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Low birth weight and air pollution in California: Which sources and components drive the risk?

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ABSTRACT

Introduction: Intrauterine growth restriction has been associated with exposure to air pollution, but there is a need to clarify which sources and components are most likely responsible. This study investigated the associations between low birth weight (LBW, <2500 g) in term born infants (≥37 gestational weeks) and air pollution by source and composition in California, over the period 2001–2008.

Methods: Complementary exposure models were used: an empirical Bayesian kriging model for the interpolation of ambient pollutant measurements, a source-oriented chemical transport model (using California emission inventories) that estimated fine and ultrafine particulate matter ($PM_{2.5}$ and $PM_{0.1}$, respectively) mass concentrations (4 km × 4 km) by source and composition, a line-source roadway dispersion model at fine resolution, and traffic index estimates. Birth weight was obtained from California birth certificate records. A case-cohort design was used. Five controls per term LBW case were randomly selected (without covariate matching or stratification) from among term births. The resulting datasets were analyzed by logistic regression with a random effect by hospital, using generalized additive mixed models adjusted for race/ethnicity, education, maternal age and household income.

Results: In total 72,632 singleton term LBW cases were included. Term LBW was positively and significantly associated with interpolated measurements of ozone but not total fine PM or nitrogen dioxide. No significant association was observed between term LBW and primary PM from all sources grouped together. A positive significant association was observed for secondary organic aerosols. Exposure to elemental carbon (EC), nitrates and ammonium were also positively and significantly associated with term LBW, but only for exposure during the third trimester of pregnancy. Significant positive associations were observed between term LBW risk and primary PM emitted by on-road gasoline and diesel or by commercial meat cooking sources. Primary PM from wood burning was inversely associated with term LBW. Significant positive associations were also observed between term LBW and ultrafine particle numbers modeled with the line-source roadway dispersion model, traffic density and proximity to roadways.

Discussion: This large study based on complementary exposure metrics suggests that not only primary pollution sources (traffic and commercial meat cooking) but also EC and secondary pollutants are risk factors for term LBW.

1. Introduction

Intrauterine growth restriction has been associated with both short and long term adverse health effects, including increased risk of metabolic syndrome, systolic hypertension, obesity, type 2 diabetes mellitus and cardiovascular diseases (Chernausek, 2012; Salam et al., 2014). Results from several epidemiological studies suggest that exposure of pregnant women to air pollution results in higher risks of low birth weight (LBW, <2500 g) in term born infants, which is a marker for intrauterine growth restriction (Dadvand et al., 2013; Pedersen et al., 2013; Stieb et al., 2012, 2015). However, the sources and components of air

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pollution most likely to be responsible for the observed associations still need to be clearly identified.

Recent publications have suggested a possible influence of primary emissions from traffic on birth weight (e.g.: Lakshmanan et al., 2015; Laurent et al., 2013a, 2014; Malmqvist et al., 2011; Padula et al., 2012). The combustion of coal and biomass in the home where the pregnant women lived during pregnancy was also found to be positively associated with term LBW (Amegah et al., 2014). However, the influence of other sources of air pollution has seldom been investigated (Laurent et al., 2014; Wilhelm et al., 2012).

Only a few studies investigated the relation between PM composition and birth weight (e.g.: Basu et al., 2014; Bell et al., 2010, 2012; Darrow et al., 2011; Ebisu and Bell, 2012; Laurent et al., 2014). In these studies, the PM components most frequently associated with term LBW were elemental carbon (EC) (Basu et al., 2014; Bell et al., 2010; Darrow et al., 2011; Ebisu and Bell, 2012; Laurent et al., 2014; Pedersen et al., 2013; Slama et al., 2007; Wilhelm et al., 2012), iron (Basu et al., 2014; Bell et al., 2010; Laurent et al., 2014), titanium (Bell et al., 2012; Ebisu and Bell, 2012; Laurent et al., 2014) and nickel (Basu et al., 2014; Bell et al., 2010; Ebisu and Bell, 2012). All the aforementioned studies except one (Laurent et al., 2014) attributed measurements from nearby monitors to subjects (within buffers up to a few kilometers) as a proxy for exposure. However, such exposure assessment methods may generate exposure misclassification (Laurent et al., 2013a; Schlesinger et al., 2006). In addition, restricting study populations to subjects living nearby monitors may result in selection bias and leave only a limited number of health outcomes for analyses, notably for relatively rare events such as LBW in term born infants. This issue is especially critical for the study of PM components, since monitors allowing for the assessment of PM composition remain very sparse (Basu et al., 2014).

Chemical transport models (CTMs) can help overcome many of the aforementioned limitations. CTMs can predict the chemical composition of primary and secondary PM with reasonable temporal and spatial resolution, while keeping track of source information. This approach can apply to pollutants for which direct measurement data are sparse. CTMs allows covering large domains where monitoring stations are not available, therefore avoiding study population restrictions, related selection bias and loss of statistical power (Laurent et al., 2016). Although CTMs have seldom been used to investigate the association between term LBW and air pollution by source and composition (Laurent et al., 2014), a recent major modeling effort conducted in California over a vast domain and a long duration now make it possible (Hu et al., 2014a, 2014b, 2015).

This work aimed at studying the relationships between LBW in term born infants and air pollution by source and composition in California. For that purpose, it builds not only on recent efforts of spatiotemporal chemical transport modeling of both primary and secondary particles by source and composition, but also on more commonly used air pollution metrics such as interpolated measurement data, local traffic dispersion modeling, and traffic indices.

2. Methods

2.1. Air pollution metrics

The air pollution indicators used in this study have been extensively described in other papers (Benson, 1989; Hu et al., 2014a, 2014b, 2015; Laurent et al., 2013a, 2014; Wu et al., 2009) and recently summarized in an open access publication (Laurent et al., 2016). These indicators are briefly presented below.

2.1.1. Empirical Bayesian kriging of monitoring station measurements

Measurements from monitoring stations throughout the state for years 2000–2008 were obtained from the California Air Resources Board for total $PM_{2.5}$, nitrogen dioxide (NO_2) and ozone (O_3). Hourly gaseous pollutant measurements were converted to daily means using a criterion of 75% data completeness at a 24-hour basis. Only data for the 10 am–6 pm time windows were used to calculate eight-hour daily means for O_3. Monthly averages for pollutants were then calculated for stations with >75% days of valid data in a month. These monthly averaged concentrations were spatially interpolated between stations using an empirical Bayesian kriging (EBK) model (Pilz and Spöck, 2007) implemented in ArcGIS 10.1 (ESRI, Redlands, CA). Pollutant surface predictions were generated for 200 m ∗ 200 m grids.

2.1.2. Chemical transport modeling

The daily mass concentration of primary PM (PM emitted directly into the atmosphere) and of secondary PM (formed in the atmosphere from gas-phase precursors) were estimated at 4 km × 4 km spatial resolution across two domains covering 92% of the California population for the period of 2000–2008, using the University of California-Davis/California Institute of Technology (UCD/CIT) chemical transport model (Hu et al., 2015). In the present study, the simulated PM concentrations were calculated for two particle size fractions ($PM_{2.5}$ and $PM_{0.1}$). The UCD/CIT model includes a complete description of atmospheric transport, deposition, chemical reaction, and gas-particle transfer. This model provided mass concentration estimates for primary PM total mass and for several chemical species in PM (OC, EC, nitrates, sulfates, ammonium and secondary organic aerosols (SOA)).

In addition, the University of California Davis/CIT_Primary (UCD_P) chemical transport model was used across the same geographical domain for the period of 2000–2006 to predict the daily mass concentrations for further chemical species and for the total mass of primary PM broken down by source (Hu et al., 2014a, 2014b). The model simulated daily primary PM mass concentrations, also at a 4 km × 4 km grid resolution, from ~900 sources. Composition profiles were applied combined with the primary PM mass concentration results from the UCD_P model to estimate the concentrations of chemical species in primary PM. The mass, source, and composition of size-resolved PM were tracked during model calculations. We decided a priori to include in our analyses UCD_P estimates of sources and components of primary PM for which detailed validation results were available: onroad gasoline, onroad diesel, commercial meat cooking and wood burning (Hu et al., 2014a). Nine species of PM (potassium, chromium, iron, titanium, magnesium, strontium, arsenic, calcium and zinc) were selected, all with the correlation above 0.8 between modeled and measured monthly average concentrations (Hu et al., 2014b).

2.1.3. CALINE4 dispersion modeling for road sources

A modified version of CAlifornia LINE Source Dispersion Model Version 4 (CALINE4) (Benson, 1989; Wu et al., 2009) was used to predict ambient concentrations from local traffic emissions of CO, NO_x, and ultrafine particle number (UFP) up to 3 km from maternal residences. Model inputs included roadway geometry and traffic counts, emission factors, and meteorological parameters (wind direction, wind speed, temperature stability class, and mixing heights). CALINE4 predictions in this study did not incorporate background levels of pollutants, thus solely represents the contribution from local traffic emissions.

2.1.4. Traffic and distance to roadways

Traffic densities within circular buffers of different sizes centered on maternal homes were calculated based on 2002 annual average daily traffic counts (AADT) data from the California Department of Transportation (CALTRANS, 2012). To estimate traffic density, AADT on each road segment was weighted by the length of this same road segment within the buffer. These traffic densities for year 2002 were then scaled to other years by multiplying them by the ratio of total vehicle miles traveled in California for the given year to the total vehicle miles traveled in California for year 2002 (CALTRANS, 2013). U.S. major roads data based on TeleAtlas streets (ESRI, 2010) were used to calculate the distance from each maternal home to the nearest major roadway (which could be a