Original Contribution

Elective Deliveries and Neonatal Outcomes in Full-Term Pregnancies

Julien O. Teitler*, Rayven Plaza, Thomas Hegyi, Lakota Kruse, and Nancy E. Reichman

* Correspondence to Dr. Julien O. Teitler, School of Social Work, Columbia University, 1255 Amsterdam Avenue, New York, NY 10027-5927 (e-mail: teitler@columbia.edu).

Initially submitted May 31, 2018; accepted for publication January 14, 2019.

Cesarean and induced delivery rates have risen substantially in recent decades and currently account for over one-third and one-fourth of US births, respectively. Initiatives to encourage delaying deliveries until a gestational age of 39 weeks appear to have slowed the increases but have not led to declines. The rates are at historic highs and the consequences of these interventions when not medically necessary have not been systematically explored at the population level. In this study, we used population-level data on births in New Jersey (1997–2011) to document trends in elective deliveries (induced vaginal delivery, cesarean delivery with no labor trial, and cesarean delivery after induction) and estimate logistic and linear regression models of associations between delivery method and neonatal morbidities and cost-related outcomes in low-risk pregnancies. We found that elective deliveries more than doubled during the observation period and were associated with neonatal morbidities and cost-related outcomes even at gestational ages of 39 and 40 weeks. Findings suggest that delaying beyond 39 weeks and avoiding delivery interventions when not medically necessary would improve infant health and reduce health-care costs.

cesarean delivery; elective delivery; induced delivery; neonatal morbidities; newborn costs

Abbreviations: ARRIVE, A Randomized Trial of Induction Versus Expectant Management; GA, gestational age; NICU, neonatal intensive care unit.

Rates of cesarean and induced deliveries have risen substantially in the United States over recent decades; cesarean deliveries increased by 41% and inductions increased by 159% between 1990 and 2015 (1). Cesarean deliveries currently account for over one-third of US births, and over one-fourth of all US births are induced (1). Only 5% of births were by cesarean delivery in 1970; that figure more than tripled to 17% in 1980 and subsequently doubled (2). There is little indication that increases in obstetrical risk factors (such as maternal age, obesity, and medical conditions) explain the increase in cesarean deliveries since 1990 (3). Rates of cesarean delivery and induction vary little by maternal race/ethnicity, education, and marital status (1). The rates have stabilized since about 2006 but remain at peak levels (1). While increases in cesarean deliveries before 2000 were accompanied by reductions in infant and fetal mortality, increases afterward coincided with no such improvements (4, 5), and maternal mortality did not decline over the 2–3 decade period (6).

At the same time, the gestational age (GA) distribution of births changed markedly. Notably, among births that were full-term

(37–41 completed weeks; approximately 90% of all births), births at 40 and 41 weeks decreased, while those at 37, 38, and 39 weeks increased (1). Since about 2006, births at 38 weeks decreased and those at 39 weeks increased, while births at 40 and 41 weeks continued to decline (1). There has been speculation that increases in “elective” (not medically necessary) cesarean deliveries and inductions have been responsible for the changes in the GA distribution of US births. A recent study found evidence that recent increases in births at 39 weeks and decreases in births at 37 and 38 weeks reflect efforts by the American College of Obstetricians and Gynecologists, March of Dimes, and other organizations to delay deliveries until 39 weeks (7).

While the initiatives to delay deliveries until 39 weeks appear to have been successful, rates of obstetrical interventions remain at historic highs, and the consequences of these interventions, when not medically necessary, have not been fully explored. Most previous studies of consequences of delivery interventions on neonatal outcomes have focused on cesarean deliveries with

no labor trial—an unsatisfactory approach that does not adequately take into consideration medical risk and precludes births that have been induced from being classified as elective deliveries. Moreover, the 39-week threshold has recently been called into question. Recent studies point to potential benefits for child health and development of waiting until 40 or even 41 weeks when possible (8–11). By focusing on 39 weeks as the essential threshold, the guidelines might have had the unintended effect of encouraging deliveries at 39 weeks instead of 40 or 41 weeks, both of which have continued to decline.

Delivery interventions reduce GA, and earlier GA has been associated with neonatal morbidities, including respiratory conditions and jaundice, even among full-term infants (8). Cesarean deliveries can also have direct adverse effects on newborn health (not through GA); going through the birth canal stimulates the infant's lungs, reducing the likelihood of neonatal respiratory conditions (12) and might favorably alter the infant's microbiome (13). Induced deliveries can fail, increasing the likelihood of cesarean deliveries (14). Finally, infants who are born before labor naturally occurs might be less developed, and therefore more physically vulnerable, than those born by spontaneous vaginal delivery. From a practical standpoint, neonatal morbidities and their treatment are expensive. Neonatal respiratory disorders often require ventilatory support and account for most admissions to neonatal intensive care units (NICUs) (15), where 10%–15% of infants born in the United States each year are treated (16). Hyperbilirubinemia (jaundice) is the most common condition requiring evaluation and treatment in newborns and the most common cause for hospital readmissions during the first week of life (17).

The trial A Randomized Trial of Induction Versus Expectant Management (ARRIVE) found that induction at 39 weeks, compared with expectant management, was associated with a significantly lower frequency of cesarean delivery and was not significantly associated with a composite measure of adverse perinatal outcomes among women with low-risk pregnancies (18). These findings, which confirmed previous retrospective studies of induction versus expectant management (18), are based on data from mothers who did not intend to have cesarean deliveries and cannot be generalized to the broader population of low-risk pregnancies.

Little is known about the consequences for newborns of elective cesarean deliveries and inductions at the population level. It has been difficult to identify elective cesarean deliveries and inductions for population-based research studies because such procedures are rarely noted in hospital or administrative databases (19). Three recent studies applied criteria developed by the Joint Commission and endorsed by the National Quality Forum (20, 21) to identify obstetrical interventions that are not medically justified and investigate associations between elective deliveries and neonatal outcomes. One estimated that 4% of term births at <39 weeks were by cesarean delivery or induction without medical indication and found that these interventions were associated with longer newborn hospitalizations and respiratory distress (22). The study did not focus on other neonatal outcomes or distinguish between inductions that resulted in cesarean deliveries and those that resulted in vaginal deliveries. Another found that 9% of births paid for by Medicaid were early elective deliveries (cesarean deliveries or inductions at 34–38 weeks) and that these infants had higher rates of NICU

admissions and transfers than those delivered at 39–41 weeks (23). A third found that early elective delivery rates declined after a 2011 Medicaid policy change discouraging the practice and that GA and birth weight increased for the group affected by the policy (24).

Using an algorithm based on Joint Commission guidelines to classify pregnancies as low risk, the present study documents trends in delivery interventions (induced vaginal deliveries, cesarean deliveries with no labor trial, and cesarean deliveries after induction, all of which can be considered elective) and systematically investigated associations between delivery interventions and salient neonatal outcomes (respiratory conditions, jaundice, NICU stays, extended newborn hospitalizations, and newborn hospital charges) in low-risk full-term pregnancies in a statewide population.

METHODS

Data and sample

We used New Jersey birth files that included records for all births in the state from 1997 to 2011 (>1.6 million births) (25). We linked these records to the mothers' and infants' hospital discharge records from the birth hospitalization (26). Because the birth and discharge records are from separate systems and collected for different purposes, we used probabilistic matching, with 93% of the birth records matching to maternal discharge records and 92% of the birth records matching to infant discharge records. The birth records include method of delivery, GA, maternal medical risk factors, labor and delivery complications, neonatal diagnoses (in a newborn module not available in most states' birth files), demographic factors, health insurance type, maternal prenatal behaviors, and delivery date and hospital. Relevant fields from the maternal discharge records included discharge diagnoses and procedures, and fields from the newborn discharge records included length of hospitalization, NICU stay, and hospital charges, as well as transfer and readmission status.

To create a sample at low risk of adverse pregnancy outcomes, we began with the Joint Commission guidelines for the perinatal core outcomes of “decreasing the rate of elective deliveries” and “decreasing the cesarean delivery rate in nulliparous women with a term, singleton baby in a vertex position.” Guidelines for defining the relevant populations for measuring these outcomes, based on characteristics of pregnancies and identified lists of conditions, were compiled by a panel of perinatal experts and implemented in 2014 as part of an effort to monitor perinatal outcomes for hospital accreditation. These guidelines have been adopted by public reporting agencies and initiatives (20, 21) and used in recent research studies (22–24) to characterize elective deliveries.

We combined the sample restrictions for the two core Joint Commission measures, defining the low-risk population for elective deliveries as women having singleton first births, not having any of the *International Classification of Diseases, Ninth Revision*, codes on the Joint Commission lists for “Conditions Possibly Justifying Elective Delivery Prior to 39 Weeks Gestation” (Web Appendix 1, available at <https://academic.oup.com/aje>) or “Contraindications to Vaginal Delivery” (Web Appendix 2), not having had premature rupture of the membranes, not having had prior uterine surgery, not having had

a trial of labor (except when labor was induced or resulted in a noninduced vaginal delivery), and having an infant with GA between 37 and 40 completed weeks. The restriction to first births is important because having a cesarean delivery for one birth increases the likelihood that subsequent births will be cesarean deliveries, making first-time mothers an important focus (27). The *International Classification of Diseases, Ninth Revision*, exclusion restrictions have been validated in previous work (20, 28). We excluded births with a GA of 41 weeks because many of those would be close to 42 weeks (e.g., 41 weeks + 6 days), and thus on the margin for medically indicated inductions (29), and no method of assessing of GA is accurate to the day (30).

In order to minimize false-positive classifications (i.e., pregnancies the Joint Commission algorithm would incorrectly characterize as low-risk), we have presented results from an even more conservative algorithm that further excludes mothers with any medical risk factor or labor/delivery complication recorded in the birth record, except for cases with inductions that resulted in cesarean deliveries, for which we excluded medical risk factors but not labor/delivery complications. We assessed the sensitivity of our findings to the less stringent Joint Commission measure.

Measures

Neonatal outcomes. From the newborn module of the birth records, we created a composite measure of any respiratory condition based on indications of respiratory-related diagnoses (bronchopulmonary dysplasia, meconium aspiration syndrome, pneumonia, air leak syndrome, home on oxygen, respiratory distress syndrome/hyaline membrane disease, transient tachypnea of newborn, persistent pulmonary hypertension) or interventions (assisted ventilation, continuous positive airway pressure, surfactant therapy, extracorporeal membrane oxygenation). We also created a measure indicating whether the infant had been diagnosed with hyperbilirubinemia. From the infants' discharge records, we constructed measures of newborn hospitalization >5 days, NICU stay, and total newborn hospital charges. Hospital charges are a commonly used proxy for hospital costs in population-based research studies. For infants who were transferred (0.7%) or readmitted within 30 days of initial discharge (1.1%), we had more than 1 discharge record and summed the relevant days and charges. For the analyses of infant hospital stays and hospital charges, we excluded infants who died during their newborn hospitalizations (0.2%). The low numbers of transfers, readmissions, and infant deaths reflect the low-risk nature of our sample.

Gestational age. Following the standard in obstetrical practice, we used a clinical measure of completed weeks of GA. The clinical assessment in the birth records was based on the best available information (e.g., physical examination of the infant and/or ultrasound). The vast majority (95%) of mothers in our sample had at least 1 ultrasound. We assessed the sensitivity of our findings to alternative measures of GA. Concordance across different established measures of GA is highest for term births, the focus of our study (30).

Method of delivery/elective deliveries. From the birth records, we classified deliveries as cesarean deliveries with no trial of labor, cesarean deliveries following inductions, induced

vaginal deliveries, and noninduced vaginal deliveries. The first 3 delivery methods are considered to be elective in our sample of mothers with no documented risk factors for labor/delivery complications.

Statistical analysis

First, trends in births according to delivery method were documented for New Jersey compared with the United States. Second, the low-risk sample was constructed using the New Jersey data and applying the algorithm outlined above, and trends in births according to delivery method were documented for this sample (for which we consider obstetrical interventions elective). Third, sample characteristics and neonatal outcomes were compared across delivery methods for the low-risk sample.

Finally, regression models were fitted to estimate associations between delivery method and each of the neonatal outcomes in the low-risk sample. These models controlled for GA in weeks, infant's sex and year of birth, demographic factors, and prenatal behaviors. Additional models estimated interactions between delivery methods and GA instead of controlling for GA. Sensitivity analyses used alternative established measures of GA, included alternative sets of covariates, and relaxed the sample restrictions by, alternatively, using the Joint Commission criteria to identify the low-risk sample instead of the more conservative algorithm, including cases with spontaneous labor prior to cesarean delivery, and allowing for labor and delivery complications regardless of delivery method. Logistic regression was used for models of outcomes other than hospital charges, for which ordinary least squares regression was used.

This study was approved by the institutional review boards of Columbia University, New Jersey Department of Health, and Rutgers University.

RESULTS

Rates of cesarean deliveries were 3%–5% higher in New Jersey than in the United States, but the trends in delivery methods in New Jersey between 1997 and 2011 were similar to those at the national level, with large increases in cesarean delivery rates and smaller but steady increases in rates of inductions (Figure 1).

The low-risk sample consisted of 150,032 births in New Jersey. The rate of elective deliveries in this sample more than doubled between 1997 and 2007, from 17% to 40%, and then stabilized (Figure 2). Most of the increase is accounted for by increases in cesarean deliveries with no labor trial (650%) and cesarean deliveries after inductions (275%). Overall, 31% of births in this sample involved cesarean delivery or induction. More than half of the induced deliveries ended up as cesarean deliveries (20,000 of 38,000), and the ratio of “successful” elective inductions decreased from 58% in 1997 to 41% in 2011. The observed population-level increase in the rate of cesarean deliveries following induction underscores that the finding from the ARRIVE trial—that induction at 39 weeks was associated with a significantly lower frequency of cesarean delivery compared with expectant management—does not reflect outcomes of inductions in low-risk pregnancies at the population level.

Figure 1. Percentages of births by cesarean delivery and induction, United States and New Jersey (NJ), 1990–2015. Percentages born by cesarean delivery and induction are not mutually exclusive. Data sources: Centers for Disease Control and Prevention online vital statistics 1990–2015 birth data files (1) and New Jersey birth and hospital discharge records (25, 26).

Non-Hispanic white mothers were more likely than other mothers to have induced vaginal deliveries, particularly compared with non-Hispanic black mothers. Mothers aged <20 years were less likely to have interventions, and mothers aged ≥35 years were much more likely to have interventions, than mothers ages 20–34. Interventions were also more prevalent among

highly educated mothers, married mothers, and mothers not covered by Medicaid (Table 1). Delivery method was significantly associated with neonatal respiratory conditions, NICU stays, extended hospitalizations, and neonatal hospital charges, but not jaundice. Noninduced vaginal deliveries were associated with the most favorable outcomes, followed by induced

Figure 2. Percentages of low-risk births by cesarean delivery and induction, New Jersey, 1997–2011. Sample includes singleton first births, gestational age of 37–40 weeks, no labor trial (except when labor was induced or resulted in a noninduced vaginal delivery), and no medical risk factors or labor/delivery complications recorded in birth record (exception for inductions that resulted in cesarean deliveries, for which mothers could have labor/delivery complications). Data sources: New Jersey birth and hospital discharge records (25, 26).

Table 1. Sample Characteristics and Neonatal Outcomes According to Delivery Method Among Low-Risk Births, New Jersey, 1997–2011

Characteristic ^a	Delivery Method				P Value ^b
	Vaginal		Cesarean		
	Not Induced (n = 103,545), %	Induced (n = 18,075), %	Not Induced (n = 8,276), %	Induced (n = 20,136), %	
Demographic and economic factors					
Female infant	50.81	52.54	47.04	44.51	<0.001
Mother's race/ethnicity					
White, non-Hispanic	48.92	53.34	57.84	50.33	<0.001
Black, non-Hispanic	13.09	11.81	10.05	12.63	
Hispanic	25.27	20.89	20.69	21.59	
Other	12.72	13.96	11.42	15.45	
Mother's age, years					
<20	16.69	13.01	5.52	7.28	<0.001
20–34	76.55	78.87	73.04	78.61	
≥35	6.76	8.12	21.44	14.11	
Mother US-born	63.79	66.42	68.06	64.84	<0.001
Mother's education					
Not a high-school graduate	14.99	10.74	6.40	7.91	<0.001
High-school graduate or equivalent	27.17	25.83	23.12	24.41	
Some college	20.71	21.70	20.76	22.46	
College graduate	37.13	41.73	49.72	45.21	
Mother married	60.60	65.58	73.12	68.93	<0.001
Medicaid was payer	25.54	20.77	14.00	17.56	<0.001
Prenatal behaviors					
Trimester prenatal care initiated					
First	78.78	81.71	86.45	84.00	<0.001
Second	15.69	14.02	11.16	12.77	
Third or never	5.53	4.27	2.39	3.24	
Smoked cigarettes during pregnancy	6.76	7.03	5.24	6.85	<0.001
Neonatal outcomes					
Gestational age, weeks ^c	39.02	39.20	38.85	39.33	<0.001
Respiratory condition	1.47	1.60	2.60	2.68	<0.001
Jaundice	0.79	0.84	0.90	0.92	0.291
NICU stay	2.31	2.62	5.20	5.58	<0.001
Hospital stay >5 days	2.86	2.99	3.71	4.28	<0.001
Total hospital charges, \$ ^c	3,757	4,279	8,995	8,173	<0.001

Abbreviation: NICU, neonatal intensive care unit.

^a Sample included singleton first births, gestational age of 37–40 weeks, with no labor trial (except when labor was induced or resulted in a noninduced vaginal delivery), and no medical risk factors or labor/delivery complications recorded in birth record (exception for inductions that resulted in cesarean deliveries, for which mothers could have labor/delivery complications). Data sources: New Jersey birth and hospital discharge records (25, 26).

^b P values obtained from χ^2 tests for equal means (for gestational age and total hospital charges) or equal distribution (for all other characteristics) across delivery methods.

^c Values are expressed as means.

vaginal deliveries, cesarean deliveries with no labor trial, and cesarean deliveries after inductions.

In adjusted regression models, cesarean deliveries—after no labor trial or following induction—were strongly associated with neonatal respiratory conditions, NICU stays, hospital stays

>5 days, and hospital charges (Table 2). Compared with noninduced vaginal deliveries, cesarean deliveries that did not follow inductions almost doubled the odds of a neonatal respiratory condition (odds ratio = 1.81), more than doubled the odds of a NICU stay (odds ratio = 2.13), increased the odds of an extended

Table 2. Adjusted Associations Between Delivery Method and Neonatal Outcomes Among Low-Risk Births, New Jersey, 1997–2011

Characteristic	Neonatal Outcome ^a									
	Respiratory Condition ^b (n = 144,412)		Jaundice ^b (n = 144,329)		NICU Stay ^b (n = 144,334)		Extended Hospital Stay ^b (n = 139,704)		Ln Infant Hospital Charges ^c (n = 139,704)	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OLS	95% CI
Method of delivery ^d										
Vaginal, induced	1.14	1.00, 1.30	1.06	0.89, 1.28	1.15	1.04, 1.28	1.15	1.04, 1.27	0.03	0.022, 0.041
Cesarean, not induced	1.81	1.55, 2.11	0.95	0.75, 1.22	2.13	1.91, 2.38	1.36	1.20, 1.54	0.51	0.499, 0.526
Cesarean, induced	1.97	1.77, 2.19	1.07	0.91, 1.27	2.54	2.36, 2.75	1.71	1.57, 1.86	0.51	0.505, 0.524
Gestational age, weeks ^e										
37	1.91	1.67, 2.18	1.78	1.46, 2.18	2.04	1.84, 2.27	2.57	2.33, 2.83	0.10	0.093, 0.118
38	1.15	1.03, 1.29	1.40	1.20, 1.65	1.32	1.21, 1.44	1.54	1.42, 1.68	0.04	0.033, 0.050
39	1.00	0.90, 1.10	1.17	1.02, 1.35	1.08	1.00, 1.17	1.17	1.09, 1.27	0.02	0.013, 0.028
Female infant	0.76	0.70, 0.82	0.80	0.72, 0.90	0.79	0.74, 0.84	0.80	0.75, 0.85	−0.08	−0.086, −0.074
Mother's race/ethnicity ^f										
Black, non-Hispanic	1.07	0.94, 1.22	1.29	1.05, 1.59	1.17	1.06, 1.30	1.24	1.12, 1.37	−0.01	−0.021, 0.000
Hispanic	0.90	0.80, 1.02	1.31	1.10, 1.59	0.93	0.85, 1.03	1.25	1.14, 1.37	0.10	0.099, 0.119
Other	0.85	0.73, 0.99	1.83	1.52, 2.22	0.88	0.78, 0.99	1.36	1.22, 1.53	0.07	0.063, 0.086
Mother's age, years ^g										
<20	1.02	0.90, 1.16	0.96	0.80, 1.16	0.98	0.89, 1.09	0.92	0.84, 1.01	−0.006	−0.017, 0.003
≥35	0.92	0.80, 1.07	1.04	0.85, 1.29	0.93	0.84, 1.04	0.97	0.87, 1.09	0.0009	−0.010, 0.011
Mother US-born	0.95	0.86, 1.06	0.67	0.58, 0.79	1.02	0.94, 1.11	0.95	0.88, 1.03	−0.03	−0.039, −0.023
Mother's education ^h										
Not a high-school graduate	1.01	0.88, 1.16	0.99	0.81, 1.22	1.06	0.95, 1.19	1.16	1.05, 1.28	−0.01	−0.027, −0.004
Some college	0.93	0.83, 1.05	0.96	0.81, 1.16	0.88	0.81, 0.97	0.87	0.80, 0.96	−0.004	−0.013, 0.004
College graduate	0.86	0.76, 0.96	1.05	0.88, 1.25	0.93	0.85, 1.02	0.84	0.77, 0.92	−0.01	−0.026, −0.008
Mother married	0.85	0.76, 0.95	0.88	0.75, 1.05	0.88	0.81, 0.97	0.81	0.75, 0.89	−0.01	−0.024, −0.006
Medicaid was payer	0.91	0.81, 1.01	1.04	0.89, 1.22	0.89	0.82, 0.97	1.06	0.98, 1.15	0.02	0.016, 0.034
Trimester prenatal care initiated ⁱ										
Second	1.02	0.91, 1.14	1.00	0.85, 1.18	1.01	0.93, 1.11	1.09	1.00, 1.19	0.03	0.026, 0.044
Third or never	1.16	0.97, 1.39	1.09	0.84, 1.43	1.18	1.02, 1.36	1.35	1.19, 1.53	0.07	0.058, 0.088
Smoked cigarettes	0.80	0.67, 0.95	0.82	0.61, 1.11	0.94	0.83, 1.07	1.17	1.04, 1.32	−0.01	−0.024, 0.001

Abbreviations: CI, confidence interval; NICU, neonatal intensive care unit; OLS, ordinary least squares; OR, odds ratio.

^a All models included controls for infant's year of birth and sex, as well as mother's race/ethnicity, age, nativity, marital status, education, and smoking status. We also included controls for whether the birth was paid for by Medicaid and the trimester in which prenatal care was initiated. Sample includes singleton first births, gestational age of 37–40 weeks, with no labor trial (except when labor was induced or resulted in a noninduced vaginal delivery), and no medical risk factors or labor/delivery complications recorded in birth record (exception for inductions that resulted in cesarean deliveries, for which mothers could have labor/delivery complications). Data sources: New Jersey birth and hospital discharge records (25, 26).

^b Assessed via logit; coefficients reported as odds ratios.

^c Assessed via OLS.

^d Reference category is vaginal, not induced.

^e Reference category is 40 weeks.

^f Reference category is white, non-Hispanic.

^g Reference category is ages 20–34 years.

^h Reference category is high-school graduate or equivalent.

ⁱ Reference category is first trimester.

newborn hospitalization by more than one-third (odds ratio = 1.36), and increased neonatal hospitalization costs by 67% ($e^{0.51} = 1.67$). Other than for hospital charges, the corresponding associations were slightly larger for cesarean deliveries following inductions than for cesarean deliveries with no labor trial.

Associations with neonatal outcomes were smaller for vaginal induced births than for cesarean deliveries but still statistically significant. No delivery method was independently associated with jaundice. These associations were net of GA, which had large independent associations with outcomes. Each additional

Figure 3. Adjusted proportions and 95% confidence intervals of neonatal outcomes according to delivery method and week of gestational age, among low-risk births, New Jersey 1997–2011. Figures are proportions adjusted for covariates indicated in Table 2. A) Respiratory condition; B) jaundice; C) neonatal intensive care unit stay; D) extended hospital stay; E) log hospital charges. Sample includes singleton first births, gestational age of 37–40 weeks, with no labor trial (except when labor was induced or resulted in a noninduced vaginal delivery), and no medical risk factors or labor/delivery complications recorded in birth record (exception for inductions that resulted in cesarean delivery, for which mothers could have labor/delivery complications). Data sources: New Jersey birth and hospital discharge records (25, 26).

week of GA (through 39 weeks) was associated with lower odds of neonatal jaundice, NICU stay, and extended newborn stay, as well as lower newborn hospital charges; for respiratory conditions, the association with GA was significant only through 38 weeks.

In corresponding models of associations between delivery methods and neonatal outcomes according to week of GA (Figure 3), those between cesarean deliveries and neonatal outcomes other than jaundice (Figure 3A, 3C, 3D, and 3E) were largest at 37 weeks and still present at 40 weeks for cesarean deliveries following inductions. Adverse associations between cesarean deliveries with no labor trial and both NICU stays (Figure 3C) and hospital charges (Figure 3E) were also statistically significant through 40 weeks.

Estimates were insensitive to using alternative established measures of GA, controlling for fewer factors or controlling for hospital of birth in addition to the other covariates, using the Joint Commission criteria to identify the low-risk sample instead of the more conservative algorithm, and including cases with spontaneous labor prior to cesarean delivery (which had similar estimates to those for cesarean delivery with no labor trial). In models that allowed for labor/delivery complications regardless of delivery method, the estimated associations between interventions and neonatal outcomes became smaller but the patterns and significance persisted.

DISCUSSION

Elective deliveries in low-risk full-term pregnancies more than doubled in New Jersey between 1997 and 2011 and were associated with adverse neonatal outcomes and increased utilization of health-care resources. Cesarean deliveries—with no labor trial or following inductions—almost doubled the odds of a neonatal respiratory condition and a NICU stay, increased the odds of an extended newborn hospitalization, and increased newborn hospital charges. Although the associations between induced vaginal deliveries and neonatal outcomes were smaller than those between cesarean deliveries (with no labor trial or following inductions) and neonatal outcomes, over half of the inductions were followed by cesarean deliveries, and our findings suggest that decisions to induce in those cases led to compromised neonatal health and substantially increased health-care costs.

Professional guidelines and initiatives encouraging pregnant women and health-care providers to wait until 39 weeks before intervening might have attenuated the sharp increases in cesarean deliveries and inductions in the United States and New Jersey, which leveled off after about 2006. That is, by encouraging delays, the guidelines might have increased the likelihood of spontaneous vaginal deliveries. However, cesarean deliveries and inductions remain at historic highs and were associated with adverse neonatal outcomes even beyond the recommended 39-week threshold for delaying interventions. Although the ARRIVE trial found that induction at 39 weeks was associated with significantly lower frequency of cesarean delivery compared with expectant management among women with low-risk pregnancies who did not plan to have cesarean deliveries (18), cesarean deliveries following inductions were common in the low-risk population we studied and were associated with

adverse outcomes even at 40 weeks. Unless it can be determined in advance that an induction has a high probability of success (i.e., the case meets the criteria for participation in the ARRIVE trial), our findings suggest that for many women there are benefits to waiting beyond 39 weeks for inductions as well as cesarean deliveries and avoiding these interventions altogether when not medically necessary.

Elective deliveries might lead to longer-term child health complications that we have not considered in this study. Cesarean deliveries have been associated with child asthma and obesity (31); neonatal respiratory conditions have been linked to adverse development (32, 33); and NICU stays might adversely affect infants through mechanical sound and light exposures (34, 35). Thus, by focusing on neonatal outcomes, we might have underestimated the associations between elective deliveries and adverse child outcomes. In addition, elective deliveries can result in maternal morbidities and costs, aside from direct costs associated with the procedures (e.g., cesarean deliveries confer maternal risks accompanying surgery and induced contractions increase the use of epidural anesthesia and vacuum- or forceps-assisted deliveries (36)). Thus, our findings for neonatal morbidities and costs might not reflect all relevant adverse effects of elective deliveries.

The present study is subject to certain limitations. First, the observed associations between delivery methods and neonatal outcomes might not reflect causal effects. Randomized controlled trials of the effects of cesarean deliveries in low-risk pregnancies are neither feasible nor ethical. Our approach of using a stringent low-risk sample directly minimizes selection into elective deliveries according to obstetrical risk, and we controlled for a rich set of relevant covariates. Second, neonates might remain in the hospital because their mothers have delivery-related complications; it is therefore possible that neonatal hospital stays and charges partially reflect effects of obstetrical interventions on the mother rather than the child. Third, GA is not measured with perfect accuracy. Despite the limitations, measures of GA are widely used metrics in clinical practice, research, and surveillance, and our results were insensitive to alternative measures of GA. Fourth, our coding of low-risk pregnancies, while based on professional guidelines and discharge diagnoses and designed to minimize false-positive classification, does not reflect case-by-case clinical judgments. Additionally, the Joint Commission guidelines for “Contraindications to Vaginal Delivery” exclude patients enrolled in a clinical trial from the relevant population, and we were unable to incorporate that information. Finally, the findings are from one state, New Jersey, which had the highest rate of cesarean deliveries in the United States in 2013 (38.4%) but a rate of inductions (19.1%) that was lower than the national rate of 23% that same year (1, 25).

Overall, the findings from our study suggest that reducing elective cesarean deliveries and inductions in low-risk full-term pregnancies would yield substantial reductions in neonatal morbidities and costs. Medically unnecessary obstetrical interventions are costly in terms of health-care dollars and appear to take a toll on neonatal health, even at 39 and 40 weeks’ gestation. Guidelines to delay deliveries until 39 weeks appear to have attenuated, but not reversed, the dramatic increases in cesarean deliveries and inductions that took place over recent decades but might have had the unintentional effect of encouraging interventions at 39 weeks that otherwise might have occurred

later or not at all. Our findings suggest that delaying beyond 39 weeks and avoiding delivery interventions when not medically necessary would result in improvements in infant health and associated health-care cost savings.

ACKNOWLEDGMENTS

Author affiliations: School of Social Work, Columbia University, New York, New York (Julien O. Teitler); Steve Hicks School of Social Work, University of Texas at Austin, Austin, Texas (Rayven Plaza); Department of Pediatrics, Robert Wood Johnson Medical School, Rutgers University, New Brunswick, New Jersey (Thomas Hegyi, Nancy E. Reichman); New Jersey Department of Health, Trenton, New Jersey (Lakota Kruse); and Child Health Institute of New Jersey, Robert Wood Johnson Medical School, Rutgers University, New Brunswick, New Jersey (Nancy E. Reichman).

This work was funded by the *Eunice Kennedy Shriver* National Institute of Child Health and Human Development of the National Institutes of Health (awards R01HD090119 and P2CHD058486). The research was also supported by the Robert Wood Johnson Foundation through its support of the Child Health Institute of New Jersey at Robert Wood Johnson Medical School, Rutgers University (grants 67038 and 74260).

The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health or the Robert Wood Johnson Foundation.

Conflict of interest: none declared.

REFERENCES

1. National Center for Health Statistics, Centers for Disease Control and Prevention. Vital Statistics Online Data Portal [public use birth data files for 1997 through 2011]. https://www.cdc.gov/nchs/data_access/vitalstatsonline.htm. Accessed December 14, 2014 through December 4, 2018.
2. MacDorman MF, Menacker F, Declercq E. Cesarean birth in the United States: epidemiology, trends, and outcomes. *Clin Perinatol*. 2008;35(2):293–307.
3. Main EK, Morton CH, Hopkins D, et al. Cesarean Deliveries, Outcomes, and Opportunities for Change in California: Toward a Public Agenda for Maternity Care Safety and Quality. Palo Alto, CA: California Maternal Quality Care Collaborative; 2011. <https://www.cmqcc.org/resource/cesarean-deliveries-outcomes-and-opportunities-change-california-toward-public-agenda>. Accessed September 12, 2018.
4. March of Dimes. *Maternal, Infant, and Child Health in the United States: March of Dimes Data Book for Policy Makers*. Washington, D.C: March of Dimes; 2016. 8–14.
5. Infoplease. Infant Mortality Rates. <https://www.infoplease.com/us/mortality/infant-mortality-rates-1950-2010/>. Accessed March 30, 2018.
6. Hoyert DL. Maternal mortality and related concepts. *Vital Health Stat* 3. 2007;(33):1–3.
7. Buckles K, Guldi M. Worth the wait? The effect of early term birth on maternal and infant health. *J Policy Anal Manage*. 2017;36(4):748–772.
8. Reichman NE, Teitler JO, Moullin S, et al. Late-preterm birth and neonatal morbidities: population-level and within-family estimates. *Ann Epidemiol*. 2015;25(2):126–132.
9. Rose O, Blanco E, Martinez SM, et al. Developmental scores at 1 year with increasing gestational age, 37–41 weeks. *Pediatrics*. 2013;131(5):e1475–e1481.
10. Dueker G, Chen J, Cowling C, et al. Early developmental outcomes predicted by gestational age from 35 to 41 weeks. *Early Hum Dev*. 2016;103:85–90.
11. Noble KG, Fifer WP, Rauh VA, et al. Academic achievement varies with gestational age among children born at term. *Pediatrics*. 2012;130(2):e257–e264.
12. Tutdibi E, Gries K, Bücheler M, et al. Impact of labor on outcomes in transient tachypnea of the newborn: population-based study. *Pediatrics*. 2010;125(3):e577–e583.
13. Azad MB, Konya T, Maughan H, et al. Gut microbiota of healthy Canadian infants: profiles by mode of delivery and infant diet at 4 months. *CMAJ*. 2013;185(5):385–394.
14. Seyb ST, Berka RJ, Socol ML, et al. Risk of cesarean delivery with elective induction of labor at term in nulliparous women. *Obstet Gynecol*. 1999;94(4):600–607.
15. Warren JB, Anderson JM. Newborn respiratory disorders. *Pediatr Rev*. 2010;31(12):487–495.
16. March of Dimes. Pregnancy. <http://www.marchofdimes.com/pregnancy/pregnancy.html>. Accessed March 30, 2018.
17. Watchko JF. Identification of neonates at risk for hazardous hyperbilirubinemia: emerging clinical insights. *Pediatr Clin North Am*. 2009;56(3):671–687.
18. Grobman WA, Rice MM, Reddy UM, et al. Labor induction versus expectant management in low-risk nulliparous women. *N Engl J Med*. 2018;379(6):513–523.
19. Signore C, Klebanoff M. Neonatal morbidity and mortality after elective cesarean delivery. *Clin Perinatol*. 2008;35(2):361–371.
20. National Quality Forum. *Perinatal and Reproductive Health Endorsement Maintenance: Technical Report*. Washington, DC; 2012. http://www.qualityforum.org/Publications/2012/06/Perinatal_and_Reproductive_Health_Endorsement_Maintenance.aspx. Accessed September 12, 2018.
21. National Quality Forum. *Playbook for the Successful Elimination of Early Elective Deliveries*. Washington, DC; 2014. https://www.qualityforum.org/publications/2014/08/early_elective_delivery_playbook_-_Maternity_action_team.aspx. Accessed September 12, 2018.
22. Kozhimannil KB, Macheras M, Lorch SA. Trends in childbirth before 39 weeks' gestation without medical indication. *Med Care*. 2014;52(7):649–657.
23. Fowler TT, Schiff J, Applegate MS, et al. Early elective deliveries accounted for nearly 9 percent of births paid for by Medicaid. *Health Aff (Millwood)*. 2014;33(12):2170–2178.
24. Dahlen HM, McCullough JM, Fertig AR, et al. Texas Medicaid payment reform: fewer early elective deliveries and increased gestational age and birthweight. *Health Aff (Millwood)*. 2017;36(3):460–467.
25. New Jersey Department of Health. New Jersey State Health Assessment Data: birth data technical notes. <https://www-doh.state.nj.us/doh-shad/query/BirthQueryTechNotes.html>. Accessed December 7, 2018.
26. New Jersey Department of Health. Health Care Quality Assessment: NJ Hospital Discharge Data Collection System. <https://www.nj.gov/health/healthcarequality/health-care-professionals/njddcs/>. Accessed December 7, 2018.

27. Spong CY, Berghella V, Wenstrom KD, et al. Preventing the first cesarean delivery: summary of a joint *Eunice Kennedy Shriver* National Institute of Child Health and Human Development, Society for Maternal-Fetal Medicine, and American College of Obstetricians and Gynecologists Workshop. *Obstet Gynecol.* 2012;120(5):1181–1193.
28. Clark SL, Meyers JA, Milton CG, et al. Validation of the joint commission exclusion criteria for elective early-term delivery. *Obstet Gynecol.* 2014;123(1):29–33.
29. Mozurkewich E, Chilimigras J, Koepke E, et al. Indications for induction of labour: a best-evidence review. *BJOG.* 2009;116(5):626–636.
30. Mustafa G, David RJ. Comparative accuracy of clinical estimate versus menstrual gestational age in computerized birth certificates. *Public Health Rep.* 2001;116(1):15–21.
31. Keag OE, Norman JE, Stock SJ. Long-term risks and benefits associated with cesarean delivery for mother, baby, and subsequent pregnancies: systematic review and meta-analysis. *PLoS Med.* 2018;15(1):e1002494.
32. Stevens CP, Raz S, Sander CJ. Peripartum hypoxic risk and cognitive outcome: a study of term and preterm birth children at early school age. *Neuropsychology.* 1999;13(4):598–608.
33. Lipkin PH, Davidson D, Spivak L, et al. Neurodevelopmental and medical outcomes of persistent pulmonary hypertension in term newborns treated with nitric oxide. *J Pediatr.* 2002;140(3):306–310.
34. Blackburn S. Environmental impact of the NICU on developmental outcomes. *J Pediatr Nurs.* 1998;13(5):279–289.
35. Gray L, Philbin MK. Effects of the neonatal intensive care unit on auditory attention and distraction. *Clin Perinatol.* 2004;31(2):243–260.
36. American Public Health Association. *Reducing Non Medically Indicated Elective Inductions of Labor*. Policy Number: 20141; November 18, 2014. <https://www.apha.org/policies-and-advocacy/public-health-policy-statements/policy-database/2015/01/23/09/03/reducing-non-medically-indicated-elective-inductions-of-labor>. Accessed September 12, 2018.