Understanding State-Level Variations in the US Infant Mortality: 2000 to 2015

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Abstract

Objective To exploit state variations in infant mortality, identify diagnoses that contributed to reduction of the infant mortality rate (IMR), and examine factors associated with preterm-related mortality rate (PMR).

Study Design Using linked birth-infant deaths files, we examined patterns in the leading causes of IMR. We compared these rates at both national and state levels to find reduction trends. Creating a cross-sectional time series of states' PMR and some explanatory variables, we implemented a fixed-effect regression model to examine factors associated with PMR at the state level.

Results We found substantial state-level variations in changes of the IMR (range = −2.87−2.08) and PMR (−1.77–0.67). Twenty-one states in which the IMR declined more than the national average of 0.99 (6.89–5.90) were labeled as successful. In the successful states, we found reduction in the PMR accounted for the largest decline in the IMR—0.90 fewer deaths. Changes in the other subgroups of leading causes did not differ significantly in successful and unsuccessful states.

Conclusion Trends in the causes of mortality are heterogeneous across states. Although its impact is not large, reducing the percentage of pregnant women with inadequate care is one of the mechanisms through which the PMR decrease.

Keywords

► infant mortality
► state-level variations
► preterm birth

The US infant mortality rate (IMR) increased in 2015 after a decade of decline—from 2005 to 2014.1 The US IMR is 71% higher than the average rate for comparable countries in the Organization for Economic Co-operation and Development.2 Although the US rate declined by 14%, from 6.89 in 2000 to 5.90 in 2015, infant mortality has declined more slowly than in comparable countries. The IMR is defined as the number of infant deaths per 1,000 live births before their first birthday, and it is a representation of population health, quality of health care, and societal well-being.3

► Fig. 1A shows the rate of infant mortality for 50 states from 2000 to 2015. The size of each dot is proportionate to the number of births in corresponding states and years. The continuous line shows the national average at each year. Two observations can be inferred from ► Fig. 1A: (1) states differ considerably in their IMR each year and (2) states experienced a diverse change in their IMR. States also vary in mortality rates for infants born preterm. ► Fig. 1B shows the changes in PMR between 2000 and 2015 for each state. The PMR increased by more than 0.5 deaths per 1,000 live births in Alaska, Maine, and South Dakota.

The Centers for Disease Control and Prevention (CDC) reports national trends of infant mortality based on five leading causes that include: congenital malformations and chromosomal abnormalities, disorders related to short gestation and low birth weight, newborns affected by maternal complications of pregnancy, sudden infant death (SID) syndrome, and accidents. Change in state IMRs and variation across states have been
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Fig. 1 Trends of states’ IMR and PMR from 2000 to 2015. (A) IMR for each state from 2000 to 2015. (B) PMR reductions: per 1,000 live births, between 2000 and 2015. The District of Columbia was dropped since the large change is attributed to demographic changes over the past decade. Vermont is not shown because of data confidentiality. IMR, infant mortality rate; PMR, preterm-related mortality rate.

Materials and Methods

We obtained individual-level data from the linked birth-infant deaths period data files for the periods 2000 to 2015 to compare states’ performance in reducing the IMR and find the factors that might be associated with the PMR. We divided the IMR into four main subgroups: the preterm-related mortality rate (PMR), the congenital malformations-related mortality rate (CMR), the sudden mortality rate (SMR), and other mortality rates (OMR) that includes all other causes of infant mortality. The first subgroup, PMR, is created based on Callaghan et al’s criteria (see Supplementary Material A [available in the online version]).

The ICD-10 code only considers “Disorders related to short gestation and low birth weight, not elsewhere classified (P07)” as PMR. Callaghan et al showed that the ICD-10 criteria for assigning causes of death do not capture the true number of prematurity-related infant deaths. Callaghan et al categorized preterm-related deaths as those that met two criteria: (1) a biological connection with preterm birth and (2) more than 75% of infants for such a given cause are born preterm.

Congenital malformations, deformations, and chromosomal abnormalities (ICD-10: Q00–Q99) are classified under the CMR as the second subgroup. The third subgroup, the SMR, includes infants who died due to SID syndrome (ICD-10: R95). All other causes are classified as OMR (see Supplementary Material A [available in the online version]). These four categories—the PMR, CMR, SMR, and OMR—are mutually exclusive, which means that they should add up to the total IMR for each state and year (see Supplementary Material B [available in the online version]).

To identify the subgroup most responsible for the reduction of the IMR at the national level (question 1), we compared changes in the PMR, CMR, SMR, and OMR between 2000 and 2015. We calculated the percentage decline in each subgroup and compared the rates using the method described by Mathews and MacDorman.

To investigate the subgroup most responsible for the IMR reduction in states (question 2), we assigned 41 states to one of two groups: successful and unsuccessful. We chose the national IMR reduction size between 2000 and 2015 (i.e., 0.99) as the cutoff point. A state with a reduction size of 0.99 or more was defined as “successful,” while all others were “unsuccessful.” We calculated the reduction in the PMR, CMR, SMR, and OMR for successful and unsuccessful states. We used pairwise Student’s t-test to discern the statistical differences of mean comparisons among states. We dropped nine states for...
the following reasons. First, some states, such as Massachusetts, had a low IMR in 2000, and a minimal opportunity to improve such rate. However, other states, such as Mississippi, experienced a large reduction in their IMR (1.19, a drop from 10.64 to 9.45), but still remained the worst state in the United States in the overall rate of infant death in 2015. Second, states in the two groups were not comparable because the mean IMR in 2000 was higher in successful states—7.53 versus 6.63. Nevertheless, we conducted the same analysis using the full sample of states and reported the results in the Supplementary Material C (available in the online version).

In addition, we used a fixed-effect, multiple linear regression analysis to investigate the association between the PMR and state-level explanatory variables (question 3). We accounted for serial correlation within states by clustering standard errors at the state level. The fixed-effect model controls for unobserved factors that are constant over time. Some of the important predictors of birth outcome were unchanged between 2000 and 2015. For example, although the IMR is higher among African American women, their birth rates did not change in every state from 2000 to 2015. We selected our explanatory variables based on evidence in the literature and availability of data in the linked data files. These variables include teen pregnancy, multiple births at infant level, prenatal care, and tobacco use during pregnancy. Teen pregnancy is defined in each state as the percentage of mothers who were 19 or younger at the time of birth. Multiple births rate is a representation of live births for cases in which a mother delivered more than one infant in the same pregnancy. Tobacco use is the percentage of mothers who reported smoking at any time during pregnancy. Prenatal care variables indicate the percentage of women in each state who received care based on the Kessner index (see Supplementary Material D [available in the online version]). This method defines three levels for prenatal care: adequate, intermediate, and inadequate. Since these three variables are perfectly correlated, we dropped the adequate category, and we interpreted the results with respect to it. The Kessner index has high predictive value for infant mortality and preterm birth.

The PMR is reported as deaths per 1,000 live births, and all explanatory variables are in percentages. Thus, to interpret the regression results, we examined how many deaths could be avoided if an explanatory variable is changed. Tobacco use and prenatal care were not available for some states between 2011 and 2015. We therefore ran two regressions. First, we regressed the PMR against teen pregnancy and multiple births using a cross-sectional time series of 50 states from 2000 to 2015 that included 800 data points (i.e., 50 states over 16 years). Second, the PMR and all explanatory variables were regressed in a dataset of 46 states between 2000 and 2010. The number of observations in the second regression analysis was 505 because some explanatory variables, such as tobacco use in California, are not available (see Supplementary Material E [available in the online version] for missing values). We also controlled for the effect of year by adding a continuous year variable. Calculations were performed on a Windows OS, using STATA/MP 14.0 software.

### Results

Table 1 shows the national trends for the IMR values and its subgroups in the United States between 2000 and 2015. The IMR declined from 6.89 to 5.90 between 2000 and 2015, representing about one fewer death. The PMR was the largest subgroup of IMR in 2000, accounting for 2.46 deaths. The PMR subgroup was reduced to 2.07 in 2015. In 2000, 1.41 deaths were caused by congenital malformations, which declined to 1.22 in 2015. The SMR, the smallest subgroup of the IMR in 2000 and 2015, also declined from 0.62 to 0.39, respectively. Other causes of deaths (OMR), the second largest subgroup, declined from 2.40 to 2.21. The highest reduction, 0.39 deaths, occurred in the PMR subgroup. The percentage change in the SMR exceeded the other subgroups.

Fig. 2 depicts the subgroups' trends in 2000 and 2015 for the two groups of successful and unsuccessful states. Successful states reduced their rates significantly in each of the subgroups (p-value < 0.05), while unsuccessful states only reduced their SMR significantly. When it came to comparing the difference in reduction sizes, the PMR was the only subgroup with a significantly different reduction in successful states versus unsuccessful. In other words, changes in the CMR, SMR, and OMR in successful states were not statistically different from changes in these subgroups in unsuccessful states.

In 2000, the mean of the IMR in successful states was 7.08, and it significantly declined to 5.47 (p-value < 0.001) in 2015, representing ~1.61 fewer deaths. The largest reduction is in the PMR in the successful states, a 0.90 reduction (p-value < 0.001), from 2.63 to 1.73. The reduction size in the CMR, SMR, and OMR are all significant and equal to 0.22 (from 1.44 to 1.22—p-value < 0.001), 0.30 (from 0.63 to 0.33—p-value < 0.001), and 0.18 (2.37 to 2.19—p-value = 0.022), respectively. Fifty-six per cent of the IMR reduction (0.90 out of 1.61) in successful states was due to PMR reduction.

In unsuccessful states, the IMR mean was 7.14 in 2000, which then declined by 0.65 (p-value < 0.001) and reached 6.49. A decrease in PMR from 2.48 to 2.34—equivalent to a reduction size of 0.14—was not significant (p-value = 0.076). The CMR declined significantly by 0.27 from 1.53 to 1.26 (p-value = 0.003), the SMR reduced by 0.09 (p-value = 0.080) from 0.65 to 0.56, and the OMR declined by 0.16 (p-value = 0.352) from 2.49 to 2.33 (Fig. 2).

| Variable | 2000 | 2015 | Reduction size | Reduction rate | p-Value |
|----------|------|------|----------------|----------------|---------|
| IMR      | 6.89 | 5.90 | 1.00           | 14%            | <0.001  |
| PMR      | 2.46 | 2.07 | 0.39           | 16%            | <0.001  |
| CMR      | 1.41 | 1.22 | 0.19           | 14%            | <0.001  |
| SMR      | 0.62 | 0.39 | 0.23           | 36%            | <0.001  |
| OMR      | 2.40 | 2.21 | 0.19           | 8%             | <0.001  |

Abbreviations: CMR, congenital malformations-related mortality rate; IMR, infant mortality rate; OMR, other mortality rates; PMR, preterm-related mortality rate; SMR, sudden mortality rate.
The change in the PMR differed significantly between successful and unsuccessful states ($p$-value < 0.001). Successful states reduced their PMRs by 0.90, while the other group experienced a slight decrease of 0.14 in their PMRs over the period of 2000 to 2015. The reduction for the CMR, SMR, and OMR was not significantly different ($p$-values are 0.115, 0.137, and 0.157, respectively) between the two groups of states. Successful states reduced their CMRs by 0.22, which is not significantly different ($p$-value = 0.115) than the reduction size in unsuccessful states—0.27. The SMR reduction size for successful states was 0.30, which is not significantly larger ($p$-value = 0.137) than the reduction size of unsuccessful states—0.09. The OMR reduction size was 0.18 in successful versus 0.16 in unsuccessful states, which was not significantly different ($p$-value = 0.157). Supplementary Material F (available in the online version) depicts the successful and unsuccessful states on the US map.

In summary, our analyses showed that the largest reduction size occurred in the PMR subgroup at the national level. Further, states with an IMR reduction above the national average—successful states—experienced a much larger decline in the PMR subgroups during the period of 2000 to 2015. Successful states had a higher PMR in 2000 compared with unsuccessful states, and reduced it substantially by 2015, while other subgroup reductions were not significantly different between the two categories of states. In the next step, we examine the association between the PMR and some of the determinants of the PMR reported in the literature.

### Regression Results for Factors Associated with PMR

Table 2 shows the summary statistics of each PMR and explanatory variables for selected years of the study period. These covariates are not weighted based on population of states and cannot be interpreted as national estimates. Few states do not report tobacco use, adequate, intermediate, and inadequate care in some years (see Supplementary Material E [available in the online version]). The first column shows the mean of each variable across the entire time frame.

#### Table 2  Summary data on preterm-related mortality and state-level factors for 50 US states from 2000 to 2015

| Variable                              | Mean (SD) | Range   | 2000  | 2003  | 2006  | 2009  | 2012  | 2015  |
|---------------------------------------|-----------|---------|-------|-------|-------|-------|-------|-------|
| PMR per 1,000 live birth             | 2.31 (0.74) | 0.52–5.02 | 2.46  | 2.50  | 2.40  | 2.25  | 2.16  | 2.06  |
| % of teen pregnancy                  | 9.34 (2.98) | 3.02–18.75 | 11.80 | 10.27 | 10.20 | 9.92  | 7.76  | 5.86  |
| % of multiple births                 | 3.35 (0.44) | 2.08–4.90 | 3.07  | 3.34  | 3.37  | 3.42  | 3.39  | 3.43  |
| % of tobacco user                    | 12.63 (5.04) | 3.84–27.26 | 14.00 | 12.88 | 12.48 | 12.62 | 12.10 | 10.69 |
| % of adequate care                   | 68.95 (8.76) | 39.35–87.38 | 72.86 | 73.31 | 68.93 | 66.86 | 64.92 | 67.76 |
| % of intermediate care               | 20.72 (5.12) | 9.13–46.95 | 18.08 | 17.98 | 18.31 | 22.11 | 23.76 | 21.50 |
| % of inadequate care                 | 9.39 (5.62) | 1.39–41.00 | 5.07  | 8.71  | 8.93  | 11.04 | 11.32 | 10.73 |

Abbreviations: PMR, preterm-related mortality rate; SD, standard deviation.
Source: Linked birth/infant death period data, 2000–2015.
Note: Data represented unweighted averages across states and should not be interpreted as national estimates. Tobacco use, adequate, intermediate, and inadequate care have missing data points (see Supplementary Material D [available in the online version]).
The rate of mortality related to sleeping dropped 36% on average in the United States between 2000 and 2015. Reduction of the OMR also did not differ in successful and unsuccessful states from 2000 to 2015. However, the decline in the OMR (8%) was substantially less than the 36% reduction seen in the SMR.

Prenatal care may improve birth outcomes even in low income and resource settings.\textsuperscript{22-25} Prior studies have found that prenatal care is associated with reduced PMRs. Our analysis revealed that a 1% point decline in mothers who received inadequate care led to a decrease in preterm-related deaths of 0.011 per 1,000 live births. The magnitude of this variable relative to the mean PMR is not large, suggesting that an increase in prenatal care as currently practiced would not lead to a state-level reduction in the PMR. The small-effect size of prenatal care might also be due to a limitation of data collection or lack of control for other key explanatory variables such as adhering to prevention programs.

Despite the emphasis on prenatal care, access to obstetric services is decreasing in the United States. More than 9% of rural counties lost their obstetric services from 2004 to 2014, which made access to care harder for 28 million women of reproductive age.\textsuperscript{26} Our findings highlight the importance of eliminating an inadequacy of care. Models such as coordinated care organizations significantly increase access to care with broad financing and delivery reforms that can reduce disparities in prenatal care and improve birth outcomes through a reduction in inadequate care.\textsuperscript{27} The adoption of expanded access to Medicaid has also been an effective policy. States that adopted Medicaid expansion have observed a reduction in their IMRs.\textsuperscript{28}

The risk factors, corresponding interventions, and causes of preterm mortality vary by target population. Iams et al classified all possible interventions for a reduction of PMR risk factors into three main categories: primary (directed to all women), secondary (focusing on reducing existing risk), and tertiary (for improving preterm-infant outcomes).\textsuperscript{29} Of these, the most improvement in the survival of preterm infants can be attributed to better neonatal care access.\textsuperscript{30} Obstetric interventions, such as antenatal corticosteroid treatment for women delivering preterm, also contribute to the decline in neonatal mortality.

Another preconceptional strategy to decrease infant mortality is the adoption of steps to reduce the risk of higher order gestation.\textsuperscript{30} We found that the percentage of women with multifetal pregnancies is significantly and positively associated with the PMR in the first regression in which we controlled for teen pregnancy. After adding prenatal care variables and tobacco use to our model, multifetal births still correlate positively with the PMR, but statistical significance is lost, perhaps for two reasons: (1) The second regression has fewer observations (for 46 states from 2000 to 2010) than the first regression (50 states from 2000 to 2015). (2) The first regression might have omitted the variable bias so that the p-value of multifetal pregnancy changed when we controlled for prenatal care and tobacco use. Our analysis investigates the percentage impact of multifetal birth at the state level to examine the factors that might be associated with state variations in infant mortality, while previous studies compared the IMR between singleton and multifetal births. Furthermore,
these studies did not use a multivariate analysis to disentangle the effects of multiple risk factors over time.16,31,32

It is estimated that 5% of infant mortality and 5.0 to 7.3% of preterm-related deaths are attributable to maternal smoking.33,34 Our findings are not consistent with these studies, which may be attributed to our different design. Traditional studies of smoking in pregnancy have examined cross-sectional data. We assessed the association of the PMR and smoking using cross-sectional time series data. Notably, between 2000 and 2004 in the United States, smoking among childbearing age women decreased from 25.5 to 21.7%, while preterm birth rates increased from 11.6 to 12.5%.35

Our study was limited by the quality of CDC data that may vary by state and hospital over time.36 In addition, due to a lack of information, we could not control for some behavioral risk factors (e.g., drug abuse prevalence and behavioral factors, such as pregnant women’s adherence to prevention programs), which may bias our regression results.

Overall, some states performed better in terms of reducing their IMRs over the past decade. Reducing preterm-related death was the biggest factor in states that have improved their infant deaths. It appears that state variations in reducing preterm-related deaths can be partially explained by better access to prenatal care, although the impact size is not large. More qualitative and in-depth analyses are needed to understand why some states have successfully reduced their preterm-related deaths better than others.

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Conflict of Interest
None declared.

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