Environmental Research 134 (2014) 488–495

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Sources and contents of air pollution affecting term low birth weight in Los Angeles County, California, 2001–2008

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ARTICLE INFO

Article history:
Received 1 November 2013
Received in revised form
9 April 2014
Accepted 4 May 2014
Available online 29 July 2014

Keywords:
Air pollution
Birth weight
Source
Speciation
Ultrafine particle

ABSTRACT

Background: Low birth weight (LBW, <2500 g) has been associated with exposure to air pollution, but it is still unclear which sources or components of air pollution might be in play. The association between ultrafine particles and LBW has never been studied.
Objectives: To study the relationships between LBW in term born infants and exposure to particles by size fraction, source and chemical composition, and complementary components of air pollution in Los Angeles County (California, USA) over the period 2001–2008.
Methods: Birth certificates (n=960,945) were geocoded to maternal residence. Primary particulate matter (PM) concentrations by source and composition were modeled. Measured fine PM, nitrogen dioxide and ozone concentrations were interpolated using empirical Bayesian kriging. Traffic indices were estimated. Associations between LBW and air pollution metrics were examined using generalized additive models, adjusting for maternal age, parity, race/ethnicity, education, neighborhood income, gestational age and infant sex.
Results: Increased LBW risks were associated with the mass of primary fine and ultrafine PM, with several major sources (especially gasoline, wood burning and commercial meat cooking) of primary PM, and chemical species in primary PM (elemental and organic carbon, potassium, iron, chromium, nickel, and titanium but not lead or arsenic). Increased LBW risks were also associated with total fine PM mass, nitrogen dioxide and local traffic indices (especially within 50 m from home), but not with ozone. Stronger associations were observed in infants born to women with low socioeconomic status, chronic hypertension, diabetes and a high body mass index.
Conclusions: This study supports previously reported associations between traffic-related pollutants and LBW and suggests other pollution sources and components, including ultrafine particles, as possible risk factors.

1. Introduction

Intrauterine growth restriction and resulting low birth weight (LBW, defined as birth weight less than 2500 g) have been associated with increased risks of chronic diseases in later life such as the metabolic syndrome, type 2 diabetes mellitus and cardiovascular diseases, (Chernausek, 2012), but also wheezing and asthma in childhood (Caudri et al., 2007). Air pollution induces oxidative stress, inflammation (Schlesinger et al., 2006) and hemodynamic changes, which are suspected to impair oxygen and nutrient transport to the fetus, and in turn, intrauterine growth (Kannan et al., 2006). Results from a growing number of epidemiological studies do suggest that exposure of pregnant women to air pollution may result in higher risks of LBW (Dadvand et al., 2013; Pedersen et al., 2013; Stieb et al., 2012).

Abbreviations: LBW, low birth weight; IQR, inter-quartile range; OR, odds ratios; CI, confidence intervals; $PM_{2.5}$, particulate matter of less than 2.5 μm in aerodynamic diameter; $PM_{0.1}$, particulate matter of less than 0.1 μm in aerodynamic diameter; EBK, empirical Bayesian kriging; UCD_P, University of California Davis/CIT_Primary chemical transport model; CTM, chemical transport models; NO_2, nitrogen dioxide; O_3, ozone; FRC, Functional Road Classes; BMI, body mass index; EC, elemental carbon; OC, organic carbon; LUR, land use regression; PAH, polycyclic aromatic hydrocarbons

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http://dx.doi.org/10.1016/j.envres.2014.05.003
0013-9351/

However, associations between air pollution exposure and LBW differ widely depending on study settings and designs (Brauer et al., 2008; Laurent et al., 2013).

It is suspected that the different definitions of air pollution metrics partly contribute to discrepancies in the literature (Dadvand et al., 2013). Characterizing exposure to air pollution is challenging and the different exposure assessment methods present advantages and limitations (e.g., in terms of temporal and spatial resolutions). Consequently, assessing the consistency of epidemiological results obtained using complementary exposure metrics can be useful to draw more informed conclusions. For instance, in Los Angeles positive associations were observed between the risk of preeclampsia and ambient nitrogen oxides concentrations, whether these concentrations were estimated by monitoring station measurements, land use regression or deterministic modeling, which strengthened confidence in this finding (Wu et al., 2011b).

Particulate matter (PM) has various core compositions and absorbs transition metals, polycyclic aromatic hydrocarbons (PAHs) and other organic compounds, that are able to generate oxidative stress and inflammation to various extents (Schlesinger et al., 2006; Delfino et al., 2010). Differences in PM composition have therefore been hypothesized to modify the relationship between total PM mass and LBW (Ebisu and Bell, 2012). Notable spatial contrasts in PM composition have been documented across the U.S. (Bell et al., 2007). However, few studies investigated the relation between PM composition and birth weight (Bell et al., 2010, 2012; Darrow et al., 2011; Ebisu and Bell, 2012), probably because of the scarcity of particle speciation data.

There are also open questions, of direct relevance to policy, on the sources of air pollution most likely to generate detrimental effects on pregnancy outcomes. Recent publications have suggested a possible influence of primary emissions from traffic on LBW (e.g.: Laurent et al., 2013; Wilhelm et al., 2012). Such an influence is biologically plausible since some components of primary traffic emission (e.g.: organic compounds such as PAHs, elemental carbon, trace metals) promote systemic inflammation and decrease antioxidant enzyme activity (Delfino et al., 2010). The possible influence of other sources of air pollution (e.g.: wood burning and meat cooking, that notably generate PAHs and other organic compounds) has also been suggested (Boy et al., 2002; Wilhelm et al., 2012). However, only one study attempted to assess simultaneously the relative contributions from different sources to the risk of LBW (Wilhelm et al., 2012), probably since results from source apportionment methods (e.g.: Chemical Mass Balance or Positive Matrix Factorization) are relatively rare and remain site-specific.

Chemical transport models (CTMs) have been used to address issues of the lack of source information and measurement scarcity for certain air pollutants (Hu et al., 2014a). For instance CTMs can predict the detailed size and chemical composition of primary PM with reasonable temporal and spatial resolution, while keeping track of source information. This approach can also apply to particles of certain size fractions for which direct measurement data are usually too rare to be directly usable in epidemiological studies, such as particles less than 0.1 μm in aerodynamic diameter ($PM_{0.1}$) (Abernethy et al., 2013). Concerns exist about the toxicity of $PM_{0.1}$ due to their specific properties (potential for translocation into the blood or other organs than lung, large number concentration and surface-to-volume ratio) (Knol et al., 2009). To the best of our knowledge, the relationship between birth weight and $PM_{0.1}$ has never been studied.

This work aimed at studying the relationships between air pollution and LBW in term born infants in Los Angeles County, California. It extends previous research on this topic, by using spatiotemporal chemical transport modeling of primary particles by source and composition and by studying $PM_{0.1}$ exposure. It also makes use of more commonly used air pollution metrics such as interpolated measurement data, traffic indices and proximity to roads. This allows for comparison of results according to complementary exposure metrics for traffic-related air pollution.

2. Methods

2.1. Study population

Birth certificate records for all births occurring from January 1, 2001 to December 31, 2008 to women residing in Los Angeles County ($n=1{,}203{,}782$) were obtained from the Health Information and Research Section at the California Department of Public Health. Multiple births ($n=35{,}213$) were excluded along with infants with recorded birth defects or unknown birth defects status ($n=3353$ and $n=398$, respectively). Births with missing information for gestational age ($n=62{,}724$), or implausible combinations of birth weight and gestational age (Alexander et al., 1996) were also excluded ($n=4995$). Further, infants born before 260 or after 308 estimated days of gestation ($n=141{,}485$ and $n=22{,}839$ respectively) were excluded (Bell et al., 2010). Several exclusion criteria overlapped for certain births, leaving 960,945 births for analyses.

Maternal addresses of residence recorded on birth certificates were geocoded using the University of Southern California GIS Research Laboratory geocoding engine (Goldberg et al., 2008), which geocoded births at the centroid of tax parcels whenever feasible. In total, we had 53% of addresses geocoded to a specific parcel, 42.5% using address range interpolation,[1] 4.5% at the Zip code centroid level, and 0.05% at the city centroid.

2.2. Air pollution metrics

2.2.1. Chemical transport modeling

The University of California Davis/CIT_Primary (UCD_P) chemical transport model (Hu et al., 2014a) estimated primary ground-level PM element concentrations across densely populated areas of California including Los Angeles County at a 4 km × 4 km grid resolution for particles ranging from 0.01 to 20 μm from approximately 900 sources. In the present study, the simulated PM concentrations were calculated for two particle size fractions ($PM_{2.5}$ and $PM_{0.1}$) for the period of 2000–2006. The UCD_P model was developed to track primary PM (emitted directly from sources) through a simulation of emission, advection, diffusion and deposition. The detailed descriptions of the model and its validation are the purpose of other publications (Hu et al., 2014a, 2014b), but its main components are summarized below.

Size and composition resolved particle emissions were derived from a library of primary particle source profiles measured during actual source tests. Gridded emissions were prepared using the raw emissions inventory provided by the California Air Resources Board (Hu et al., 2014a). Meteorological inputs were prepared using the Weather Research and Forecast (WRF) model version 3.1 (Skamarock et al., 2008). Published papers describe the bulk advection and turbulent diffusion algorithm (Kleeman and Cass, 2001), the dry deposition approach (Kleeman et al., 1997), the vertical advection scheme (Hu et al., 2010), and the wet deposition scheme (Mahmud et al., 2010) used in the model. Every source with a unique emissions inventory code (EIC) in the emissions database was tracked separately through model simulations. In the present study, we defined seven broad source categories, namely gasoline, diesel, shipping, high sulfur combustion sources (including aircraft, electricity generation, petroleum refining and other industries), commercial meat cooking, wood burning, and other sources. The mass and density of size-resolved PM were tracked during model calculations, with composition profiles applied during post-processing of results. UCD_P only tracked primary PM and did not account for the formation of secondary PM produced by chemical reactions in the atmosphere, which might have different health effects (Delfino et al., 2010) and will be studied in future works.

Women living in each of the 448 model grid cells covering Los Angeles County (see Appendix Fig. A.1) at the time of delivery were assigned daily concentrations estimated for the corresponding cell, which were then averaged for specific pregnancy periods (entire pregnancy, 1st, 2nd or 3rd trimester).

2.2.2. Monitoring station measurements

Measurements from government monitoring stations for the period 2000–2008 were obtained from the California Air Resources Board for total $PM_{2.5}$, nitrogen

[1] If no parcel match could be found for an address, an approximate location for this address was determined by using the address range for the matched street segment – the location was determined by computing where the address would fall as a proportion of the total address range associated with the appropriate side of the street segment. This proportion was then applied to the total length of the street segment (Goldberg et al., 2007).