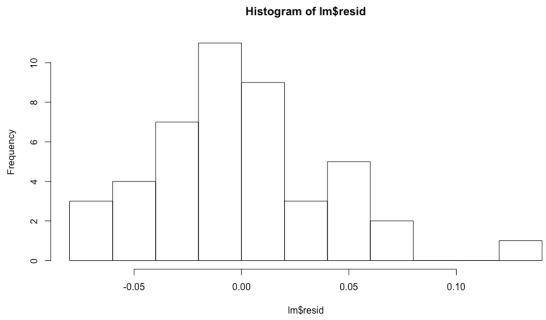
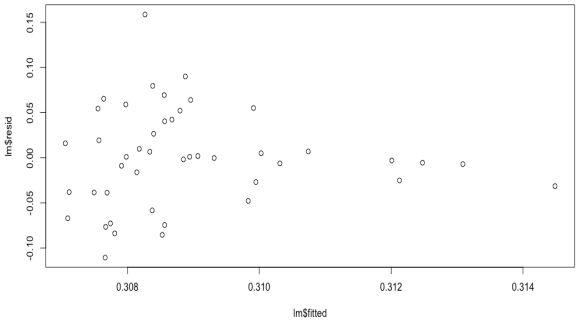
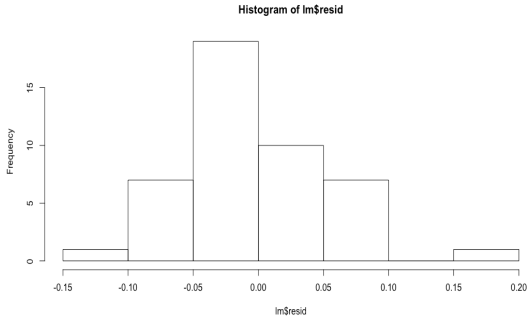

Histogram of lm$resid
Frequency
0
2
4
6
8
10
-0.05
0.00
0.05
0.10
lm$resid

Figure 5.2. Residual plots and histograms of hospital cesarean delivery rate and continuous hospital variables. A: Total beds B: Public payer percentage C: Case mix index D: Readmission rate

A. Total bed residual plot (1) and histogram (2)

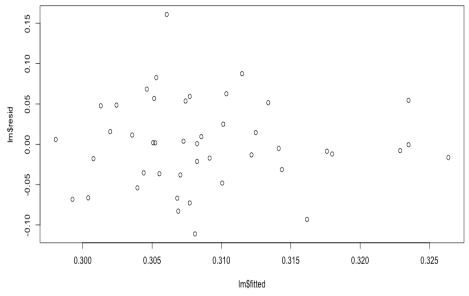
1. 2.

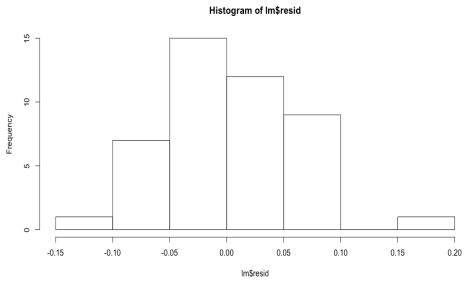




B. Public payer percentage residual plot (1) and histogram (2)

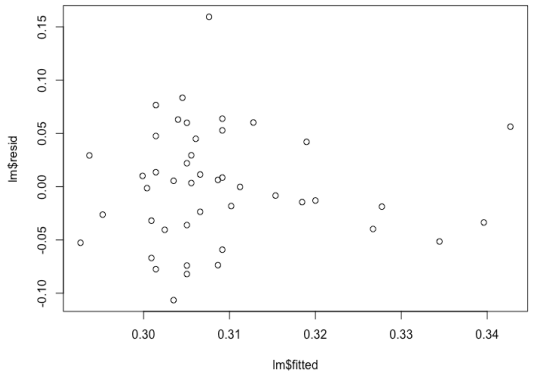
1. 2.

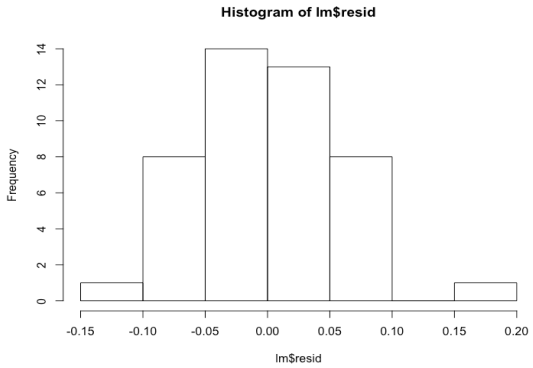




C. Case mix index residual plot (1) and histogram (2)

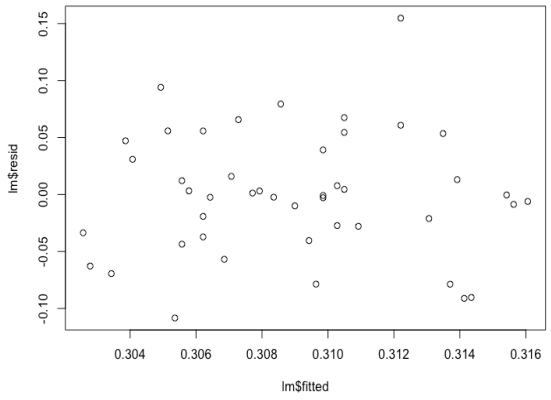
1. 2.





D. Readmission rate residual plot (1) and histogram (2)

1. 2.



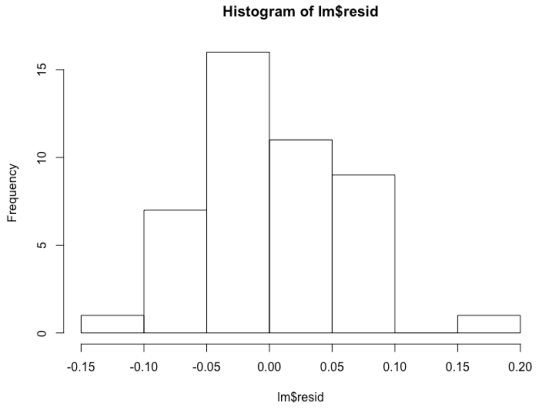
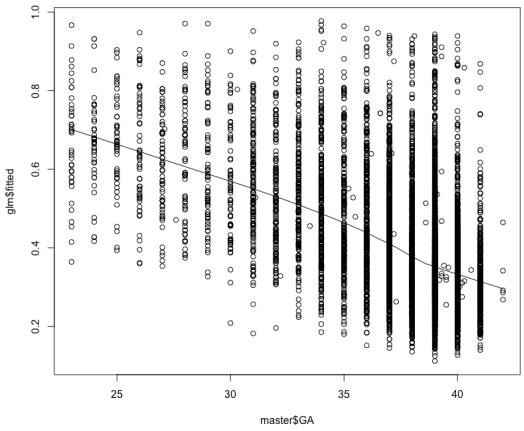
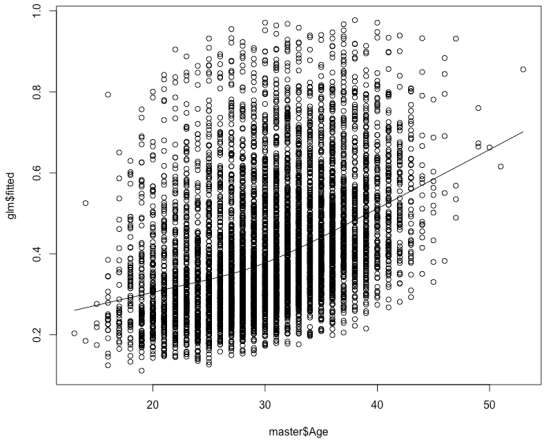


Figure 5.3. Assessment of the linearity assumption for continuous co-variates of (A) gestational age, (B) maternal age, and (C) BMI by Lowess curves.

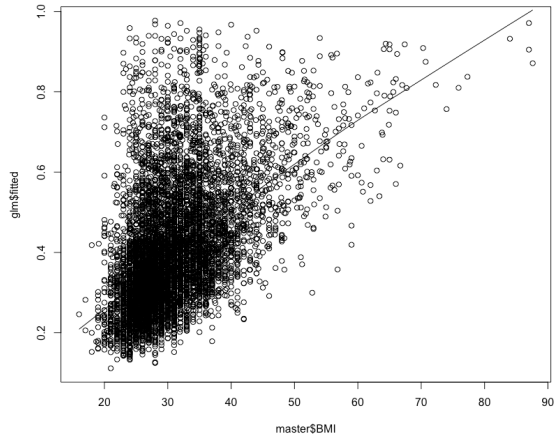
A.



B.



C.



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