OBSTETRICS

Hospital variation in utilization and success of trial of labor after a prior cesarean

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BACKGROUND: Trial of labor after cesarean delivery is an effective and safe option for women without contraindications.

OBJECTIVES: The objective of the study was to examine hospital variation in utilization and success of trial of labor after cesarean delivery and identify associated institutional characteristics and patient outcomes.

STUDY DESIGN: Using linked maternal and newborn hospital discharge records and birth certificate data in 2010—2012 from the state of California, we identified 146,185 term singleton mothers with 1 prior cesarean delivery and no congenital anomalies or clear contraindications for trial of labor at 249 hospitals. Risk-standardized utilization and success rates of trial of labor after cesarean delivery were estimated for each hospital after accounting for differences in patient case mix. Risk for severe maternal and newborn morbidities, as well as maternal and newborn length of stay, were compared between hospitals with high utilization and high success rates of trial of labor after cesarean delivery and other hospitals. Bivariate analysis was also conducted to examine the association of various institutional characteristics with hospitals' utilization and success rates of trial of labor after cesarean delivery.

RESULTS: In the overall sample, 12.5% of women delivered vaginally. After adjusting for patient clinical risk factors, utilization and success rates of trial of labor after cesarean delivery varied considerably across hospitals, with a median of 35.2% (10th to 90th percentile range: 10.2—67.1%) and 40.5% (10th to 90th percentile range: 8.5—81.1%), respectively. Risk-standardized utilization and success rates of trial of labor after cesarean delivery demonstrated an inverted U-shaped relationship such that low or excessively high use of trial of labor after cesarean delivery was associated with lower success rate. Compared with other births, those delivered at hospitals with above-the-median utilization and success rates of trial of labor after cesarean delivery had a higher risk for uterine rupture (adjusted risk ratio, 2.74, $P < .001$), severe newborn respiratory complications (adjusted risk ratio, 1.46, $P < .001$), and severe newborn neurological complications/trauma (adjusted risk ratio, 2.48, $P < .001$), but they had a lower risk for severe newborn infection (adjusted risk ratio, 0.80, $P = .003$) and overall severe unexpected newborn complications (adjusted risk ratio, 0.86, $P < .001$) as well as shorter length of stays (adjusted mean ratio, 0.948 for mothers and 0.924 for newborns, $P < .001$ for both). Teaching status, system affiliation, larger volume, higher neonatal care capacity, anesthesia availability, higher proportion of midwife-attended births, and lower proportion of Medicaid or uninsured patients were positively associated with both utilization and success of trial of labor after cesarean delivery. However, rural location and higher local malpractice insurance premium were negatively associated with the utilization of trial of labor after cesarean delivery, whereas for-profit ownership was associated with lower success rate.

CONCLUSION: Utilization and success rates of trial of labor after cesarean delivery varied considerably across hospitals. Strategies to promote vaginal birth should be tailored to hospital needs and characteristics (eg, increase availability of trial of labor after cesarean delivery at hospitals with low utilization rates while being more selective at hospitals with high utilization rates, and targeted support for lower capacity hospitals).

Key words: cesarean, hospital, length of stay, morbidity, trial of labor, vaginal birth after cesarean, variation

The rate of cesarean delivery in the United States had increased from 20.7% in 1996 to 31.9% in 2016.[1] Because uterine scar from a prior cesarean delivery may increase the risk for uterine rupture and abnormal placentation in future pregnancies,[2] the high rate of cesarean delivery has important implications for management of subsequent childbirths. For women with a previous cesarean delivery, elective repeat cesarean is commonly performed, with preventing uterine rupture during labor being a frequently cited reason.[3] In the United States, 87.6% of women who had a prior cesarean delivery were delivered via repeat cesarean in 2016.[1]

However, cesarean delivery places the mother and fetus at increased risk for other morbidities such as surgical injuries, maternal thromboembolic and anesthesia complications, and neonatal respiratory distress.[4] The risks for placenta previa, morbidly adherent placenta, and obstetric hemorrhage in subsequent pregnancies also increase from repeated cesarean deliveries.[4,5] Considering the overall risks and benefits, the American College of Obstetricians and Gynecologists recommends that trial of labor after cesarean delivery (TOLAC) can be an effective and safe option for women without contraindications.[6]

Many nonclinical factors (eg, provider litigation concerns, hospital support, and patient preference) influence practice as well,[5,7,8] resulting in variable practice of TOLAC. A recent study reported the rate of vaginal birth after cesarean (VBAC), which we refer to as successful TOLAC, ranging from 0% to 37.3% across hospitals.[9] Nonetheless, the VBAC rate can be influenced by both utilization rate and success rate,[10] and hospitals may have low VBAC rates for very different reasons and hence require different remedies. Yet there has been little research

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AJOG at a Glance

Why was this study conducted?

There has been little research separately examining hospitals' utilization and success rates of trial of labor after cesarean (TOLAC) and their respective facilitating and impeding factors.

Key Findings

- Utilization and success rates of TOLAC varied considerably across hospitals.
- The relationship between TOLAC utilization and success rates among hospitals demonstrated an inverted U shape.
- Some institutional characteristics affect both utilization and success rates of TOLAC, whereas others were associated only with TOLAC utilization rate or TOLAC success rate alone.

What does this add to what is known?

- Trial of labor should be encouraged at hospitals with low TOLAC rates, yet more cautious patient selection may be needed at hospitals with overly high TOLAC rates.
- Strategies to promote vaginal birth should be tailored to hospital needs (eg, increase utilization rate or improve success rate) and characteristics (eg, enhance support for lower-capacity hospitals).

separately examining hospitals' TOLAC utilization and success rates and their respective facilitating and impeding factors.

This study aimed to understand variation in practice of TOLAC among hospitals in California and the implications for patient outcomes. We also analyzed institutional characteristics that were associated with varying utilization and success rates of TOLAC. The findings may inform ways to safely reduce cesarean delivery in this patient population and improve quality and efficiency in care.

TABLE 1
Sample characteristics (n = 146,185 births)

Characteristic	n	%
Maternal age, y, median (interquartile range)	30	(26, 35)
Gestational age, wks, median (interquartile range)	39	(38, 39)
Parity		
1	109,125	74.6
2	22,166	15.2
≥3	14,894	10.2
Race/ethnicity		
Non-Hispanic white	38,272	26.2
Non-Hispanic black	7988	5.50
Hispanic	76,185	52.1
Other	23,721	16.2
Unknown	19	0.01
Primary payer		
Private insurance	71,060	48.6
Medicaid	69,197	47.3
Other payer	2972	2.0
Self-pay	2956	2.0

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Materials and Methods

Data sources

We used a data file with linked information from hospital discharge records and birth certificates on hospital-delivered births statewide in California.[11] The file contained detailed measures on patient sociodemographic characteristics as well as clinical characteristics such as obstetric risk factors and outcomes, date and source of admission, date and disposition of hospital discharge, *International Classification of Diseases* diagnoses and procedure codes, and diagnosis-related group. We combined data from 2010 through 2012, the latest 3 years of linked data available, to help enhance stability of estimated hospital performance measures.[12] This study was approved by the Yale University Human Investigation Committee and the California Committee for the Protection of Human Subjects.

Study population

Our analytic sample included term (37—42 weeks' gestation), singleton, live births with 1 previous cesarean delivery and no congenital anomalies or clear contraindications for trial of labor (ie, malpresentation, genital herpes, placenta previa, or vasa previa). Gestational age and number of prior cesarean deliveries were determined based on birth certificate information. Singleton status, fetal presentation, congenital anomalies, and genital herpes were ascertained using combined information from birth certificates and diagnosis codes on hospital discharge records, whereas placenta previa and vasa previa were identified based on diagnosis codes.

We further excluded 33 births in which the mother was transferred in from another facility because we might not have complete information about her trial of labor status. Births with extreme values (<0.01th or >99.99th percentile) on maternal age, maternal

TABLE 1
Sample characteristics (n = 146,185 births) *(continued)*

Characteristic	n	%
Kotelchuck Adequacy of Prenatal Care Utilization Index		
Inadequate	12,669	8.7
Intermediate	21,516	14.7
Adequate	75,839	51.9
Adequate plus	31,890	21.8
Unknown	4271	2.9
Body mass index category		
<18.5 (underweight)	3375	2.3
18.5–24.9 (normal weight)	56,602	38.7
25.0–29.9 (overweight)	38,991	26.7
30.0–34.9 (obese)	32,966	22.6
≥35 (morbidly obese)	7428	5.1
Unknown	6823	4.7
Hypertensive disorders of pregnancy (prepregnancy or gestational)	9038	6.2
Diabetes or abnormal glucose tolerance (prepregnancy or gestational)	18,688	12.8
Small for gestational age[a]	9770	6.7
Large for gestational age[b]	20,192	13.8
Group B streptococcus infection/colonization	18,943	13.0
Other infections	2283	1.6
Isoimmunization	5315	3.6
Oligohydramnios	2178	1.5
Hydramnios/polyhydramnios	719	0.5

Percentages may not add up to 100% because of rounding.

[a] Less than the 10th percentile of sex-, gestational age–, and race/ethnicity-specific birthweight in the United States; [b] Greater than the 90th percentile of sex-, gestational age–, and race/ethnicity-specific birthweight in the United States.

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body mass index, or infant birthweight were also excluded because they might suggest unrealistic values or poor-quality data. To ensure a reasonable sample size for estimating a hospital's performance, we excluded 1 hospital that had fewer than 25 eligible births during the study period, resulting in a final analytic sample of 146,185 births from 249 hospitals.

Measures

We classified a birth as undergoing trial of labor if it met one of the following criteria: (1) delivery method on birth certificate noted vaginal delivery, trial of labor attempted, vacuum attempted, or forceps attempted; (2) labor and delivery procedures on birth certificate reported prolonged labor, precipitous labor, induction of labor, or augmentation of labor; or (3) diagnosis and procedure codes on hospital discharge records indicated vaginal delivery or process of labor (see Appendix A).[10,13]

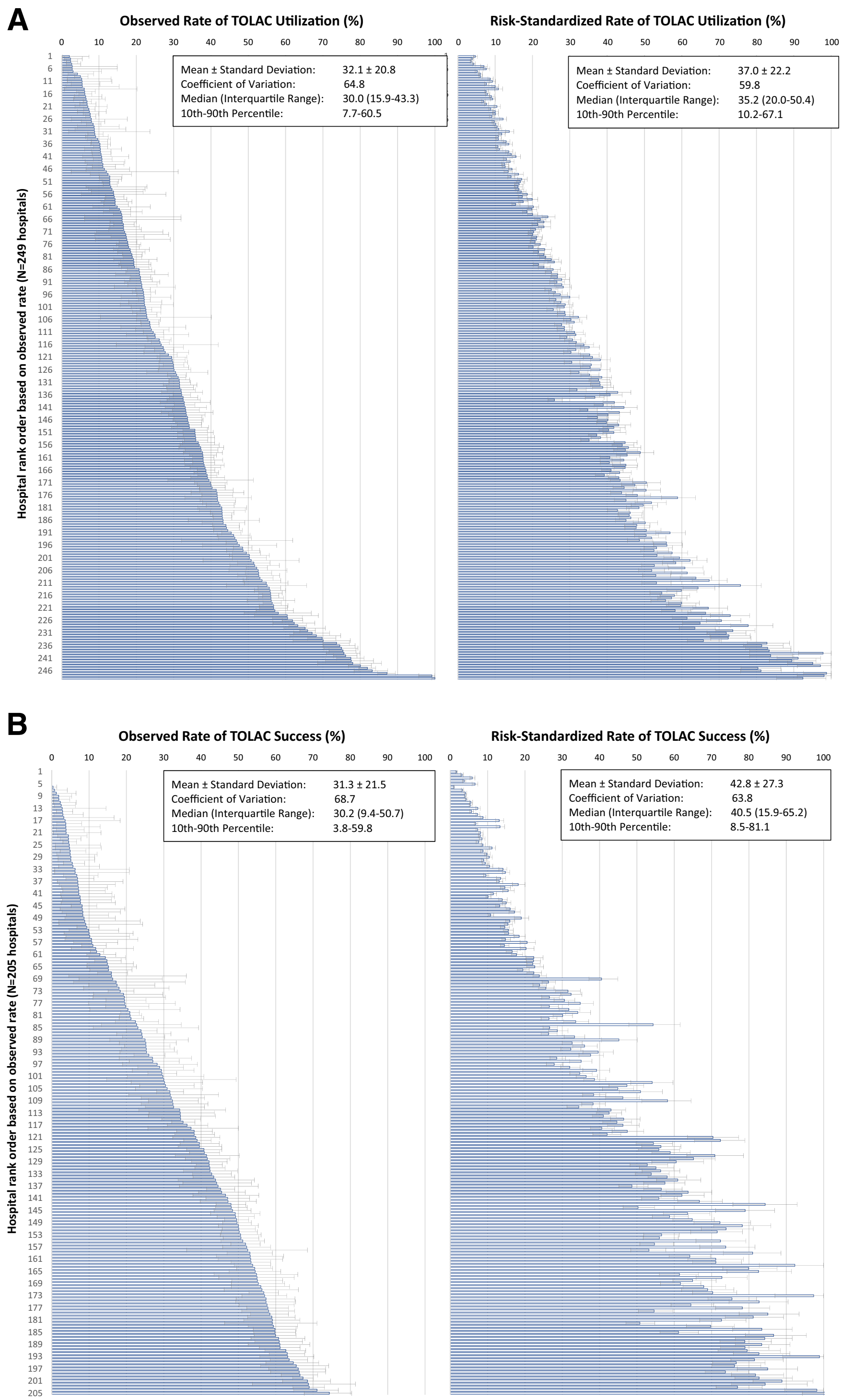
Among births that attempted labor, we further determined whether they were eventually delivered vaginally based on diagnosis and procedure codes and diagnosis-related group codes on hospital discharge records (see Appendix A) as well as final mode of delivery documented on birth certificates.[10,13]

For maternal outcomes, we measured a composite binary indicator for overall severe maternal morbidity (yes/no) as defined by the Centers for Disease Control and Prevention (see Appendix B)[14,15] as well as the following indicators: uterine rupture (yes/no), peripartum hysterectomy (yes/no), and blood transfusion (yes/no). Newborn outcomes were assessed using an overall composite indicator for severe unexpected complications (yes/no) developed by the California Maternal Quality Care Collaborative (see Appendix B)[16] as well as separate subcategories of morbidities: severe infection (yes/no), severe respiratory complication (yes/no), severe shock/resuscitation (yes/no), severe neurological complication/trauma (yes/no), and an Apgar score ≤3 at 5 or 10 minutes (yes/no). Additionally, we measured whether the infant was admitted to neonatal intensive care unit (yes/no). These maternal and newborn morbidities were identified using a combination of birth certificate data elements, hospital disposition status code, and diagnosis/procedure codes, with additional criteria on length of stay to capture significant morbidities.[14–16] To inform how TOLAC might affect resource utilization, we also assessed maternal and newborn length of stay for the childbirth hospitalization.

Patient clinical characteristics included maternal age, comorbidities (eg, obesity, diabetes, hypertensive disorders), and obstetric risk factors (eg, parity, gestational age, isoimmunization) measured using a combination of diagnosis/procedure codes and birth certificate data elements. These variables were selected based on clinical relevance, availability of data, and evidence from prior research regarding their relationship to birth outcomes.[13,17–25] The exact definition and measurement of these clinical risk factors are reported elsewhere.[26] Additionally, we measured maternal race/ethnicity and type of primary payer to assess sociodemographic characteristics of the included sample.

Hospital characteristics included teaching status and urban/rural location, type of ownership, multihospital system affiliation, level of neonatal care capacity, in-house availability of blood bank, and 24 hour on premises coverage of

FIGURE 1
Variation in utilization and success rates of trial of labor across hospitals



Error bars reflect 95% confidence intervals. **A,** Hospital variation in rate of TOLAC utilization. **B,** Hospital variation in rate of TOLAC success among births that attempted TOLAC (note that the observed rate of TOLAC success was 0% at the first 5 hospitals).

TOLAC, trial of labor after cesarean.

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anesthesiologists. We obtained these measures from the 2011 American Hospital Association annual survey[27] and each hospital's annual financial report,[28] supplemented by information from the California Perinatal Quality Care Collaborative.[29]

In addition, using the linked hospital discharge and birth certificate data, we measured each hospital's annual total birth volume, proportion of its live births attended by midwives, and proportion of live births covered by Medicaid or were uninsured. We also assessed each hospital's local medical-legal environment using county-specific average malpractice insurance premium for obstetrics-gynecology reported by major insurers in the Medical Liability Monitor annual rate survey.[30]

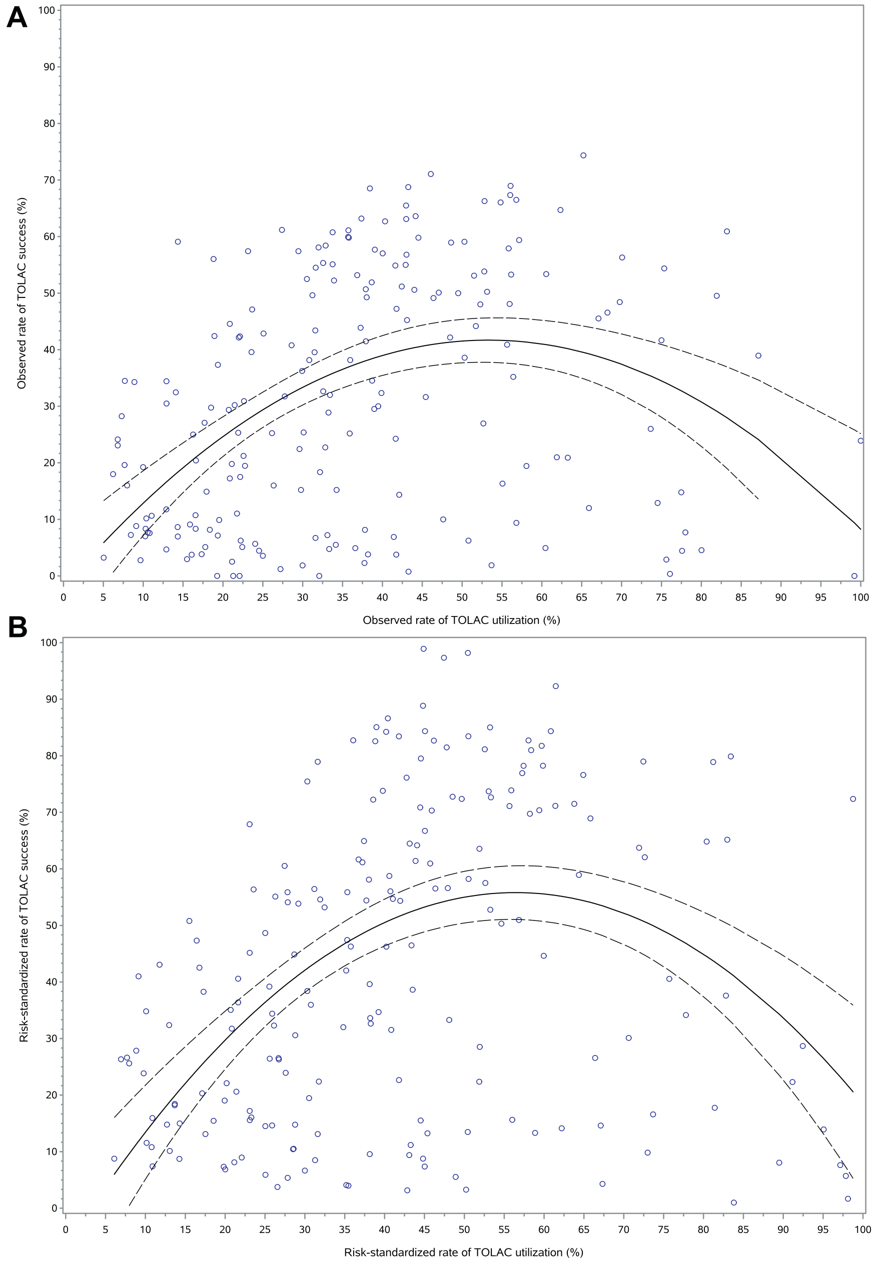
Statistical analysis

Following prior research,[26,31,32] when evaluating hospital performance on utilization of TOLAC, we used a hierarchical generalized linear model with logit link, binomial distribution, and hospital random intercept for risk adjustment (see Appendix C for a complete list of risk factors included). Based on results from this model, we calculated risk-standardized rate of TOLAC utilization for each hospital.

Likewise, we estimated risk-standardized rate of TOLAC success (among births that attempted labor) for each hospital. Analysis of TOLAC success rate was limited to hospitals with at least 25 TOLAC births in 2010−2012 to ensure a reasonable volume for estimation. For each hospital, we calculated the 95% confidence intervals (CIs) for its observed rates of TOLAC utilization and TOLAC success using the exact binomial method, and we estimated the 95% CIs for its risk-standardized rates using a bootstrap method.

Variation in TOLAC utilization and success rates across hospitals was assessed by coefficient of variation, defined as the ratio of standard deviation to mean multiplied by 100. A value greater than 15 generally indicates large variation.[33] We also examined the relationship between TOLAC utilization rate

FIGURE 2
Relationship between utilization and success rates of trial of labor across hospitals



The *solid line* in each figure reflects the predicted relationship between utilization and success rates of TOLAC among hospitals, and the *dashed lines* reflect the 95% confidence intervals. **A,** Relationship between observed rates of TOLAC utilization and success. **B,** Relationship between risk-standardized rates of TOLAC utilization and success.

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and success rate among hospitals. A quadratic function was used for this purpose as the relationship demonstrated a non-monotonic pattern.

To examine the impact of TOLAC on birth outcomes and resource use, we identified hospitals that had risk-standardized rates of both utilization and success above the respective sample medians (referred to as high utilization and high success rates hospitals hereafter). We compared maternal and newborn morbidities, as well as maternal and newborn length of stay, between births that occurred at high utilization and high success rates hospitals and other hospitals. A χ^2 test (for morbidities) and Wilcoxon rank sum test (for length of stay) were used for bivariate analysis, and multivariable Poisson regression analysis was used to estimate risk ratio[34] for morbidities and mean ratio for length of stay while adjusting for patient clinical characteristics.

To identify institutional characteristics associated with a hospital's utilization and success of TOLAC, we compared characteristics of high utilization and high success rates hospitals with other hospitals. To elucidate potential mechanisms of such association, we further examined the relationship between various institutional characteristics and risk-standardized rate of TOLAC use and TOLAC success, separately. A χ^2 test (for categorical variables) and Wilcoxon rank sum test/Kruskal-Wallis test (for continuous variables) were used for this purpose.

For multicategory variables that showed overall significant association, we further performed pairwise comparisons between categories with correction for multiple comparison. All data analysis was performed using SAS version 9.4 (SAS Inc, Cary, NC).

Results

Sample characteristics

Most mothers in our sample (74.6%) had 1 previous birth, whereas the rest had 2 or more prior births (Table 1). Median maternal age was 30 years, 47.3% of the mothers had Medicaid coverage, and 52.1% were Hispanic. Among mothers, 27.6% were obese or morbidly obese, 6.2% had hypertensive disorders, and 12.8% had diabetes or abnormal glucose tolerance. For fetuses, 13.8% were large for gestational age, 13.0% had group B streptococcus infection or colonization, and 3.6% had isoimmunization.

TABLE 2

Comparison of birth outcomes at high utilization and high success rates hospitals vs other hospitals

Outcomes	Births at high utilization and high success rates hospitals (n = 58,948)[a] n	%	Births at other hospitals (n = 82,127)[a] n	%	*P* value	Adjusted analysis[b] Risk ratio	95% CI
Maternal outcome							
Uterine rupture	202	0.34	79	0.10	< .001	2.74	(2.08–3.61)
Peripartum hysterectomy	60	0.10	46	0.06	.002	1.23	(0.81–1.87)
Blood transfusion	652	1.11	683	0.83	< .001	0.89	(0.80–1.002)
Overall severe maternal morbidity	874	1.48	866	1.05	< .001	0.94	(0.85–1.04)
Overall severe maternal morbidity (excluding blood transfusion)	312	0.53	265	0.32	< .001	1.04	(0.87–1.25)
Length of stay (days), mean ± SD, median (10th to 90th percentile)	2.74 ± 1.09	3 (2–4)	2.85 ± 0.91	3 (2–4)	< .001	0.948[c]	(0.941–0.954)[c]
Neonatal outcome							
NICU admission	1722	2.92	2,142	2.61	< .001	1.01	(0.94–1.08)
Overall severe unexpected newborn complication	888	1.51	1393	1.70	.005	0.86	(0.78–0.93)
Severe infection	336	0.57	572	0.70	.003	0.80	(0.70–0.93)
Severe respiratory complication	211	0.36	180	0.22	< .001	1.46	(1.19–1.79)
Severe shock/resuscitation	121	0.21	146	0.18	.24	1.06	(0.83–1.35)
Extremely low Apgar score	54	0.09	79	0.10	.78	0.79	(0.53–1.15)
Severe neurological complication or trauma	99	0.17	53	0.06	< .001	2.48	(1.75–3.49)
Length of stay (days), mean ± SD, median (10th to 90th percentile)	2.67 ± 1.48	3 (1–4)	2.87 ± 1.52	3 (2–4)	< .001	0.924[c]	(0.918–0.930)[c]

CI, confidence interval; *NICU*, neonatal intensive care unit.

[a] Based on 141,075 births from the 205 hospitals that had at least 25 women attempting trial of labor during study period (2010–2012); [b] All models were adjusted for patient clinical risk factors; [c] Results for length of stay were reported as mean ratios (ie, exponentiation of the coefficient estimates).

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Variation in TOLAC utilization and success

Of the 146,185 births in our sample, 49,756 (34.0%) attempted labor. Among women who attempted, 18,337 (36.9%) successfully delivered vaginally, resulting in an overall vaginal birth rate of 12.5%.

Utilization and success rate of TOLAC, however, varied considerably across hospitals. Adjustment for patient clinical risk factors had little impact on the variation (Figure 1, A and B). Median risk-standardized rate of TOLAC utilization was 35.2% among the 249 hospitals (10th to 90th percentile range, 10.2–67.1%, coefficient of variation, 59.8) (Figure 1A). Of the 249 hospitals, 205 had at least 25 women attempting TOLAC, and their median risk-standardized success rate was 40.5% (10th to 90th percentile range, 8.5–81.1%, coefficient of variation, 63.8) (Figure 1B).

The relationship between hospitals' TOLAC utilization rate and success rate demonstrated an inverted U shape. When TOLAC utilization was below 53.3%, the success rate was positively associated with utilization rate; however, among hospitals with TOLAC rates above 53.3%, higher utilization was associated with lower success rate (linear slope, 1.64, $P <$ .001; quadratic slope, −0.02, $P <$ .001) (Figure 2A). A similar relationship was observed between risk-standardized rates of TOLAC utilization and success (linear slope, 2.22, $P <$ .001; quadratic slope, −0.02, $P <$ .001) (Figure 2B).

Birth outcomes

Compared with other births, those delivered at high utilization and high success rates hospitals had a higher risk for uterine rupture (adjusted risk ratio [aRR], 2.74, 95% CI, 2.08–3.62) but similar maternal risk for peripartum hysterectomy, blood transfusion, and overall severe morbidities (Table 2). Maternal length of stay was shorter at high utilization and high success rates hospitals (adjusted mean ratio, 0.948, 95% CI, 0.941–0.954).

Newborns at high utilization and high success rates hospitals had a lower risk for severe infection (aRR, 0.80, 95% CI, 0.70−0.93) but a higher risk for severe respiratory complication (aRR, 1.46, 95% CI, 1.19−1.79) and neurological complication/trauma (aRR, 2.48, 95% CI, 1.75−3.49) than other hospitals (Table 2). The risk for overall severe newborn complications, however, was significantly lower at high utilization and high success rates hospitals (aRR, 0.86, 95% CI, 0.78−0.93). Newborn stay was shorter at high utilization and high success rates hospitals than other hospitals (adjusted mean ratio, 0.924, 95% CI, 0.918−0.930).

Institutional characteristics

Compared with other hospitals, high utilization and high success rates hospital were more likely to be teaching hospitals or have a system affiliation, larger volume, level IV neonatal care, high proportion of midwife-attended births, or low proportion of Medicaid/uninsured patients (Table 3). In contrast, for-profit hospitals and hospitals in counties with higher malpractice insurance premium were less likely to have high utilization and high success rates.

Further analysis of TOLAC utilization and success rates separately showed that teaching status, system affiliation, volume, level IV neonatal care, high proportion of midwife-attended births, and low proportion of Medicaid/uninsured patients were positively associated with both TOLAC utilization and TOLAC success (Table 3). However, for-profit ownership was associated only with a lower success rate, whereas rural location and higher local malpractice insurance premium was linked only to lower TOLAC utilization. Twenty-four hour on the premises coverage of anesthesiologists was associated both higher TOLAC utilization and success but not the likelihood of being a high utilization and high success rates hospital, possibly because of the relatively small sample size.

Comment

We found large variation across hospitals in California in their utilization and success of TOLAC. Hospitals with relatively high rates of TOLAC utilization and success generally had comparable birth outcomes but shorter length of stay compared with other hospitals. Several institutional characteristics were significantly associated with hospitals' utilization and success of TOLAC.

Although outcomes of the current birth at high utilization and high success rates hospitals were similar to other hospitals, it is important to consider that reduced use of cesarean in these births can benefit mothers in their future pregnancies. It is well established that maternal and fetal risks for adverse outcomes, such as placenta previa, morbidly adherent placenta, and perioperative morbidity/mortality, progressively increase with each additional cesarean.[5,35] Moreover, we observed significantly shorter length of stay at high utilization and high success rates hospitals than other hospitals. Appropriate use of TOLAC may therefore help conserve medical resources and improve maternal outcomes in the long run.

We identified several factors that may influence a hospital's use of TOLAC. Teaching status, rural location, volume, neonatal care level, and anesthesia availability are likely surrogate indicators for overall capability of obstetric care. Hospitals with lower capabilities and fewer on-demand resources may have greater concerns about back-up support in case of obstetric emergency (eg, availability and experience of obstetric providers, surgical assistants and technicians). Likewise, litigation risk of adverse outcomes could prompt providers to limit TOLAC use, as observed in previous research showing higher rates of cesarean delivery in places with more litigious medical-legal environment.[8] In contrast, hospitals with more midwife-attended deliveries may have a less interventional culture,[36] and system- or network-affiliated hospitals may benefit from shared resources, expertise, and standardized safety and quality improvement processes.[37,38] Therefore, future efforts providing additional support to lower-capacity hospitals (eg, enhanced simulation training and staffing models), tort reforms to reduce litigation concerns, and integration of a midwifery model of care may help promote TOLAC use.

However, increasing TOLAC utilization alone is not sufficient. Among hospitals with similar utilization rates, we found wide variation in success rates. Further evaluation of practices (eg, selection of candidate patients, approaches to labor augmentation/induction, and thresholds to intervene) at successful hospitals, especially those with high utilization and high success rates, will be informative. Moreover, we identified several institutional characteristics associated with TOLAC success rates. In particular, for-profit ownership and a high proportion of Medicaid/uninsured patients were associated with lower success rates. For-profit hospitals may have a stronger financial incentive to perform cesarean deliveries, and prior literature has shown lower vaginal birth rate at for-profit than not-for-profit hospitals.[39] Hospitals with a higher safety-net burden (Medicaid/uninsured patients) may have more socially and economically disadvantaged patient population, which can complicate their care. Efforts to better address these patients' needs and attention to potential disparity in care may help improve outcomes.

The inverted U-shaped relationship between utilization and success rates of TOLAC suggests a need for more cautious patient selection at hospitals with very high TOLAC rates. Excessive use of trial of labor can increase the risk for cesarean delivery, uterine rupture, and other serious maternal and neonatal complications.[40,41] Careful consideration of factors that influence a woman's chance of success (eg, previous vaginal delivery and indications for previous cesarean) is important during patient selection.[6] Adoption and refinement of prediction models for TOLAC success (eg, validation at nonacademic hospitals and understanding the role of race) may be helpful as well.[6,42] Furthermore, the TOLAC utilization rate in which the success rate was maximized in our analysis is sample dependent. Its exact value may vary when studied in different cohorts of hospitals with different patient characteristics and practices. Hence, caution is needed to not interpret it as an ideal TOLAC rate to target.

TABLE 3
Association of institutional characteristics with risk-standardized rates of trial of labor utilization and success

Institutional characteristic	High utilization and high success rates hospital Yes (n = 81)	No (n = 124)	P value	TOLAC utilization rate (risk standardized) (n = 249 hospitals) n	Median (IQR)	P value	TOLAC success rate (risk standardized) (n = 205 hospitals) n	Median (IQR)	P value
Teaching/urban-rural status			< .001[a]			< .001[a,b]			< .001[a]
Urban teaching	48 (59.3%)	21 (16.9%)		71	45.1 (31.9, 58.0)		69	64.8 (45.2, 78.9)	
Urban nonteaching	30 (37.0%)	99 (79.8%)		158	28.6 (16.4, 44.8)		129	27.8 (11.6, 54.1)	
Rural	3 (3.7%)	4 (3.2%)		20	25.3 (12.8, 44.5)		7	38.6 (13.9, 68.9)	
Type of ownership			< .001[c]			.47			< .001[c]
Government (nonfederal)	18 (22.2%)	17 (13.7%)		47	40.2 (19.9, 53.3)		35	46.5 (15.6, 72.6)	
Private nonprofit	60 (74.1%)	76 (61.3%)		163	35.2 (21.0, 49.7)		136	45.6 (22.2, 70.6)	
Private for-profit	3 (3.7%)	31 (25.0%)		39	29.2 (13.1, 45.4)		34	15.4 (8.5, 39.6)	
Health care system affiliation			.01			.009			.006
Yes	68 (84.0%)	84 (67.7%)		178	39.1 (21.4, 52.6)		152	44.9 (16.3, 71.9)	
No	13 (16.0%)	40 (32.3%)		71	28.3 (15.5, 40.8)		53	30.6 (14.6, 50.8)	
Annual birth volume, median (IQR)	2266 (1332, 3421)	1864 (1171, 2667)	.03	249	0.24[d]	< .001	205	0.26[d]	< .001
Level of NICU care			< .001[e]			< .001[e]			< .001[e,f]
I	8 (9.9%)	37 (29.8%)		85	20.3 (10.9, 45.4)		45	14.8 (8.8, 39.6)	
II	23 (28.4%)	34 (27.4%)		61	40.2 (26.6, 50.5)		57	34.4 (14.6, 64.2)	
III	32 (39.5%)	53 (42.7%)		85	31.6 (23.1, 44.6)		85	46.3 (26.5, 64.9)	
IV	18 (22.2%)	0 (0.0%)		18	59.8 (53.0, 64.4)		18	74.9 (64.8, 79.0)	
Blood bank available in-house			.09			.38			.07
Yes	71 (87.7%)	97 (78.2%)		203	35.5 (21.0, 49.7)		168	43.8 (17.5, 70.3)	
No	10 (12.3%)	27 (21.8%)		46	30.3 (13.5, 58.0)		37	30.1 (14.1, 56.4)	
24 hour on-premises coverage of anesthesiologists			.15			.01			.02
Yes	52 (64.2%)	67 (54.0%)		134	38.2 (23.6, 53.3)		119	51.0 (20.6, 70.9)	
No	29 (35.8%)	57 (46.0%)		115	28.8 (15.5, 45.1)		86	31.6 (13.5, 58.9)	

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(continued)

TABLE 3

Association of institutional characteristics with risk-standardized rates of trial of labor utilization and success *(continued)*

	High utilization and high success rates hospital			TOLAC utilization rate (risk standardized) (n = 249 hospitals)			TOLAC success rate (risk standardized) (n = 205 hospitals)		
Institutional characteristic	Yes (n = 81)	No (n = 124)	*P* value	n	Median (IQR)	*P* value	n	Median (IQR)	*P* value
Proportion of live births attended by midwife[g]			< .001[h]			< .001[h]			< .001[i]
Low (0%)	16 (19.8%)	63 (50.8%)		107	26.6 (13.8, 42.8)		79	23.9 (9.6, 45.2)	
Medium (>0–8.6%)	25 (30.9%)	47 (37.9%)		79	33.8 (22.1, 50.5)		72	40.1 (24.4, 60.7)	
High (>8.6%)	40 (49.4%)	14 (11.3%)		63	48.5 (37.7, 58.9)		54	70.0 (40.5, 81.0)	
Proportion of live births covered by Medicaid or were uninsured[j]			< .001[k]			.03[l]			< .001[k]
Low (<43.0%)	44 (54.3%)	33 (26.6%)		83	40.2 (27.8, 50.5)		77	63.6 (34.8, 79.5)	
Medium (43.0–68.9%)	20 (24.7%)	43 (34.7%)		83	31.3 (20.1, 50.2)		63	33.3 (15.0, 56.4)	
High (>68.9%)	17 (21.0%)	48 (38.7%)		83	26.7 (12.7, 48.9)		65	26.4 (11.6, 50.3)	
Malpractice insurance premium, median (IQR)	34256 ($33004, $63434)	$59269 ($34256, $66039)	.01	249	−0.21[d]	< .001	205	−0.11[d]	.11

IQR, interquartile range; *NICU*, neonatal intensive care unit.

[a] Urban teaching hospitals differed significantly from urban nonteaching hospitals in pairwise comparison (after correcting *P* values for multiple comparison); [b] Urban teaching hospitals differed significantly from rural hospitals in pairwise comparison (after correcting *P* values for multiple comparison); [c] Private for-profit hospitals differed significantly from government (nonfederal) hospitals and private nonprofit hospitals in pairwise comparison (after correcting *P* values for multiple comparison); [d] Statistics were reported as Spearman correlation coefficient; [e] Level IV hospitals differed significantly from level I, level II, and level III hospitals in pairwise comparison (after correcting *P* values for multiple comparison); [f] Level I hospitals differed significantly from level II, level III, and level IV hospitals in pairwise comparison (after correcting *P* values for multiple comparison); [g] Because nearly half of the hospitals had no live births attended by midwives, we used 0% and upper quartile (8.6%) of the variable distribution to determine the cutoffs for defining the low, medium, and high categories; [h] Hospitals with a high proportion of midwife-attended births differed significantly from hospitals with low and medium proportion of midwife-attended births in pairwise comparison (after correcting *P* values for multiple comparison); [i] Hospitals with low, medium, and high proportion of midwife-attended births differed significantly from each other in pairwise comparison (after correcting *P* values for multiple comparison); [j] Variable was categorized as low, medium, and high using the lower and upper tertiles of its distribution as the cutoff values; [k] Hospitals with a low proportion of Medicaid-covered or uninsured births differed significantly from hospitals with medium and high proportions of Medicaid-covered or uninsured births in pairwise comparison (after correcting *P* values for multiple comparison); [l] Hospitals with a low proportion of Medicaid-covered or uninsured births differed significantly from hospitals with a high proportion of Medicaid-covered or uninsured births in pairwise comparison (after correcting *P* values for multiple comparison).

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Several limitations of this study should be acknowledged. First, as a single-state analysis, our findings may not generalize to other areas in the United States. Second, administrative and birth certificate data may lack sufficient detail or accuracy for measuring TOLAC-related variables, clinical risk factors, and obstetric outcomes, which may result in misclassification. However, research supports that combining information in hospital discharge record and birth certificate, as in our study, can enhance quality in measurement of obstetric variables.[43] Third, we could not distinguish the type (eg, low-transverse vs low-vertical incision) or reason (eg, labor arrest vs other nonrecurring indications) of prior cesarean, which might affect patients' risk for adverse outcomes.[6] Moreover, we excluded births in which the mother was transferred in from another facility since we might not have complete information about their care. Because these births likely involved obstetric emergencies associated with TOLAC, we might underestimate morbidities for TOLAC. However, this affected only a very small number of births, and they were not clustered within any given hospital. Its impact on our evaluation of hospital variation should be minimal.

Appropriate use of TOLAC plays an important role for safely reducing cesarean delivery and improving patient outcomes across the reproductive health span. Our study showed wide variation in hospitals' utilization of TOLAC and identified opportunities for improvement. Trial of labor should be encouraged at hospitals with low TOLAC rates, yet more cautious patient selection may be needed at hospitals with overly high TOLAC rates. The institutional characteristics associated with hospitals' utilization and success rates of TOLAC can help target future research and intervention activities to improve patient access while optimizing success. ■

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APPENDIX A

***International Classification of Diseases*, ninth revision, Clinical Modification diagnosis and procedure codes and DRG codes used to define trial of labor and cesarean delivery**

Measure	ICD-9 Diagnosis Code	ICD-9 procedure code	DRG code
Trial of labor	650, 653.4x, 653.5x, 653.8x, 653.9x, 658.2x, 658.3x, 659.0x-659.3x, 660.x-662.x, 664.x, 665.1x, 669.5x, 763.2, 763.3, 763.6, 763.82	72.0-72.4, 72.7x-72.9, 73.1, 73.3-73.6, 73.9x, 75.32, 75.38, 75.6x	
Cesarean delivery	649.8x, 669.7x, 763.4, V3x.01	74.0-74.2, 74.4, 74.99	765, 766

DRG, diagnosis-related group; *ICD-9*, *International Classification of Diseases*, ninth revision.

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APPENDIX B

Measures of maternal and newborn outcomes

For maternal outcomes, we measured the following binary indicators: uterine rupture (yes/no), peripartum hysterectomy (yes/no), blood transfusion (yes/no), and overall severe maternal morbidity (yes/no). Overall severe maternal morbidity was measured using a composite indicator developed by the Centers for Disease Control and Prevention, encompassing in-hospital death, transfer to another hospital, and 21 severe complications (Callaghan et al, 2012;[14] Centers for Disease Control and Prevention, 2017[15]). The 21 severe complications included acute myocardial infarction, aneurysm, acute renal failure, adult respiratory distress syndrome, amniotic fluid embolism, cardiac arrest/ventricular fibrillation, conversion of cardiac rhythm, disseminated intravascular coagulation, eclampsia, heart failure/arrest during surgery or procedure, puerperal cerebrovascular disorders, pulmonary edema/acute heart failure, severe anesthesia complications, sepsis, shock, sickle cell disease with crisis, air and thrombotic embolism, blood transfusion, hysterectomy, temporary tracheostomy, and ventilation (Centers for Disease Control and Prevention, 2017[15]). Following prior research (Centers for Disease Control and Prevention, 2017[15]), we reported the overall severe maternal morbidity both with and without the blood transfusion item because blood transfusion was the predominant morbidity in the composite.

Newborn outcomes were assessed by a composite indicator (yes/no) for severe unexpected newborn complications developed by the California Maternal Quality Care Collaborative (California Maternal Quality Care Collaborative, 2016[16]). This composite encompassed in-hospital death, transfer, Apgar score of 3 or less at 5 or 10 minutes, and 6 types of severe complications. The 6 types of severe complications included severe birth trauma, severe hypoxia/asphyxia, severe shock/resuscitation, severe respiratory complications, severe infection (including severe septicemia with longer than 4 days of hospital stay), and severe neurological complications. Specific diagnosis and procedure codes used for defining each of these complications are available at the California Maternal Quality Care Collaborative website (California Maternal Quality Care Collaborative, 2016[16]). To better inform the impact of TOLAC on different types of complications, we also examined separate categories of these morbidities: severe infection (yes/no), severe respiratory complication (yes/no), severe shock/resuscitation (yes/no), severe neurological complication or trauma (yes/no), and Apgar score of 3 or less at 5 or 10 minutes (yes/no). Additionally, we measured whether the infant was admitted to the NICU (yes/no).

These measures of maternal and newborn morbidities were defined using a combination of hospital disposition status code, diagnosis and procedure codes, and birth certificate data elements, with additional criteria on length of stay when needed to improve accuracy in capturing significant morbidities (Callaghan et al, 2012;[14] Centers for Disease Control and Prevention, 2017;[15] California Maternal Quality Care Collaborative, 2016[16]). For example, if a patient had a diagnosis code for one of the maternal morbidities included in the Centers for Disease Control and Prevention composite measure but had a short length of stay (defined as $<$90th percentile by mode of delivery), she would not be considered as having severe maternal morbidity (Callaghan et al, 2012[14]). More details about the coding algorithms of these measures were published elsewhere (Callaghan et al, 2012;[14] Centers for Disease Control and Prevention, 2017;[15] California Maternal Quality Care Collaborative, 2016[16]).

To inform the impact of TOLAC on resource utilization, we also assessed maternal and newborn length of stay for each birth. Maternal length of stay was calculated as the number of days between date of admission and date of discharge for the childbirth hospitalization. Newborn length of stay was measured as the number of days between the newborn's date of birth and date of discharge from the initial childbirth hospitalization.

NICU, neonatal intensive care unit; *TOLAC*, trial of labor after cesarean.

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APPENDIX C

Risk-adjustment models for utilization and success of trial of labor after a prior cesarean (n = 146,185 births)

Clinical risk factor	TOLAC utilization		TOLAC success	
	Odds ratio	(95% CI)	Odds ratio	(95% CI)
Maternal age, y				
<18	1.46	(1.16—1.85)	1.21	(0.79—1.85)
18—24	1.00	(0.97—1.04)	1.09	(1.02—1.17)
25—29	Reference		Reference	
30—34	0.93	(0.90—0.96)	0.89	(0.84—0.94)
35—39	0.87	(0.84—0.90)	0.74	(0.69—0.79)
≥40	0.79	(0.74—0.83)	0.59	(0.53—0.66)
Gestational age at delivery, wks				
37	0.50	(0.47—0.53)	0.95	(0.86—1.04)
38	0.49	(0.47—0.51)	0.78	(0.73—0.84)
39	0.40	(0.39—0.42)	0.48	(0.45—0.51)
40	Reference		Reference	
41	1.49	(1.37—1.61)	0.84	(0.76—0.93)
42	1.15	(0.90—1.47)	0.79	(0.57—1.10)
Parity				
1	Reference		Reference	
2	1.68	(1.62—1.74)	3.52	(3.32—3.73)
≥3	2.44	(2.34—2.54)	7.10	(6.62—7.61)
BMI category				
Underweight (BMI <18.5 kg/m^2)	1.01	(0.94—1.10)	1.08	(0.93—1.24)
Normal weight (18.5 kg/m^2 ≤ BMI <25 kg/m^2)	Reference		Reference	
Overweight (25 kg/m^2 ≤ BMI <30 kg/m^2)	0.95	(0.92—0.98)	0.75	(0.71—0.79)
Obese (30 kg/m^2 ≤BMI <40 kg/m^2)	0.87	(0.84—0.90)	0.56	(0.53—0.60)
Morbidly obese (BMI ≥40 kg/m^2)	0.86	(0.81—0.91)	0.35	(0.30—0.39)
Unknown	0.98	(0.92—1.05)	0.85	(0.76—0.95)
Maternal comorbid conditions				
Hypertensive disorders of pregnancy (prepregnancy or gestational)	0.95	(0.90—1.003)	0.61	(0.55—0.67)
Diabetes or abnormal glucose tolerance (prepregnancy or gestational)	0.92	(0.88—0.95)	0.82	(0.77—0.88)
Endocrine disorders other than diabetes	0.94	(0.87—1.01)	0.81	(0.71—0.93)
Chronic pulmonary disease	0.89	(0.84—0.95)	0.79	(0.71—0.88)
Renal abnormalities	1.00	(0.78—1.28)	0.82	(0.52—1.27)
Liver disease	1.04	(0.84—1.31)	1.47	(0.98—2.20)
Paralysis or neurological disorders	0.79	(0.64—0.96)	0.66	(0.45—0.97)
Substance use[a]	0.94	(0.83—1.07)	1.10	(0.89—1.36)
Tabacco use	0.82	(0.76—0.89)	0.66	(0.57—0.78)
Mental disorders	0.99	(0.92—1.07)	0.87	(0.76—0.999)
Heart or peripheral vascular disease	0.89	(0.77—1.04)	0.67	(0.50—0.88)
Soft tissue disorders of pelvis	0.86	(0.81—0.90)	0.19	(0.16—0.21)

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(continued)

APPENDIX C

Risk-adjustment models for utilization and success of trial of labor after a prior cesarean (n = 146,185 births) *(continued)*

Clinical risk factor	TOLAC utilization		TOLAC success	
	Odds ratio	(95% CI)	Odds ratio	(95% CI)
Autoimmune/collagen vascular disorders	0.80	(0.62—1.03)	0.92	(0.57—1.49)
Malignancy	0.73	(0.56—0.94)	0.97	(0.60—1.55)
Gastrointestinal diseases	0.75	(0.70—0.80)	0.43	(0.38—0.49)
Pulmonary circulation diseases	0.94	(0.73—1.23)	1.26	(0.79—2.00)
Coagulation disorders	0.90	(0.81—0.998)	0.71	(0.59—0.85)
Anemia	0.91	(0.88—0.95)	0.61	(0.57—0.66)
Fluid and electrolyte disorders	1.00	(0.74—1.35)	0.40	(0.21—0.76)
Obstetric and fetal conditions				
Small for gestational age	0.90	(0.86—0.95)	1.28	(1.17—1.40)
Large for gestational age	0.99	(0.95—1.03)	0.52	(0.49—0.56)
Uterine scar unrelated to cesarean	0.66	(0.48—0.89)	0.11	(0.04—0.33)
Group B streptococcal infection or colonization	1.28	(1.23—1.32)	1.28	(1.20—1.36)
Other infections	0.97	(0.88—1.07)	0.84	(0.71—0.995)
Isoimmunization	1.02	(0.96—1.09)	0.85	(0.76—0.95)
Oligohydramnios	0.88	(0.80—0.98)	0.60	(0.50—0.71)
Hydramnios/polyhydramnios	0.88	(0.73—1.05)	0.24	(0.16—0.38)
Antepartum bleeding/placental abruption	1.49	(1.28—1.75)	0.35	(0.27—0.46)
Adequacy of prenatal care utilization index				
Inadequate	0.97	(0.92—1.01)	1.01	(0.93—1.10)
Intermediate	0.98	(0.94—1.01)	0.96	(0.90—1.03)
Adequate	Reference		Reference	
Adequate plus	0.96	(0.93—0.99)	0.90	(0.85—0.96)
Unknown	0.97	(0.90—1.05)	0.84	(0.73—0.96)

BMI, body mass index; *CI*, confidence interval; *TOLAC*, trial of labor after cesarean.

[a] Includes maternal use of alcohol, drug, antiinfectives, antimetabolic agents, or other noxious substance.

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