Environmental Research 128 (2014) 42–51

Contents lists available at ScienceDirect

Environmental Research

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

Effects of fine particulate matter and its constituents on low birth weight among full-term infants in California

Rupa Basu [a,*], Maria Harris [b], Lillian Sie [c], Brian Malig [a], Rachel Broadwin [a], Rochelle Green [a]

[a] California Office of Environmental Health Hazard Assessment, Air Pollution Epidemiology Section, Oakland, CA, USA
[b] School of Public Health, Boston University, Boston, MA, USA
[c] School of Public Health, University of California, Berkeley, CA, USA

ARTICLE INFO

Article history:
Received 7 May 2013
Received in revised form
21 October 2013
Accepted 24 October 2013
Available online 17 December 2013

Keywords:
Particulate matter
Constituents
Low birth weight
Full-term infants
California
Retrospective cohort

ABSTRACT

Relationships between prenatal exposure to fine particles ($PM_{2.5}$) and birth weight have been observed previously. Few studies have investigated specific constituents of $PM_{2.5}$, which may identify sources and major contributors of risk. We examined the effects of trimester and full gestational prenatal exposures to $PM_{2.5}$ mass and 23 $PM_{2.5}$ constituents on birth weight among 646,296 term births in California between 2000 and 2006. We used linear and logistic regression models to assess associations between exposures and birth weight and risk of low birth weight (LBW; <2500 g), respectively. Models were adjusted for individual demographic characteristics, apparent temperature, month and year of birth, region, and socioeconomic indicators. Higher full gestational exposures to $PM_{2.5}$ mass and several $PM_{2.5}$ constituents were significantly associated with reductions in term birth weight. The largest reductions in birth weight were associated with exposure to vanadium, sulfur, sulfate, iron, elemental carbon, titanium, manganese, bromine, ammonium, zinc, and copper. Several of these $PM_{2.5}$ constituents were associated with increased risk of term LBW. Reductions in birth weight were generally larger among younger mothers and varied by race/ethnicity. Exposure to specific constituents of $PM_{2.5}$, especially traffic-related particles, sulfur constituents, and metals, were associated with decreased birth weight in California.

1. Introduction

Low birth weight (LBW; <2500 g) is a risk factor for greater infant mortality (Hauck et al., 2011; Kochanek et al., 2012; Mathews and MacDorman, 2007) and morbidity throughout adulthood (Johnson and Schoeni, 2011). Although some risk factors for LBW have been studied, the etiology remains largely unknown, and the rate of LBW continues to rise (Donahue et al., 2010). Term LBW babies have been shown to have challenges that are lifelong, ranging from respiratory difficulties throughout childhood (Caudri et al., 2007) and psychological distress in adulthood (Wiles et al., 2005). To date, many studies of fine particulate matter ($PM_{2.5}$) and LBW have been conducted (Shah and Balkhair, 2011), but the effect of specific $PM_{2.5}$ constituents on birth outcomes remains largely unstudied. Examining specific constituents of $PM_{2.5}$ rather than total $PM_{2.5}$ mass may more accurately capture the specific risk factors for reduced birth weight, and may help elucidate the biological mechanisms involved. To date, only a few studies have evaluated the effects of $PM_{2.5}$ mass and some $PM_{2.5}$ constituents on birth weight using data from Connecticut and Massachusetts (Bell et al., 2012, 2010), Atlanta, Georgia (Darrow et al., 2011), Los Angeles, California (Wilhelm et al., 2012), and most recently, the Northeast and mid-Atlantic regions (Ebisu and Bell, 2012).

Studies in California are warranted, since the chemical constituents, sources, and levels of particulate matter differ between the western and eastern coasts of the US (Blanchard, 2003). Furthermore, California has a number of air pollution monitors located throughout the state that measure pollutant concentrations for a population diverse in race/ethnicity, socioeconomic status, and age, providing the opportunity to study impacts on potentially vulnerable subgroups. A few previous studies reported associations between $PM_{2.5}$ and birth weight among full-term infants in California even after controlling for carbon monoxide (CO), although $PM_{2.5}$ constituents were not examined (Morello-Frosch et al., 2010; Parker et al., 2005; Wilhelm and Ritz, 2005). A recent study conducted in Los Angeles, California, by Wilhelm et al. found $PM_{2.5}$, nitric oxide, nitrogen dioxide (NO_2), and polycyclic aromatic hydrocarbons (PAHs) to be associated with term LBW (Wilhelm et al., 2012). Only a few $PM_{2.5}$ constituents were considered in the Los Angeles metropolitan area. More studies are needed in

---

[*] Correspondence to: Air Pollution Epidemiology Section, California Office of Environmental Health Hazard Assessment, 1515 Clay St., 16th floor, Oakland, California 94612, USA. Fax: +1 510 622 3210.
E-mail address: Rupa.Basu@oehha.ca.gov (R. Basu).

0013-9351/$ - see front matter © 2013 Elsevier Inc. All rights reserved.
http://dx.doi.org/10.1016/j.envres.2013.10.008

California specifically to examine $PM_{2.5}$ constituents associated with LBW so that compounds and major sources with particularly strong impacts on birth weight can be identified.

In the current study, we examined exposures to $PM_{2.5}$ and several $PM_{2.5}$ constituents on LBW among full-term infants in California over a seven-year period. We stratified by season of births, and also identified vulnerable subgroups by exploring possible modification of effects by maternal characteristics.

2. Methods

2.1. Study population

Our study population consisted of infants born between 2000 and 2006 to mothers residing in California, with birth records accessed from the Natality Database supplied by the California Department of Public Health (California Department of Health Services, 2006). We included singleton live full-term births with gestational ages from 37 through 44 weeks with data available for birth date, birth weight, gestational age, infant sex, maternal ethnicity, maternal educational attainment, maternal age and maternal residential zip code. Births with maternal age >49 years, unreasonable gestational ages ($>$ 44 weeks) or unreasonable combinations of gestational age and birth weights were excluded (Alexander et al., 1996).

2.2. Particulate matter data and exposure assessment

We accessed data on ambient $PM_{2.5}$ mass and concentrations of $PM_{2.5}$ constituents from US EPA monitors in eight sites in California that supplied data during our study period (Los Angeles, Riverside, El Cajon, San Jose, Simi Valley, Bakersfield, Fresno, and Sacramento) (California Air Resources Board, 2011). Data were available from 2000 through 2006, with varying start dates by site (ranging from 2000 to 2002) and some gaps in operation. Monitoring frequency was every 3 or 6 days. $PM_{2.5}$ constituents were included in the analysis if the constituent was monitored continuously throughout the study period and was detected at levels above the laboratory detection limit for at least 30% of sampling days.

We used Arc GIS (Version 9.2) to calculate the distance between the geocoded monitor location and the population-weighted centroid of the 2000 US Census zip code tabulation area associated with the maternal residential zip code reported in the birth record. Zip Code Tabulation Areas are area units developed by the US Census Bureau to represent the geographic boundaries of US Postal Service zip codes (Grubesic and Matisziw, 2006). All births with valid maternal zip codes located within 20 km of a monitor were assigned exposures from that monitor, while all other births were excluded. If there was more than one monitor within 20 km, we assigned exposures using the closest monitor.

We calculated exposure to $PM_{2.5}$ constituents for the full gestational period of each infant, defined as the period between conception (estimated as 2 weeks past the last menstrual period) and birth date. We estimated the date of last menstrual period by subtracting total gestational days from each birth's reported date of birth. We estimated exposures for each trimester of pregnancy, defining the first trimester as the gestational weeks three to 13 post-last menstrual period, the second trimester as the 14–26th weeks and the third trimester as the 27th week through birth. We calculated trimester exposures as the average of weekly mean exposures for all weeks in the trimester if mean data were available for at least 75% of the weeks in that trimester. Weekly exposures were calculated as the mean of all readings for a given $PM_{2.5}$ constituent during each gestational week, provided there was at least one reading during that week. Weekly means for partial weeks occurring at the end of a pregnancy were included in the third trimester mean if the partial week included at least 4 days. Full pregnancy exposure was estimated as the mean of all three trimesters, with births missing exposure measurements for one or more trimesters excluded from the analysis. Calculating trimester and full pregnancy exposures using weekly means reduces bias that may result from variation in sampling frequency across monitors (Bell et al., 2010).

2.3. Covariates

We used demographic covariates from the birth certificate database including maternal race/ethnicity (White: non-Hispanic White, Black: non-Hispanic Black, Hispanic: Hispanic of any race, Asian: non-Hispanic Asian), maternal age (less than 20, 20–24, 25–34, 35–39, greater than 39 years) and maternal educational attainment (fewer than 12 years, 12 years, 13–15 years, 16 years or greater). Additional covariates included: weeks of gestational age, used to account for birth weight differences attributable to variation in gestational age; month of birth, used to control for seasonal patterns in birth weight; year of birth; and infant sex. We calculated average apparent temperature for each trimester and full gestational period using data from centrally located temperature monitors using techniques similar to those used for $PM_{2.5}$ and $PM_{2.5}$ constituents. Temperature and relative humidity readings used to calculate apparent temperature originated from three databases: the US Environmental Protection Agency Data Mart (U.S. EPA, 2009), the National Climatic Data Center (NCDC, 2012), and the California Irrigation Management and Information System (Office of Water Use Efficiency, 2009).

2.4. Statistical analyses

We conducted linear regression analyses relating birth weight to continuous measures of full gestational and trimester exposures to total $PM_{2.5}$ mass and $PM_{2.5}$ constituents, with a separate model used for each exposure variable. All models were adjusted for maternal race/ethnicity, maternal age, maternal educational attainment, weeks of gestational age, month and year of birth, infant sex, and gestational apparent temperature exposure. We also conducted analyses stratified by season of birth (warm, May 1–October 31; or cool, November 1–April 30) and several maternal factors (age, education, and race/ethnicity) to examine whether associations differed across levels of these covariates. To account for potential confounding by regional factors, we adjusted for region: Northern California/ Central Valley (monitors located in San Jose, Sacramento, Fresno, and Bakersfield) and Southern California (monitors located in Simi Valley, Los Angeles, Riverside, and El Cajon). We used percentage groupings for unemployment (0–85%, 86–90%, 91–92.5%, 92.6–95%, 96% and higher), non-White race/ethnicity (10–19%, 20–39%, 40–59%, 60–79%, 80% and higher), and home ownership (under 20%, 20–39%, 40–59%, 60–79%, 80% and higher) by zip code tabulation area provided by the 2000 US Census to adjust for community-level race and socioeconomic status. We also conducted sensitivity analyses limiting our study population to subjects residing within a 5 km and 10 km radius of each monitor. Furthermore, we conducted analyses stratified by maternal age, maternal race/ethnicity, and maternal education and were examined to investigate possible effect modification by these factors. SAS statistical software was used to conduct all analyses (SAS Institute Inc., 2008).

Results are presented as the change in birth weight associated with each interquartile range increase in trimester and full gestational exposures for total $PM_{2.5}$ mass and each constituent. We also conducted logistic regression analyses relating LBW (birth weight less than 2500 g) and full gestational and trimester exposures to total $PM_{2.5}$ mass and $PM_{2.5}$ constituents. Results are presented as percent change ((odds ratio -1) × 100) in risk of LBW per interquartile increase in trimester and full gestational exposures for total $PM_{2.5}$ mass and each constituent. Statistical significance of effect modification was assessed using models with an interaction term between the pollutant and the stratification variable. As a sensitivity analysis, we added a squared term for the $PM_{2.5}$ and each $PM_{2.5}$ constituent in our model as a statistical test of linearity. For models improved by the squared term, we used generalized additive models replacing the linear constituent exposure term with a cubic regression spline term with four degrees of freedom to better visualize the relationship.

3. Results

There were a total of 3,673,224 live, singleton births in California from 2000 through 2006. After excluding the births with missing data on our variables of interest, maternal age greater than 49 years, gestational age greater than 44 weeks or unreasonable combinations of age/birth weight, 3,221,706 births remained. Of these births, 2,930,300 were full-term (from 37 through 44 weeks of gestation), but only 1,078,166 births occurred in the counties included in our study to mothers residing within 20 km of a monitor. Our final study population consisted of 646,296 singleton full-term births from eight counties with full gestational exposure information available for $PM_{2.5}$ and $PM_{2.5}$ constituents. Fig. 1 depicts a map of California with the location of the $PM_{2.5}$ monitors used in our analysis of eight sites.

As shown in Table 1, the majority of mothers were Hispanic, and aged 25–34 years at the time of giving birth. About 32.5% of mothers had completed less than a high school education. A total of 2.4% of infants were found to be term LBW. In addition, infants were slightly more likely to be male, had an average weight of 3401 g, and a mean gestation of 39.3 weeks. Total $PM_{2.5}$ mass and 23 $PM_{2.5}$ constituents had sufficient data to be included in the final analysis (means and standard deviations by site listed in Table 2). In Table 3, the correlation between $PM_{2.5}$ and each $PM_{2.5}$ constituent are listed, as well as the correlations between the gaseous