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The association of $PM_{2.5}$ with full term low birth weight at different spatial scales ☆

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ABSTRACT

There is interest in determining the relationship between fine particulate matter air pollution and various health outcomes, including birth outcomes such as term low birth weight. Previous studies have come to different conclusions. In this study we consider whether the effect may vary by location and gestational period. We also compare results when using different spatial resolutions for the air concentration estimates. Among the seven states considered, New Jersey and New York had the highest $PM_{2.5}$ levels (average full gestation period exposures of 13 $\mu g/m^3$) and the largest rate of low birth weight births (2.6 and 2.8%, respectively); conversely Utah and Minnesota had the lowest $PM_{2.5}$ levels (9 $\mu g/m^3$) and the lowest rates of low birth weight births (2.1 and1.9%, respectively). There is an association between $PM_{2.5}$ exposure and low birth weight in New York for the full gestation period and all three trimesters, in Minnesota for the full gestation period and the first and third trimesters, and in New Jersey for the full gestation period and the first trimester. When we pooled the data across states, the OR for the full gestation period was 1.030 (95% CI: 1.022–1.037) and it was highest for the first trimester (OR 1.018; CI: 1.013–1.022) and decreasing during the later trimesters. When we used a finer spatial resolution, the strengths of the associations tended to diminish and were no longer statistically significant. We consider reasons why these differences may occur and their implications for evaluating the effects of $PM_{2.5}$ on birth outcomes.

1. Introduction

While the United States has made great strides in reducing air pollution since the 1970s, regions continue to consistently exceed ambient air quality standards. While the most excessive levels of pollutants have been reined in, the breadth of the health effects of lower exposures is still not well understood. This is particularly true of fine particulate matter, which is not a single chemical but rather a complex of chemicals that varies depending upon regional and local sources. Certain health effects of exposure to particulate matter, such as overall mortality and cardiovascular disease, have been widely studied, and the associations are well established (U.S. EPA, 2009). Adverse birth outcomes such as low birth weight are less well studied and have mixed results.

Fine particulate matter ($PM_{2.5}$) is a common pollutant that is regularly monitored throughout the US. It consists of particles less than 2.5 μm in aerodynamic diameter. The major sources of $PM_{2.5}$ vary by geographic location, but are typically from dust, fuel combustion, and industrial emissions. $PM_{2.5}$ can go deep into lung tissue and get into the bloodstream. The EPA has concluded that exposure to $PM_{2.5}$ causes mortality and cardiovascular effects, and is likely to cause respiratory effects (U.S. EPA, 2009).

However, whether there is a positive association between exposure to particulate matter and adverse birth outcomes is less

Abbreviations: PM2.5, particulate matter with aerodynamic diameter smaller than 2.5 μm; LBW, low birth weight; TLBW, term low birth weight; EPA, U.S. Environmental Protection Agency; OR, odds ratio; NCHS, National Center for Health Statistics; CT, Connecticut; ME, Maine; MN, Minnesota; NJ, New Jersey; NY, New York; UT, Utah; WI, Wisconsin; CMAQ, Community Multi-scale Air Quality model; CI, confidence interval; NMB, normalized mean bias; LMP, last menstrual period

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clear. In their most recent Integrated Science Assessment, the EPA find that the evidence suggests that $PM_{2.5}$ causes reproductive and developmental effects (U.S. EPA, 2009).

Low birth weight is a major predictor of perinatal mortality and morbidity and therefore of public health importance. Low birth weight (LBW) infants have mortality rates more than 20 times those of normal weight infants (MacDorman and Atkinson, 1999). They are at increased risk for neurological outcomes, particularly cerebral palsy (Goldenberg and Culhane, 2007). Low birth weight is associated with health issues in adolescence and beyond, including asthma, low IQ, and hypertension (Ashdown-Lambert, 2005; Barker, 1995; Godfrey and Barker, 2000; Richards et al., 2001; Steffensen et al., 2000). Hospital costs associated with LBW infants are also large: Almond et al., 2005 estimates the excess hospital costs for 2–2.5 kg birth at $600, $6800 for 1.5–2 kg birth, and over $20,000 for lower birth weights.

Full-term low birth weight (LBW) babies are those that are born at 37 to 41 weeks of gestation but weigh less than 2500 g. Among full-term births, 3.1% were LBW in the U.S. in 2012 (Martin et al., 2013), and ranged between 2.9% and 3.2% between 1997 and 2012 (source: National Vital Statistics Reports, "Births: Final Data" for each of the years). Well-established risk factors for LBW births include race, young maternal age, high parity, maternal smoking, alcohol and/or drug use, poor nutrition, and stress (Ashdown-Lambert, 2005).

While it is understood that fetal health can be impacted by environmental pollution, studies of the impact of pollutants on LBW have had mixed results. Recent reviews have come to different conclusions. Bosetti et al. (2010) found that current evidence does not support an association between exposure to ambient particulate matter and adverse birth outcomes (low birth weight and preterm birth). Stieb et al. (2012) found that $PM_{2.5}$ was associated with LBW. Through a meta-analysis, they estimated an OR of 1.05 (99% CI: 0.99–1.12) per 10 $\mu g/m^3$ increase in $PM_{2.5}$. The authors found that the heterogeneity among studies was primarily due to differences in study designs and varying definitions of exposure periods. In a multi-country study, Dadvand et al. (2013) found that ambient exposure to $PM_{2.5}$ was significantly associated with LBW (OR 1.10, 95% CI 1.03–1.18) per 10 $\mu g/m^3$ increase in $PM_{2.5}$. They reported that the heterogeneity among studies was due to median $PM_{2.5}$ exposure levels and temporal versus spatio-temporal exposure contrasts. Sapkota et al. (2012) did a meta-analysis of 20 studies of LBW, and calculated a combined OR of 1.09 (95% CI: 0.90–1.32) per 10 $\mu g/m^3$ increase in $PM_{2.5}$.

With $PM_{2.5}$, it may also be that different compositions can lead to different health outcomes. Because $PM_{2.5}$ is made of a mixture of sources and the sources will vary by location, it may be unreasonable to expect the effect of $PM_{2.5}$ on birth outcomes to be constant across geography. Studies have found associations between specific components of $PM_{2.5}$ and low birth weight. Bell et al. (2010, 2012) found Al, elemental C, K, Ni, Si, Ti, V, and Zn to be associated with LBW. Ebisu and Bell (2012) found associations of LBW with Al, Ca, Cd, elemental C, Ni, Si, Ti, and Zn. Darrow et al. (2011) found associations of LBW with elemental carbon and $PM_{2.5}$ water soluble metals in the Atlanta region. Wilhelm et al. (2012), however, did not find associations of LBW with nitrate, sulfate, elemental C, organic C, nor V.

The impact that a pollutant has on fetal growth may depend upon the stage of fetal development when the exposure occurs. Multiple studies have found effects to be confined to exposure during specific trimesters. Bell et al. (2007) found associations during the second and third trimesters using data from Massachusetts and Connecticut. Rich et al. (2009) found associations of PM2.5 with small for gestational age births during the first and third trimesters using New Jersey birth data. Morello-Frosch et al. (2010) studied births in California and the associations of PM2.5 and reduction in birth weight varied in size by trimester. Parker et al. (2005) did find an association between $PM_{2.5}$ and birth weight for exposures across the full pregnancy, but did not see differences in the associations by trimester. Parker and Woodruff (2008) also did not find an association between $PM_{2.5}$ and birth weight for any trimester, nor for the full pregnancy. Hyder et al. (2014) found significant associations between low birth weight and $PM_{2.5}$ in the first trimester, but not the second or third trimester, using satellite and monitor data of PM2.5 concentrations in Connecticut and Massachusetts. Savitz et al. (2014) found reductions in birth weight with increases in PM2.5 concentrations during all three trimesters in New York City. Ebisu and Bell (2012) found associations of $PM_{2.5}$ components with LBW differed by trimester, but did not find an overall association with total PM2.5 in northeastern and mid-Atlantic United States.

An important issue in assessing these effects of air pollution is the assignment of dose values to individual births (Waller and Gotway, 2004). Direct monitoring of the air pollution levels to which individual pregnant women are exposed is not feasible for large-scale epidemiologic studies. Actual monitor data are routinely collected only at fairly scattered locations. Consequently, studies differ in terms of how air concentration values from the monitors in the region of each mother's residence are utilized for the assignment of exposure values. Furthermore, issues of confidentiality often preclude investigators from obtaining exact geographic locations of the residences of the women whose births are studied. Consequently, if, for example, the only information available concerning location is county of residence, then exposure values ascribed to individual births must be based on some sort of average or interpolated measure at the county level rather than on some more individualized values.

Our study was conducted within the Centers for Disease Control and Prevention's Environmental Public Health Tracking Program. Several state health departments in the Tracking Program expressed interest in assessing whether variation in PM2.5 within their states was associated with adverse birth outcomes. Public health officials in all the participating states, and particularly in those states that share borders with other participating states, were interested to learn whether combining and comparing data across states might help to clarify these effects of PM2.5.

The study was conducted within the framework of public health surveillance, which is defined as "the ongoing systematic collection, analysis, and interpretation of outcome-specific data for use in the planning, implementation, and evaluation of public health practice" (Thacker and Berkelman, 1988). In that context, a key goal was to assess whether associations between PM2.5 and birth outcomes could be validly evaluated with currently available databases that are routinely collected over time and do not require special permissions and extensive time commitments of research staff. In that way, the states would be able to evaluate the efficacy of interventions designed to reduce exposure of pregnant women via assessment of changes over time in the contribution of PM2.5 to adverse birth outcomes in the population.

Consequently, the goal of our study was to assess if there is an association between exposure to PM2.5 and low birth weight, and whether that association varied according to spatial and temporal resolution of the exposure or according to timing of the exposure during the pregnancy.

2. Methods

2.1. Data sources

2.1.1. Birth certificate data

Birth certificate data for CT, ME, MN, NJ, NY, UT, and WI were obtained from the National Center for Health Statistic's vital statistics Public Use Micro Data (National