



Birth history as a predictor of adverse birth outcomes: Evidence from state vital statistics data

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ABSTRACT

One of the most important predictors of preterm births (PTBs) or low-birth-weight births (LBWBs) is whether a mother has had a history of these birth outcomes. This study examined how different characterizations of birth history (e.g., any previous incidence of PTBs or LBWBs, immediate previous birth that was preterm or of low birth weight, and number of previous PTBs or LBWBs) were associated with PTBs or LBWBs. Based on birth records ($n = 98,776$) reported to the vital statistics electronic registration system in Nebraska from 2005 to 2014, mothers with a history of PTBs or LBWBs were more likely to have recurrences of these outcomes than those who did not have any history of PTBs or LBWBs. The adjusted odds ratios for recurrent PTBs ranged from 2.82 (95% CI: 2.62, 3.04) to 5.54 (95% CI: 4.67, 6.57) depending on how previous incidence of PTBs or LBWBs were characterized. The corresponding adjusted odds ratio for LBWBs ranged from 1.58 (95% CI: 1.43, 1.74) to 6.75 (95% CI: 4.96, 9.17). Relative to other measures used to characterize birth history, the use of number of previous PTBs or LBWBs allows for identifying mothers most vulnerable to recurrences of these birth outcomes. To help identify mothers at risk for future PTBs or LBWBs, it is beneficial to develop state-wide surveillance of recurrences for adverse birth outcomes which is feasible by integrating all separated birth records for the same mother using vital statistics data.

1. Introduction

Adverse birth outcomes, such as preterm births (PTBs, being born before the 37th week of gestation) and low-birthweight births (LBWBs, birthweight of fewer than 2500 g or 5.5 lbs.), is a significant public health issue in the United States. In 2015, about 1 in 10 newborns were preterm, and about 1 in 12 newborns were of low birthweight in the U.S. (Birthweight, 2017). These adverse birth outcomes represent the leading causes of infant mortality. Furthermore, infants who have low birthweight (LBW) or born before term are at increased risk for neurodevelopmental impairments and respiratory and gastrointestinal complications (Goldenberg et al., 2008). The annual economic burden due to these adverse birth outcomes was estimated to be more than \$26 billion, which included the costs for immediate and long-term medical care, early intervention, and lost productivity due to disabling conditions (Butler & Behrman, 2007).

One of the most important predictors of PTBs is whether a mother had a PTB before the current pregnancy (Adams et al., 2000; Grantz et al., 2015). The recurrence risk of a preterm singleton delivery ranges from 16 to 30.2% (Goldenberg et al., 2008; van Zijl et al., 2016). Similar findings also hold true in the incidence of LBWBs. Mothers who had a history of delivering very LBWBs (less than 1500 g) were far more likely to have subsequent LBWBs (Bratton et al., 1996). Among mothers with two previous LBWBs, almost half had LBW recurrences in following deliveries (Barros et al., 2006; Sclowitz et al., 2013). These findings underscore the importance of using birth history to identify mothers at risk for adverse birth outcomes and to develop targeted interventions that address underlying risk factors if possible. Despite an extensive body of literature documenting risk factors associated with PTBs or LBWBs, few studies have focused on the repetitions of PTBs or LBWBs (Sclowitz & Santos, 2016), and how vital statistics data regularly collected by state governments can be used to monitor recurrences of

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these outcomes and identify mothers most vulnerable to these recurrences based on birth history.

In this study, we used population-based vital statistics data at the state level to assess the associations between previous incidence of PTBs or LBWBs and birth outcomes of the most recent pregnancy among mothers with complete birth history and at least two singleton births. In particular, we explored how different characterizations of birth history (e.g., any previous incidence of PTBs or LBWBs, immediate previous birth that was preterm or of LBW, and number of previous PTBs or LBWBs) were associated with PTBs or LBWBs with or without controlling for selected covariates. Based on our study findings, we discussed the feasibility and promise of establishing state-wide surveillance on recurrence of PTB or LBWB and how this surveillance system can help inform the design and implementation of interventions that seek to reduce recurrence of these adverse birth outcomes among vulnerable women.

2. Methods

2.1. Data

Data on birth outcomes and characteristics of mothers in the State of Nebraska for the period from 2005 to 2014 were collected from birth records reported to the vital statistics electronic registration system at the Nebraska Department of Health and Human Services. A mother index, a numeric code assigned to each unique mother in the dataset, was created so that multiple births from the same mother could be tracked over time. The probabilistic record linkage software LinkPlus 2.0 was utilized for a deduplication process to self-match mothers with multiple children (matching by a mother's first/last name, date of birth, and a unique identifier (such as the mathematical transformation of the mother's social security number, if available)). This software was developed by the Centers for Disease Control and Prevention and was commonly used in detecting duplicative records or in linking health data from different sources. It automatically treats null or empty values as missing data and allows the user to indicate additional values to be treated as missing data (Centers for Disease Prevention and Control, n.d.). A matching score was selected as a cut off value to filter out mismatches, with a mismatch rate of less than 5% based on a quality check of 200 randomly selected records. Mothers without social security numbers were still matched on the other criteria; however, births from these mothers were less likely to be matched to other births in the dataset given their lower match scores.

Deliveries with birth weights less than 500 g or gestational age less than 22 weeks were excluded from the study sample. Additionally, any births that were out of the likely range of weight given their gestational age, based on Alexander et al.'s criteria, were removed (Alexander et al., 1996). Only singleton births were included in the dataset. Mothers with any non-singleton births or missing parities since 1995 (any parity less than maximum parity in the dataset for each mother) were removed from the dataset; records from 1995 to 2014 births of mothers in the sample were used to collect data on any previous birth outcomes to help create historical variables for the 2005–2014 births used in this study. The range 2005–2014 was selected because data for some important predictors were not collected before 2005. Births of first parity were ultimately removed from the final sample as they did not have historical data to predict birth outcome. The final study sample contained 98,776 singleton births of second parity or greater with complete, verifiable birth histories from 72,873 mothers.

2.2. Measurements

2.2.1. Outcomes

There were two dependent variables in this study. One was PTBs, defined as live births with a gestational age of fewer than 37 weeks. The other dependent variable was LBWBs, defined as births weighing less

than 2500 g. While PTB and LBWB are closely correlated with each other, they are not identical. Some PTBs can still have normal birth weights, and some full-term births can result in low birth weight.

2.2.2. Historical predictors

In order to use previous birth outcomes as predictor variables, historical variables were created and fell into three general types, where each type had a separate variable for preterm birth and low birthweight (both of which had the same definition as the outcome variables): 1. Any previous PTB or LBWB, looking at any of a mother's births before her most recent birth (yes/no), 2. Immediate previous PTB or LBWB, the outcome of the birth that immediately preceded her most recent birth (yes/no), and 3. The number of previous PTBs and LBWBs (0, 1, or 2 or more).

2.2.3. Control variables

Since birth records from 2005 to 2014 were used in the analysis, a categorical variable "Birth Year" was created to denote the period in which the baby was born (2005–2009 or 2010–2014). Mother's demographics were characterized by age (< 18 years, 18–35 years, or 36+ years), race/ethnicity (Hispanic, or non-Hispanic (NH) White, NH Black, NH Asian, NH Native American, or NH Other), marital status (married or unmarried), and urban or rural residence based on the county where the mother lived.

Two variables were related to mother's economic status. One was mother's education (< 12 years, high school degree, some college, or college degree or above). The other variable was mother's health insurance coverage at birth (Medicaid, private, self-pay, or other).

Several variables were used to characterize mother's health or health behavior before or during pregnancy, including pre-pregnancy BMI (underweight, normal weight, overweight, or obese), pre-pregnancy diabetes (yes or no), chronic hypertension (yes or no), tobacco use during pregnancy, pregnancy induced diabetes (yes or no), and pregnancy-associated hypertension (yes or no). We also included variables on whether birth was delivered through C-section, parity (2, 3, or 4 or above), and birth interval (18 months or less vs. 19 months or longer).

2.3. Statistical analysis

Frequencies and percentages of all variables used in the analysis were calculated. Cross-tabulations were generated, and chi-square tests were calculated to assess the associations between each of the six birth history variables and PTBs or LBWBs. Generalized estimating equations (GEE) were used to determine the odds of PTBs or LBWBs based on history of PTBs or LBWBs with (adjusted odds ratio) or without (unadjusted odds ratio) controlling for the effect of selected variables on mother's demographics, SES, health, and health behavior before or during pregnancy, C-section use, parity, and birth interval.

The GEE models in our analysis used alternating logistic regressions with exchangeable log odds ratios to account for the repeated observations from mothers with more than one birth represented in the dataset (Carey et al., 1993). Areas under the Receiver Operating Characteristic (ROC) curve (AUC), along with Quasi-likelihood under the Independence Model Criteria (QICu), were used to compare prediction between different models. All statistical analyses were run using SAS software version 9.4 (SAS Institute Inc., 2013), and p-values less than < 0.05 were considered statistically significant.

3. Results

The frequency distribution of all the variables used in the analysis is listed in Table 1. Regarding the two dependent variables, 7.9% of singleton births in the sample were PTBs, and 3.7% were LBWBs.

About 8.4% of the current or most recent births in the sample were immediately preceded by a PTB, whereas 4.8% were immediately

Table 1
A description of the variables used in the analysis: Nebraska 2005–2014.

Variables	N	Percent
Birth outcomes		
Preterm		
Less than 37 weeks	7805	7.9
37 + weeks	90,971	92.0
Low birth weight		
< 2500 g	3744	3.7
2500 + g	95,032	96.2
Birth history		
Immediate previous birth gestational age		
Less than 37 weeks	8323	8.4
37 + weeks	90,453	91.5
Any previous preterm birth		
No	87,346	88.4
Yes	11,430	11.5
Immediate previous birth weight		
< 2500 g	4817	4.8
2500 + g	93,959	95.1
Any previous low birth weight birth		
No	92,048	93.1
Yes	6728	6.8
Number of previous preterm births		
0	87,346	88.4
1	10,474	10.6
2 +	956	0.9
Number of previous low birth weight births		
0	92,048	93.1
1	6264	6.3
2 +	464	0.4
Other explanatory variables		
Birth year		
2005–2009	46,972	47.5
2010–2014	51,804	52.4
Race/ethnicity		
Non-Hispanic White	81,601	82.6
Non-Hispanic Black	5671	5.7
Hispanic	8599	8.7
Non-Hispanic Asian	1631	1.6
Non-Hispanic Native American	1038	1.0
Non-Hispanic Others	112	0.1
Mother's age		
< 18 years	229	0.2
18–35 years	90,510	91.6
36 + years	8036	8.1
Marital status of mother		
Married	73,655	74.5
Unmarried	25,120	25.4
Mother's education		
< 12 years	8474	8.5
High School Degree	18,672	18.9
Some College	36,781	37.2
College Degree +	34,788	35.2
Mother's health insurance coverage		
Medicaid	28,822	29.1
Private	62,756	63.5
Self-pay	2999	3.0
Other	4199	4.2
Tobacco used during pregnancy		
Yes	14,071	14.2
No	84,652	85.7
Urban/rural of mother's residence		
Urban	53,024	53.6
Rural	45,752	46.3
Mother's pre-pregnancy BMI		
Underweight	2990	3.0
Normal weight	47,128	47.7
Overweight	24,511	24.8
Obese	23,222	23.5
Pre-pregnancy diabetes		
Yes	637	0.6
No	98,139	99.3
Pregnancy induced diabetes		
Yes	4540	4.5
No	94,236	95.4
Chronic hypertension		

Table 1 (continued)

Variables	N	Percent
Yes	828	0.8
No	97,948	99.1
Pregnancy associated hypertension		
Yes	2589	2.6
No	96,187	97.3
C-section		
Yes	29,277	29.6
No	69,499	70.3
Parity		
2	62,372	63.1
3	26,343	26.6
4 +	10,061	10.1
Birth interval		
18 months or less	11,436	11.5
19+ months	87,340	88.4

Note: The percentages in this table usually do not add up to 100% since there are missing values.

preceded by a LBWB. In terms of current births being preceded by any previous PTB or LBWB, 11.5% of current births in the sample were preceded by at least one PTB, and 6.8% were preceded by at least one LBWB. Over 88% of the mothers did not have any previous PTB or LBWB, as compared to 10.6% of mothers who had one PTB, and 0.9% who had two or more PTBs. The corresponding percentages in the case of number of previous LBWBs were 93.1%, 6.3%, and 0.4%, respectively.

There were considerable variations regarding mothers' health and health behavior. Close to half of the mothers were either overweight or obese before pregnancy, and 3% were underweight. Over 14% of the mothers reported tobacco use during pregnancy. In terms of diabetes prevalence, 0.6% of the mothers had pre-pregnancy diabetes, and 4.5% had pregnancy induced diabetes. About 0.8% of the mothers had chronic hypertension, and 2.6% had pregnancy-associated hypertension. Almost 30% of the births were delivered via C-sections. Over 88% of the mothers had a birth interval of 19 months or longer between their most recent birth and the previous birth, whereas 11.5% of the mothers had a birth interval of 18 months or less.

Bivariate associations between history of PTBs or LBWBs and outcomes of the most recent birth were illustrated in Table 2. The results revealed that having previous PTB(s) or LBWB(s) was strongly associated with the incidence of PTB or LBWB in the subsequent birth ($p < 0.0001$ in all cases). Among mothers who had at least one previous LBWB, 16.7% of them had a LBWB in their most recent birth, as compared to 2.8% among mothers with no history of LBWBs. Among mothers who had at least one previous PTB, the recurrence rate of PTB in the subsequent birth was 19.9%, as compared to 6.3% among mothers with no history of PTB. Similar findings were revealed when only the immediate previous PTB or LBWB was used to replace any previous PTB or LBWB to examine these associations.

There was a significant association between the number of previous PTBs or LBWBs and recurrence rates of PTBs or LBWBs in subsequent births. For example, among mothers with no previous PTBs, 6.3% of them had PTBs in their subsequent birth, as compared to 18.7% among mothers with one previous PTB and 32.5% among mothers with two or more PTBs. A similar association was found between number of previous LBWBs and the recurrence rates of LBWB.

Table 3 presents the unadjusted and adjusted odds ratios of PTBs or LBWBs associated with each of the six birth history variables. Overall, these results confirmed the highly significant associations between previous PTBs or LBWBs and recurrence of these adverse birth outcomes as revealed in Table 2 ($p < 0.001$ in all estimated odds ratios). For instance, based on unadjusted odds ratio estimates, the odds for mothers who had any previous PTB to have a subsequent PTB was 3.41 times as much as mothers without any previous PTB. The corresponding

Table 2
Associations between birth history and adverse birth outcomes: a bivariate analysis of vital statistics data in Nebraska 2005–2014.

	Preterm birth					Low birth weight birth				
	Yes		No		Chi-square p-Value	Yes		No		Chi-square p-Value
	N	%	N	%		N	%	N	%	
Any previous low birth weight birth										
Yes	1459	21.6	5269	78.3	< 0.001	1129	16.7	5599	83.2	< 0.001
No	6346	6.8	85,702	93.1		2615	2.8	89,433	97.1	
Any previous preterm birth										
Yes	2279	19.9	9151	80.0	< 0.001	1119	9.7	10,311	90.2	< 0.001
No	5526	6.3	81,820	93.6		2625	3.0	84,721	96.9	
Immediate previous low birth weight birth										
Yes	1171	24.3	3646	75.6	< 0.001	933	19.3	3884	80.6	< 0.001
No	6634	7.0	87,325	92.9		2811	2.9	91,148	97.0	
Immediate previous preterm birth										
Yes	1857	22.3	6466	77.6	< 0.001	920	11.0	7403	88.9	< 0.001
No	5948	6.5	84,505	93.4		2824	3.1	87,629	96.8	
Number of previous low birth weight births										
0	6346	6.8	85,702	93.1	< 0.001	2615	2.8	89,433	97.1	< 0.001
1	1283	20.4	4981	79.5		959	15.3	5305	84.6	
2+	176	37.9	288	62.0		170	36.6	294	63.3	
Number of previous preterm births										
0	5526	6.3	81,820	93.6	< 0.001	2625	3.0	84,721	96.9	< 0.001
1	1968	18.7	8506	81.2		961	9.1	9513	90.8	
2+	311	32.5	645	67.4		158	16.5	798	83.4	

adjusted odds ratio was 3.07 when all selected variables were controlled.

The association between the number of previous PTBs or LBWBs and recurrence rates of these outcomes, as revealed in the bivariate associations in Table 2, were further confirmed when the effect of selected variables was controlled. Relative to mothers who had no previous PTBs, the odds for mothers who had one previous PTB to have a subsequent PTB became 2.99 times as much and the corresponding odds increased to 5.54 times as much for mothers who had at least two previous PTBs. Similar findings were also revealed in the recurrences of LBWBs.

Area Under the ROC Curves (AUCs) is presented alongside

unadjusted and adjusted odds ratios related to the historical variables in Table 3, as indicators of the predictive ability of the model associated with each variable. For reference, the AUC for a model with all adjustment variables and no historical variables is 0.639 for PTBs and 0.887 for LBWBs. The results suggested that historical variables related to PTBs tended to be slightly more relevant predictors of PTB recurrences than historical LBWB variables, and similarly, historical variables associated with LBWBs tended to be slightly better predictors of LBWB recurrences than historical PTB variables. In both cases, the AUC values were slightly larger when congruent birth outcomes were used, suggesting better model fitness. There were virtually no differences between the use of immediate previous PTB or LBWB and the use

Table 3
Associations between birth history and adverse birth outcomes expressed as unadjusted and adjusted odds ratios^a: Nebraska 2005–2014.

Variables on birth history	Preterm births				Low-birth-weight births			
	Unadjusted OR (95% CI)	AUC	Adjusted OR (95% CI)	AUC	Unadjusted OR (95% CI)	AUC	Adjusted OR (95% CI)	AUC
Any previous low birth weight		0.57		0.67		0.62		0.90
No	1.00 (Ref)		1.00 (Ref)		1.00 (Ref)		1.00 (Ref)	
Yes	3.43 (3.20, 3.68)***		2.82 (2.62, 3.04)***		6.30 (5.79, 6.85)***		3.27 (2.94, 3.63)***	
Any previous preterm birth		0.60		0.69		0.60		0.89
No	1.00 (Ref)		1.00 (Ref)		1.00 (Ref)		1.00 (Ref)	
Yes	3.41 (3.22, 3.61)***		3.07 (2.89, 3.26)***		3.11 (2.86, 3.37)***		1.58 (1.43, 1.74)***	
Immediate previous low birth weight		0.56		0.66		0.60		0.90
No	1.00 (Ref)		1.00 (Ref)		1.00 (Ref)		1.00 (Ref)	
Yes	3.58 (3.31, 3.87)***		2.99 (2.76, 3.24)***		7.04 (6.44, 7.71)***		3.47 (3.09, 3.89)***	
Immediate previous preterm birth		0.58		0.68		0.58		0.89
No	1.00 (Ref)		1.00 (Ref)		1.00 (Ref)		1.00 (Ref)	
Yes	3.78 (3.56, 4.02)***		3.41 (3.20, 3.64)***		3.16 (2.90, 3.46)***		1.62 (1.46, 1.80)***	
Total number of previous low birth weight		0.57		0.67		0.62		0.90
0	1.00 (Ref)		1.00 (Ref)		1.00 (Ref)		1.00 (Ref)	
1	3.29 (3.06, 3.54)***		2.73 (2.53, 2.94)***		6.03 (5.56, 6.55)***		3.14 (2.82, 3.49)***	
2+	5.93 (4.77, 7.38)***		4.61 (3.69, 5.77)***		16.45 (13.14, 20.59)***		6.75 (4.96, 9.17)***	
Total number of previous preterm births		0.60		0.69		0.60		0.89
0	1.00 (Ref)		1.00 (Ref)		1.00 (Ref)		1.00 (Ref)	
1	3.31 (3.12, 3.50)***		2.99 (2.82, 3.18)***		3.01 (2.77, 3.28)***		1.55 (1.40, 1.71)***	
2+	6.04 (5.16, 7.07)***		5.54 (4.67, 6.57)***		4.36 (3.45, 5.52)***		1.98 (1.54, 2.54)***	

^a Each adjusted odds ratio associated with a certain birth history variable was estimated after controlling for the effect of birth periods, mother's age, race/ethnicity, marital status, education, health insurance coverage, tobacco use during pregnancy, urban/rural, chronic hypertension, pregnancy associated hypertension, pre-pregnancy diabetes, pregnancy-induced diabetes, C-section, parity and birth interval.

*** p < 0.001. AUC = Area Under Curve for model associated with historical variable.

of any previous PTB or LBWB in predicting recurrence of these birth outcomes. Models with the 'number' of previous adverse birth outcomes, concordant with the outcome of interest, yielded the best (i.e., lowest) QICu values, suggesting relatively better model fitness.

4. Discussion and conclusions

Birth data constitute an integral component of vital statistics routinely collected at the state level; however, birth records of the same mother are not necessarily linked to each other in current birth registries. Isolated birth records might not be very instrumental when it comes to assessing disparities in birth outcomes since the risk of having adverse birth outcomes is more concentrated among mothers with a history of these birth outcomes. By establishing birth history through a mother index approach to linking all birth records of the same mother, our study findings highlight the usefulness of identifying mothers at risk for PTB or LBWB at the population level. The mother-index approach, as exemplified by this study, allows for examining the birth history of a mother and assessing the risk for PTB or LBWB in future pregnancies.

Knowing a woman's risk for a subsequent PTB or LBWB is only useful if interventions are available to mitigate risk. Strategies have been identified that are suitable for use in clinical practice and can be expected to safely reduce the risk of these outcomes (Newnham et al., 2014). Although not all of these strategies can be easily implemented at the level of individual patients (i.e., 17-progesterone therapy, cervical cerclage, judicious use of fertility treatments), control of smoking and tobacco use should be a significant priority. Smoking during pregnancy causes preterm birth in addition to a dose-dependent reduction in birthweight (Goldstein et al., 1964; Colicchia & Simhan, 2016). Smoking cessation interventions can be effective in reducing the rates of preterm births (Simpson, 1957). With 14% of the mothers in our study reporting smoking during pregnancy, tobacco control remains a relevant focus for risk management.

Our use of the mother-index approach to identifying mothers at risk for future PTBs or LBWBs based on vital statistics data points to the feasibility and promise of establishing state-wide surveillance of recurrence of PTB and LBWB. This surveillance system should consist of a state level public health agency that can monitor trends in recurrence of adverse birth outcomes based on analysis of vital statistics data, a network of stakeholders who can make informed decisions over developing and implementing specific interventions to reduce recurrence of PTB and LBWB, and an effective communication channel that allows for timely dissemination of information. For example, there was evidence that providing prenatal care coordination for pregnant women covered by Medicaid was associated with reduced risk of PTB and LBWB (Van Dijk et al., 2011). If the state surveillance on birth outcomes can capture this impact for Medicaid mothers based on solid findings, then it would be important for these findings to be disseminated to policymakers, care providers, and other payers in a timely fashion so that more pregnant women could potentially benefit from prenatal care coordination and reduce their risk for having adverse birth outcomes.

Consistent with findings from other studies (Goldenberg et al., 2008; Adams et al., 2000; Grantz et al., 2015; van Zijl et al., 2016; Bratton et al., 1996; Barros et al., 2006; Sclowitz et al., 2013), we found that mothers with a history of PTB or LBWB were more likely to have recurrence of these adverse birth outcomes than those without histories of PTB or LBWB. Findings from our study add to previous studies by assessing the predictability of different indicators of birth history for the odds of PTB or LBWB of the most recent birth. In particular, we found evidence supporting the congruent use of indicators characterizing birth history and the focal current birth outcome under consideration in that previous PTB, relative to previous LBWB, better predicted PTB in the most recent birth. Similarly, this kind of congruence is also recommended when it comes to predicting the odds of LBWBs based on previous incidence of adverse birth outcomes.

Results from this study underscore the unique value of number of

previous PTBs or LBWBs in predicting future risk of these birth outcomes. While a dichotomized categorization of yes or no for history of adverse birth outcomes is helpful, it does not provide information as detailed as the number of previous PTBs or LBWBs since the latter also allows an examination of tremendously elevated risks associated with those mothers who had multiple adverse birth outcomes before. Although the percentages of mothers with multiple previous PTBs or LBWBs are rather small (less than 1% as indicated in this study), addressing the underlying causes of their recurrent PTBs or LBWBs is critical to reducing their risk for future recurrence of these outcomes. The observation that mothers with two or more previous PTBs or LBWBs had a much higher risk of recurrences of these birth outcomes in subsequent births than mothers with one previous PTB or LBWB, as reflected by findings from this study, is indicative of the lack of effectiveness of preventive measures at the population level. Health care providers need to consider this as they strive to collect needed information to gauge the risk of PTBs or LBWBs based on mother's birth history.

Several limitations of this study are noteworthy. First, the data used in this study contained no information on the specific causes of PTBs or LBWBs. Knowing the causes is important to understand the recurrences of these outcomes, which would then allow for the development of effective and targeted interventions to reduce recurrences. Some risk factors, such as health behaviors before or during pregnancy (e.g., smoking, alcohol use, illicit drug use, and unhealthy dietary behaviors), are relatively easier to address compared to genetic predispositions or chronic diseases such as diabetes or hypertension. Second, some of the data used in the study (e.g., smoking during pregnancy) were based on mothers' self-report. Therefore, recall biases or underreporting because of social desirability could be a potential issue (Phillips & Clancy, 1972). Finally, population-based vital statistics data on birth records as used in this study have some limitations, such as inconsistency in data collection over time, missing records, and lack of detailed codebook and documentation of sources of information. Despite these limitations, this study represents a rare effort in using state level population-based birth records to systematically examine the associations between the history of adverse birth outcomes and the recurrence of these outcomes and to assess the robustness of these associations by using alternative indicators of history of adverse birth outcomes and different modeling strategies.

Reducing future incidences of PTBs or LBWBs calls for more attention and services to mothers who have already had a history of these adverse birth outcomes. Recurrences of these outcomes become less likely when at-risk mothers are promptly identified, and underlying causes of PTBs or LBWBs are addressed (Shapiro-Mendoza, 2016). When effective interventions are implemented at the population level (e.g., regulations that restrict the use of non-medically indicated or elective C-sections, new medical reimbursements for services to help women quit smoking, alcohol abuse, or the use of illicit drugs before or during pregnancy, and better access to prenatal care), recurrences of negative outcomes will decrease. These changes can be captured and reflected by birth records data collected at the state level. Findings from this study point to the promise of this data to be used for surveillance of recurrences of adverse birth outcomes at the state level and how the data could potentially help evaluate and guide strategies to reduce adverse birth outcomes among high-risk mothers.

Conflict of interest

The authors have no financial or any other conflict of interest to declare.

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References

- Adams, M.M., Elam-Evans, L.D., Wilson, H.G., Gilbertz, D.A., 2000. Rates of and factors associated with recurrence of preterm delivery. *J. Am. Med. Assoc.* 283 (12), 1591–1596.
- Alexander, G.R., Himes, J.H., Kaufman, R.B., Mor, J., Kogan, M., 1996. A United States national reference for fetal growth. *Obstet. Gynecol.* 87 (2), 163–168.
- Bratton, S.L., Shoultz, D.A., Williams, M.A., 1996. Recurrence risk of low birthweight deliveries among women with a prior very low birthweight delivery. *Am. J. Perinatol.* 13 (03), 147–150.
- Butler, A.S., Behrman, R.E., 2007. *Preterm Birth: Causes, Consequences, and Prevention*. National Academies Press.
- Carey, V., Zeger, S.L., Diggle, P., 1993. Modelling multivariate binary data with alternating logistic regressions. *Biometrika* 517–526.
- CDC, 2017. *Birthweight and Gestation*. Retrieved from. <https://www.cdc.gov/nchs/fastats/birthweight.htm>.
- Centers for Disease Prevention and Control Overview of Link Plus. <https://www.hcup-us.ahrq.gov/datainnovations/raceethnicitytoolkit/or17.pdf>, Accessed date: 27 March 2018.
- Colicchia, L.C., Simhan, H.N., 2016. Optimizing subsequent pregnancy outcomes for women with a prior preterm birth. *Am. J. Perinatol.* 33 (03), 267–275.
- Goldenberg, R.L., Culhane, J.F., Iams, J.D., Romero, R., 2008. Epidemiology and causes of preterm birth. *Lancet* 371 (9606), 75–84.
- Goldstein, H., Goldberg, I.D., Frazier, T.M., Davis, G.E., 1964. Cigarette smoking and prematurity: review. *Public Health Rep.* 79 (7), 553–560.
- Grantz, K.L., Hinkle, S.N., Mendola, P., Sjaarda, L.A., Leishear, K., Albert, P.S., 2015. Differences in risk factors for recurrent versus incident preterm delivery. *Am. J. Epidemiol.* 182 (2), 157–167.
- Newnham, J.P., Dickinson, J.E., Hart, R.J., Pennell, C.E., Arrese, C.A., Keelan, J.A., 2014. Strategies to prevent preterm birth. *Front. Immunol.* 5, 584.
- Phillips, D., Clancy, K., 1972. Some effects of “Social Desirability” in survey studies. *Am. J. Sociol.* 77 (5), 921–940.
- SAS Institute Inc., 2013. *Base SAS® 9.4 Procedures Guide*. SAS Institute Inc., Cary, NC.
- Scowitz, I.K.T., Santos, I.S., 2016. Risk factors for repetition of low birth weight, intrauterine growth retardation, and prematurity in subsequent pregnancies: a systematic review. *Cadernos De Saúde Pública* 22 (6), 1129–1136.
- Scowitz, I.K.T., Santos, I.S., Domingues, M.R., Matijasevich, A., Barros, A.J., 2013. Prognostic factors for low birthweight repetition in successive pregnancies: a cohort study. *BMC Pregnancy Childbirth* 13 (1), 20.
- Shapiro-Mendoza, C.K., 2016. CDC grand rounds: public health strategies to prevent preterm birth. *MMWR Morb. Mortal. Wkly Rep.* 65.
- Barros, A.J., Santos, I., Silva, Vitoria, C.G., et al., 2006. The 2004 pelotas birth cohort: methods and description. *Revista De Saude Publica* 40 (3), 402–413.
- Simpson, W.J., 1957. A preliminary report on cigarette smoking and the incidence of prematurity. *Am. J. Obstet. Gynecol.* 73 (4), 808–815.
- Van Dijk, J.W., Anderko, L., Stetzer, F., 2011. The impact of prenatal care coordination on birth outcomes. *J. Obstet. Gynecol. Neonatal. Nurs.* 40 (1), 98–108.
- van Zijl, M.D., Koullali, B., Mol, B.W., Pajkr, E., Oudijk, M.A., 2016. Prevention of preterm delivery: current challenges and future prospects. *International Journal of Women's Health* 8, 633.