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Air Pollution and Birth Weight Among Term Infants in California

Jennifer D. Parker, PhD*; Tracey J. Woodruff, PhD, MPH‡; Rupa Basu, PhD‡; and Kenneth C. Schoendorf, PhD, MPH*

ABSTRACT. ***Objective.*** **To examine associations between birth weight and air pollution among full-term infants in California.**

Methods. **We matched exposure data collected from air pollution monitors for small particles ($PM_{2.5}$) and carbon monoxide (CO) to California birth records for singleton births delivered at 40 weeks' gestation in 2000 using the locations of the monitors and mother's residence. Pollution measurements collected within 5 miles of the mother's residence, averaged for the time period corresponding to the duration of pregnancy and each trimester, were used as exposure variables. Logistic and linear regression models were used to estimate the associations between the pollution measures and 2 pregnancy outcomes: small for gestational age (SGA) and birth weight. Variations of the models were used to examine the robustness of the findings.**

Results. **The adjusted odds ratio for SGA for exposure in the highest compared with lowest quartile of $PM_{2.5}$ was 1.26 (95% confidence interval [CI]: 1.03–1.50). We found no association between CO and birth weight or SGA after controlling for maternal factors and $PM_{2.5}$ (mean birth weight difference: 2.6 g; 95% CI: −20.6 to 25.8). The difference in mean birth weight for infants with a 9-month exposure in the highest quartile of $PM_{2.5}$ compared with that of infants who were exposed in the lowest quartile was −36.1 g (95% CI: −16.5 g to −55.8 g); this difference was similar after controlling for CO. We did not find $PM_{2.5}$ exposure during a particular trimester most important for assessing birth weight; trimester-level associations were similar to those found using the 9-month exposure variable.**

Conclusions. **We found an increased odds of SGA and a small difference in mean birth weight between infants with the highest and lowest exposures to $PM_{2.5}$ but not CO. These findings have important implications for infant health because of the ubiquitous exposure to fine particulate air pollution across the United States.** ***Pediatrics*** **2005;115:121–128;** ***air pollution, birth weight, environmental factors, fetal growth restriction.***

ABBREVIATIONS. CO, carbon monoxide; TSP, total suspended particulate; PM_{10}, particulate matter measuring less than 10 μm; $PM_{2.5}$, particulate matter measuring less than 2.5 μm; SGA, small for gestational age; CI, confidence interval; AOR, adjusted odds ratio.

Evidence from the United States and elsewhere suggests that a variety of poor perinatal outcomes may be associated with exposure to poor air quality.[1–12] In Southern California, the risks for birth defects, preterm delivery, and low birth weight (birth weight <2500 g) have been found to be higher with higher levels of air pollution, mostly associated with particulate-matter air pollution and carbon monoxide (CO).[2–4] In the northeastern United States, however, associations between trimester exposures to various pollutants and term low birth weight were inconsistent among trimester of exposure, maternal race, and pollutant.[5] International studies have reported that Polish infants who were exposed to high levels of fine particles had lower birth weights than their counterparts with lower exposure levels[7]; Beijing mothers living in residential areas with higher exposure to sulfur dioxide and total suspended particulates (TSPs) during the third trimester were at increased risk for delivering a low birth weight infant[8] and delivering prematurely,[9] and first-trimester exposure to higher levels of pollutants increased the risk for low birth weight among term infants in Seoul.[10] A recent study in Sao Paulo, Brazil, found impaired fetal growth among infants with relatively high exposure to CO in the first trimester.[11] A study of data from the Czech Republic found that infant intrauterine growth retardation among full-term infants was more common for mothers who were exposed to high levels of particulate matter during the first trimester, although not later during pregnancy[12]; additional work from the Czech Republic led to the conclusion that some of this association could be attributed to the polycyclic aromatic hydrocarbons, bound to small particles.[13] After delivery, higher levels of air pollution may increase the risk for infant mortality.[14–17] Although socioeconomic and racial disparities in infant health outcomes are well documented and disadvantaged groups may be exposed to higher levels of pollution,[18] the potential confounding effects of demographic factors on the association between infant health and air pollution are not well understood. A systematic review of studies of particulate air pollution and infant health concluded that the evidence is consistent with a possible effect of air pollution on birth weight but also could be consistent with no effect as the studies included in review are primarily

From the *Office of Analysis and Epidemiology, National Center for Health Statistics, Hyattsville, Maryland; and the ‡National Center for Environmental Economics, US Environmental Protection Agency, Washington, DC.
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Reprint requests to (J.D.P.) Office of Analysis and Epidemiology, National Center for Health Statistics, 3311 Toledo Rd, Hyattsville, MD 20782. E-mail: jdparker@cdc.gov
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from outside the United States and show different associations for exposures during different periods of pregnancy as well as between population subgroups.[1]

Many previous studies of particulate-matter air pollution and birth outcomes have primarily focused on particulate matter measuring less than 10 μm (PM_{10}) or TSP.[1] Both PM_{10} and TSP have been shown to cause a range of other health effects, including mortality and morbidity from cardiovascular- and respiratory-related causes.[19] Studies in the past several years indicate that it may be the smaller particles, measuring less than 2.5 μm ($PM_{2.5}$), that are more likely to be associated with these health effects.[19–21] These particles are considered potentially more toxic as the majority of them are from combustion sources, such as cars, utilities, and wood burning, rather than crustal sources, such as road dust and agricultural fields. A study from the Czech Republic found similar associations between particulates and birth weight using both $PM_{2.5}$ and PM_{10}[12]; however, the components of particulates in the Czech Republic, including PM_{10} and $PM_{2.5}$, may differ from those of the United States. In addition, pollution levels are lower in the United States than in the Czech Republic. Particulate matter may have systemic influences on pregnant women, including placental development or transplacental effects, that may result in adverse birth outcomes[22] or indirectly by influencing the health of the mother. Monitoring networks for $PM_{2.5}$ have been established in the United States since 1999, which provides an opportunity to study the effects of this component of particulate-matter air pollution on health.

To assess the relationship between fine particles and perinatal health, we used the recently available monitoring data in California for $PM_{2.5}$ to examine the relationship between fine particles, as measured by $PM_{2.5}$, and birth weight among full-term infants who were delivered in 2000 and to assess whether CO is a potential confounder or contributor. Additional analysis examined the association between CO and birth weight; CO was found to be associated with birth weight in a previous study of California mothers[3] and could potentially confound the relationship between $PM_{2.5}$ and birth weight. For our study, we calculated average pollution exposure using monitoring data from all monitors within 5 miles of the mother's residence. For each birth, we calculated averages for the time periods corresponding to the 9 months of pregnancy as well as for each trimester; trimester-specific exposures were examined to identify potentially critical times during pregnancy when particulates may affect birth weight. We used 2 outcome measures: (1) birth weight, measured continuously, and (2) small for gestational age (SGA), a classification that separates infants who are below and above the 10th percentile of birth weight for gestational age. We limited the study to infants who were delivered at 40 weeks' gestation to investigate specifically the relationship between pollution and intrauterine growth, without the potentially confounding effects of pregnancy duration on birth weight; limiting the study to 1 gestational week also reduces the potential for bias associated with the calculation of the exposure over the different lengths of pregnancy.

METHODS

Exposure Measurements

Pollution monitoring data for 1999 and 2000 were obtained from the California Air Resources Board for $PM_{2.5}$ and CO (California Air Quality Data, 2003, unpublished data). $PM_{2.5}$ was measured every 6 days, for example, twice in a 12-day period, and CO was monitored each day. We used the 24-hour average CO value, which was highly correlated with the other calculated CO measures, including the 8-hour maximum average CO value. PM monitors with fewer than 45 $PM_{2.5}$ measurements over 1 year were not considered representative of the entire exposure period and were excluded. CO monitors specifically designed to collect background concentrations or source-specific concentrations of CO were excluded. No $PM_{2.5}$ monitors were specified as background or source oriented.

Before we calculated the pregnancy-specific exposure variables, we trimmed the top and bottom 5% of the annual measurements from the set of monitoring values to better approximate average exposures without the influence of extreme measurements.[23] For each birth, measurements obtained from monitors within 5 miles of the mother's residence were used for the exposure calculations. Distances between maternal residence at the time of delivery and each of the $PM_{2.5}$ and CO monitors were computed using the corresponding latitudes and longitudes; although we used an equation for the distance incorporating the curvature of the earth, because we limited our study sample to mothers who lived within 5 miles of a monitor, the actual distances calculated were nearly identical to the usual Cartesian distance between 2 points. When >1 monitor was available within 5 miles, an average of the measurements from the corresponding monitors was calculated. In turn, 9-month and trimester-specific $PM_{2.5}$ and CO variables were calculated by using the measurements and the dates of the measurements collected from the identified monitors within 5 miles of each mother's residence. For example, for an infant who was born at the beginning of December, third-trimester exposure would be calculated from the measurements obtained from the 27th week of gestation in the beginning of September until the date of birth in early December; 9-month exposure measures were calculated using all measurements during pregnancy. The median number of measurements used to calculate the 9-month $PM_{2.5}$ exposure variable was 82, with an interquartile range of 69 to 143 measurements; for the 9-month CO variable, the median number of measurements was 264, with an interquartile range of 250 to 274. Quartiles of exposure for $PM_{2.5}$ and CO were defined using the observed distributions in the study population.

Study Population

Birth certificate information was obtained from the California Department of Health Services (California Automated Vital Statistics System, 2000, unpublished data). To examine specifically the association between pollution exposure and fetal growth, we limited the eligible study population to singleton infants who were delivered in 2000 at 40 weeks' gestation; although infants who are delivered after 37 weeks are considered "full term," we did not want to complicate our analysis by considering the potential effect of pollution on gestational age, even among full-term infants; furthermore, this restriction allowed exposure measures to be calculated from measurements over the same length of time. Birth weight, measured continuously, was used as a marker of fetal growth. SGA, a dichotomous indicator of small size, was used as a marker of growth restriction; using a previously developed growth standard, for this study of infants delivered at 40 weeks, SGA was defined as a birth weight <2872 g for girls and <2986 g for boys.[23]

Maternal socioeconomic and demographic factors are associated with both pollution exposure[18] and birth weight[24,25]; thus, we excluded the few births with missing data for 1 or more of the following covariates: maternal race, maternal Hispanic origin, marital status, parity, maternal education (<12 years, 12 years, 13–15 years, and 16 or more years), and maternal age (<20 years, 20–34 years, 35 or more years). These variables were used to compare our study population with the overall population of births as well as to control for the confounding effects of demographic factors on the association between birth weight and air pollution in multiple regression models. Maternal race and Hispanic origin were collapsed into a single variable with 5 mutually exclusive categories (black, Asian, Mexican, white, and other); there were too few mothers in other groups to separate additional categories. Furthermore, although mothers who are of Hispanic origin can be of any race, nearly all Mexican mothers in this California data set were coded as white; as demographic characteristics and pollution exposures may differ between non-Hispanic white and Mexican mothers, creating separate categories for each group was appropriate. The few mothers who were Hispanic but not Mexican were categorized by race rather than included with the Mexican mothers because there are large differences in birth outcomes between Hispanic subgroups,[26] and nearly all Hispanic mothers in California are Mexican (>87% in 2000). Season of delivery was categorized into winter (January, February, and March), spring (April, May, and June), summer (July, August, and September), and autumn (October, November, and December) and included in regression models as a categorical variable.

Of the 108 420 singleton births that were delivered at 40 weeks' gestation, 689 were missing 1 or more of the maternal variables described above and 11 470 could not be geocoded and were excluded. Of the remaining births, only 18 247 lived within 5 miles of monitors for both CO and $PM_{2.5}$; these births compose our final study population. Of these mothers, 79% had a single $PM_{2.5}$ monitor and 76% had a single CO monitor within 5 miles of their residence. Resulting exposure measures were calculated from 44 CO and 40 $PM_{2.5}$ monitors located in 28 California counties. As reference, ~85% of California births occurred in these 28 counties. Our study sample of births linked to monitoring data were similar in maternal characteristics to the larger number of singleton births that were delivered at 40 weeks (Table 1).

Analysis

Beginning with the overall pregnancy, referred to as 9-month exposure, we calculated the mean birth weight and percentage SGA by quartile of exposure. With linear regression models, we estimated the change in birth weight for infants who were exposed in the highest 3 quartiles of air pollution exposure compared with those who were exposed to the levels in the lowest quartile. Similarly, we used logistic regression models to estimate the change in odds of SGA for infants who were exposed in the highest 3 quartiles of air pollution exposure compared with those who were exposed to the lowest quartile. The maternal factors described above (age, primiparity, race and ethnicity, education, and marital status), as well as season of delivery, were included in the regression models to obtain adjusted estimates. Then, both $PM_{2.5}$ and CO were included in the same models to determine the potentially confounding effects of each pollutant on the relationship between the other pollutant and birth outcome. Quartiles of pollution levels were used in the initial models because we did not want to impose a linear relationship between the exposures and the outcomes, as well as to ease interpretation of the results.

Variations of the models were fit to examine our assumptions and the robustness of the findings. First, continuous forms of the 9-month exposure variables were modeled, rather than the quartiles, to provide a summary of the associations comparable with other studies.[1] Transformations of the 9-month $PM_{2.5}$ and CO exposure variables were included in the linear and logistic regression models to capture nonlinearities implied by the quartile analysis, including logarithmic and power terms. To investigate whether associations between the 9-month pollution exposures and birth weight outcomes differed by maternal race or education, we tested interaction terms; these interactions were considered plausible given the differing associations between pollution and birth weight found among race groups in the northeastern study.[5]

Second, because the relationship between birth weight and air pollution may depend on the geographic area used to define the exposure,[23] we replicated the models using 9-month exposures calculated using measurements from just the monitor nearest the mother's residence, with and without controlling for the distance between the mother's residence and the monitor.

Third, because both the timing of pregnancy and the mother's residence differ among births, the calculated PM and CO exposures, by design, differ among births; nevertheless, the values of the PM and CO variables for mothers with proximal addresses may be similar. To account for this possible correlation, we examined the residuals of the initial models by county; this level of analysis to examine clustering was deemed suitable, if not ideal, because the exposure monitors for 95% of mothers were located within their county of residence. Additional models were fit as if exposures were clustered by county, obtaining robust standard errors in Stata.[27]

To examine trimester-level relationships, we fitted models that were comparable to the 9-month models using the quartiles of the trimester values of each pollutant. For this study, the first trimester was defined as weeks 1 to 13 of pregnancy, the second trimes-

TABLE 1. Characteristics of Births in Study Sample Compared With the Overall Population of Singleton Infants Delivered at 40 Weeks: California, 2000

Characteristics	Study Sample (*N* = 18 247)	All Singleton Infants Delivered at 40 Weeks (*N* = 107 731)
Maternal factors		
Age, %		
<20 y	11.3	10.7
20–34 y	74.7	74.6
35 y or older	14.0	14.7
Married, %	70.6	70.1
Parity, % first birth	43.9	42.5
Education, %		
<12 y	27.6	29.6
12 y	28.8	28.0
13–15 y	20.0	19.7
16 y or more	23.6	22.7
Race and Hispanic origin, %		
Asian	15.0	11.8
Black	6.0	5.8
Mexican American or Latino	40.9	42.7
White	37.4	38.9
Some other race or ethnicity	0.8	0.8
Birth outcomes		
Birth weight, mean (SD)	3523 (452)	3526 (452)
SGA, %	8.38	8.41

Study sample consists of singleton infants who were delivered at 40 weeks' gestation with information for maternal age, maternal race and Hispanic origin, maternal education, and birth weight and mothers who lived within 5 miles of PM and CO monitors. All singleton infants who were delivered at 40 weeks' gestation with information for the maternal characteristics described in the table.

ter was defined as 14 to 26 weeks, and the third trimester was defined as 27 to 40 weeks. Quartiles of exposure were defined using the 9-month cutpoints to ease comparisons; these cutpoints were similar but not identical to those that were calculated separately for each trimester. Maternal demographic variables and season of delivery were included in the trimester-specific linear and logistic regressions.

RESULTS

The mean 9-month exposure to $PM_{2.5}$ was 15.4 $\mu g/m^3$ (SD: 5.1 $\mu g/m^3$), and the mean 9-month exposure to CO was 0.75 ppm (SD: 0.23 ppm); the correlation between the 9-month $PM_{2.5}$ exposure and the 9-month CO exposure was 0.60. Slightly more SGA infants were born to mothers who lived in the highest quartile of 9-month $PM_{2.5}$ exposure, which corresponded to lower mean birth weights among infants in this group (Table 2). There was no association between SGA and quartile of 9-month CO exposure, although the mean birth weight of infants who were born to mothers who lived in areas with the highest levels of CO were lower than those who were born to mothers in other areas.

Infants who were exposed to $PM_{2.5}$ levels in the highest quartile, on average, had birth weights ~25 g lower than infants who were exposed to levels in the lowest quartile; this decrement was ~35 g after adjustment for maternal factors and season of delivery. Additional adjustment for CO did not affect the association between $PM_{2.5}$ and birth weight (Table 3). Associations for SGA were similar. However, unlike the models for birth weight, the elevated odds of SGA among infants in the highest quartile compared with those in the lowest increased after adjustment for CO. Conversely, the association between CO and birth weight disappeared after adjustment for $PM_{2.5}$. Indeed, the confidence interval (CI) for the lowered odds of SGA for high exposure for CO excludes the null value of 1.0, although there is no rationale to expect a protective effect of high CO levels on SGA (Table 3).

Estimated coefficients from linear regression models of birth weight as a continuous variable indicated a change in mean infant birth weight of −29.3 g (95% CI: −42.2 g to −16.4 g) for each 10-$\mu g/m^3$ change in 9-month $PM_{2.5}$. The strength of this association increased slightly after adjustment for maternal factors, season of delivery, and 9-month CO exposure (−38.2 g; 95% CI: −54.9 g to −21.6 g). The unadjusted odds ratio for SGA for a 10-$\mu g/m^3$ change in 9-month $PM_{2.5}$ exposure was 1.10 (95% CI: 0.99–1.22), which increased slightly when other variables were added to the regression model (adjusted odds ratio [AOR]: 1.20; 95% CI: 1.07–1.37). Associations between 9-month CO exposure and birth outcomes were weaker than those observed for $PM_{2.5}$ exposure (data not shown), and, as the categorical analysis, after controlling for 9-month PM 2.5 exposure, the relationship between CO exposure and birth outcome disappeared; for example, the AOR for a 0.5-ppm increase in CO and SGA was 0.89 (95% CI: 0.77–1.03).

To capture potential nonlinear associations between exposure and birth weight, we tested the transformations of the 9-month exposure measures. Transformed variables, however, did not perform better in the models than the untransformed variables. For example, when both the linear and the squared terms were included in the full models, the coefficient for the squared term was not significantly different from 0, suggesting that the evidence for a nonlinear relationship is weak (data not shown). Interactions between the exposure measures and 2 de-

TABLE 2. Mean Birth Weight and Percentage SGA by Quartile of Nine-Month $PM_{2.5}$ and CO Exposure

Quartiles of Exposure	Birth Weight Outcome	
	SGA, %	Birth Weight, mean g
$PM_{2.5}$ μ/m^3		
<11.9	8.5	3528
11.9–13.9	7.5	3544
13.9–18.4	8.4	3517
>18.4	9.2	3502
	$P = .04$*	$P < .001$†
CO, ppm		
<0.57	8.6	3531
0.57–0.76	8.1	3538
0.76–0.93	8.3	3515
>0.93	8.5	3507
	$P = .83$*	$P < .01$†

* Assessed using χ^2 test.
† Assessed using 1-way analysis of variance.

TABLE 3. Associations Between Birth Outcomes and Nine-Month Maternal Exposure to $PM_{2.5}$ and CO

	Birth Weight, mean g		SGA	
	β	95% CI	OR	95% CI
PM 2.5, μ/m^3				
Unadjusted				
<11.9	Referent		Referent	
11.9–13.9	16.1	−2.4 to 34.7	0.87	0.75 to 1.02
13.9–18.4	−10.5	−29.0 to 8.1	0.99	0.85 to 1.15
>18.4	−25.4	−44.0 to −6.9	1.09	0.94 to 1.26
Adjusted*				
<11.9	Referent		Referent	
11.9–13.9	8.4	−10.6 to 27.4	0.87	0.75 to 1.02
13.9–18.4	−13.7	−34.2 to 6.9	0.97	0.82 to 1.15
>18.4	−36.1	−55.8 to −16.5	1.12	0.96 to 1.31
Adjusted†				
<11.9	Referent		Referent	
11.9–13.9	11.8	−8.8 to 32.4	0.90	0.76 to 1.07
13.9–18.4	−11.3	−33.5 to 10.9	1.03	0.86 to 1.23
>18.4	−35.3	−58.6 to −12.0	1.23	1.03 to 1.50
CO, ppm				
Unadjusted				
<0.57	Referent		Referent	
0.57–0.76	7.4	−11.1 to 25.9	0.94	0.81 to 1.09
0.76–0.93	−16.1	−34.9 to 2.6	0.96	0.83 to 1.12
>0.93	−24.1	−42.8 to −5.3	0.99	0.86 to 1.15
Adjusted*				
<0.57	Referent		Referent	
0.57–0.76	3.0	−15.7 to 21.8	0.93	0.80 to 1.09
0.76–0.93	−7.3	−26.0 to 11.4	0.91	0.78 to 1.06
>0.93	−20.5	−40.1 to −0.8	0.95	0.81 to 1.12
Adjusted‡				
<0.57	Referent		Referent	
0.57–0.76	7.4	−11.7 to 26.6	0.90	0.77 to 1.06
0.76–0.93	−5.9	−26.4 to 14.4	0.91	0.77 to 1.07
>0.93	2.6	−20.6 to 25.8	0.82	0.68 to 0.99

* Adjusted for maternal race, education, marital status, age, parity, and season of delivery.
† Adjusted for above variables in * and CO.
‡ Adjusted for above variables in * and $PM_{2.5}$.

mographic variables—maternal race/ethnicity and maternal education—were tested to determine whether the effect of air pollution on birth weight or SGA differed by levels of these demographic factors; these interactions were not statistically significant (data not shown) and thus not retained in our models.

Using the measurements from the nearest monitor only, we compared the relationships between the birth weight outcomes and pollution controlling for the distance between the mother's residence and the nearest monitor; the regression coefficients were similar, suggesting that relationships between birth weight and these pollution exposures are not affected by the distance between the exposure measure and maternal residence, at least among mothers who live within a 5-mile radius of a monitor (data not shown). Controlling for possible clustering within counties increased the standard errors of the regression coefficients and, subsequently, widened the CIs. However, point estimates were nearly identical, and inferences from the model were unchanged (data not shown). Given that each mother's exposure was calculated both by location and by day of birth, this weak effect of clustering is not unexpected. Visual inspection of model residuals by county did not suggest excessive clustering. Furthermore, as exposures were defined by timing of pregnancy and mother's residence, as well as the recent finding that associations that are based on neighborhood exposures may differ from those that are based on county-level exposures,[23] we decided to present the results from the original analysis and proceed with a similar trimester-level analysis.

Trimester-Level Analysis

Mean exposure levels by trimester were similar to the 9-month exposures (Table 4). Table 5 provides correlations among the trimester-level exposures as well as between them and the 9-month exposure. Because the trimester-level exposure measures are subsets of the 9-month measure, the correlations between the trimester-level exposures and the corresponding 9-month exposure were high. Between trimesters, however, the correlations were smaller, possibly reflecting seasonal variation in exposure. Correlations between $PM_{2.5}$ and CO at each trimester were ~0.6.

The associations between birth weight and the trimester-level exposures to $PM_{2.5}$ were similar to that between birth weight and 9-month $PM_{2.5}$ exposure (Table 6). For example, after adjustment for maternal factors, season of delivery, and concurrent CO exposure, exposure to the highest $PM_{2.5}$ level in the first trimester led to a decrease in mean birth weight of 35.8 g relative to exposure in the lowest exposure group. AORs describing the association between trimester-level exposure to $PM_{2.5}$ and SGA were ~1.2 for a difference in $PM_{2.5}$ exposure between the highest and lowest levels, suggesting a persistent, if modest, effect of $PM_{2.5}$ exposure on the risk for SGA. We found no association between CO and either birth weight or SGA after adjustment for concurrent trimester-level $PM_{2.5}$ exposure (Table 6).

TABLE 4. Means and SDs of Nine-Month and Trimester Exposures to $PM_{2.5}$ and CO

Exposure	Mean	SD
$PM_{2.5}$, μ/m^3		
9-month	15.42	5.08
First trimester	15.70	6.26
Second trimester	15.40	6.53
Third trimester	14.29	6.35
CO, ppm		
9-month	0.75	0.23
First trimester	0.78	0.31
Second trimester	0.77	0.30
Third trimester	0.73	0.27

DISCUSSION

We have shown a small but consistent effect of $PM_{2.5}$ on birth weight for infants who were born full term; because our analysis includes only infants who were born at 40 weeks' gestation, these associations are not confounded by potential effects of pollution levels on length of pregnancy[2]; in addition, the calculation of pollution exposure was not complicated by differential gestational ages—all 9-month exposures, for example, were based on 40 weeks of collected measurements. We found that California mothers who lived in areas with the highest levels of $PM_{2.5}$ during their pregnancy delivered slightly smaller infants than their counterparts who lived in areas with lower levels of $PM_{2.5}$ exposure; this association persisted by trimester of exposure as well as after controlling for demographic factors and concurrent exposure to CO. Furthermore, the magnitude of the association, an approximate decrease of 30 g between the highest and lowest quartiles of $PM_{2.5}$, was compatible with the recent study from Poland, where average pollution levels were considerably higher, which reported an average birth weight decrement of ~140 g for a 40-μ/m^3 change in $PM_{2.5}$. These findings are in line with Glinianaia et al,[1] who concluded in their recent review that there may be a small association between exposure to particulate matter and birth weight.

Fine particulate matter may be affecting birth weight through direct or indirect means. Fine particles have been shown to be associated with a number of cardiovascular- and respiratory-related outcomes in adults and children.[19–22,29] Maternal exposure to fine particles during pregnancy could indirectly affect fetal health by adversely affecting the health of the mother; alternatively, fine particles could directly affect the health of the infant, as fine particles are a mixture of different substances, many of the them toxic, such as metals, and can also have toxic organic matter, such as polycyclic aromatic hydrocarbons,[13] absorbed on their surface.

In contrast, we found no persistent associations between CO and birth weight. Although the unadjusted associations between CO and birth weight were similar to those observed for $PM_{2.5}$, after controlling for $PM_{2.5}$ exposure, associations between CO and birth weight (or SGA) became negligible. In contrast, Ritz et al[3] found that CO exposure increased the risk for term low birth weight in South-

TABLE 5. Correlation Coefficients Between Nine-Month and Trimester Exposures to $PM_{2.5}$ and CO

	$PM_{2.5}$				CO			
	9-Month	First Trimester	Second Trimester	Third Trimester	9-Month	First Trimester	Second Trimester	Third Trimester
$PM_{2.5}$								
9-month	1.00							
First trimester	0.75	1.00						
Second trimester	0.88	0.58	1.00					
Third trimester	0.81	0.37	0.63	1.00				
CO								
9-month	0.60	0.48	0.53	0.39	1.00			
First trimester	0.36	0.63	0.17	0.06	0.73	1.00		
Second trimester	0.56	0.45	0.64	0.25	0.88	0.53	1.00	
Third trimester	0.48	0.07	0.41	0.60	0.74	0.22	0.55	1.00

All correlation coefficients shown are significantly different from 0, $P < .001$.

TABLE 6. Adjusted* Associations Between Birth Weight and SGA and Trimester of Maternal Exposure to $PM_{2.5}$ and CO

	Birth Weight, mean g		SGA	
	β*	95% CI	OR*	95% CI
$PM_{2.5}$, μ/m³				
First trimester				
<11.9	Referent		Referent	
11.9–13.9	−5.7	−27.9 to 16.5	1.02	0.84 to 1.23
13.9–18.4	−2.5	−24.5 to 19.5	1.12	0.93 to 1.34
>18.4	−35.8	−58.4 to −13.3	1.26	1.04 to 1.51
Second trimester				
<11.9	Referent		Referent	
11.9–13.9	11.3	−12.2 to 34.9	.89	0.73 to 1.09
13.9–18.4	−17.2	−39.4 to 4.9	1.05	0.88 to 1.26
>18.4	−46.6	−68.6 to −24.6	1.24	1.04 to 1.49
Third trimester				
<11.9	Referent		Referent	
11.9–13.9	8.3	−13.1 to 29.8	1.00	0.83 to 1.19
13.9–18.4	−8.1	−30.2 to 13.9	0.98	0.82 to 1.18
>18.4	−31.6	−52.0 to −11.1	1.21	1.02 to 1.43
CO, ppm				
First trimester				
<0.57	Referent	Referent	Referent	
0.57–0.76	−6.3	−25.9 to 13.3	0.87	0.74 to 1.02
0.76–0.93	6.9	−14.6 to 28.3	0.84	0.70 to 1.00
>0.93	−7.3	−29.7 to 15.0	0.91	0.76 to 1.09
Second trimester				
<0.57	Referent	Referent	Referent	
0.57–0.76	6.1	−12.4 to 24.6	0.93	0.80 to 1.08
0.76–0.93	8.4	−13.3 to 30.1	0.86	0.72 to 1.03
>0.93	14.2	−8.9 to 37.3	0.80	0.66 to 0.97
Third trimester				
<0.57	Referent	Referent	Referent	
0.57–0.76	−0.3	−18.0 to 17.3	0.92	0.80 to 1.06
0.76–0.93	−3.6	−24.7 to 17.6	0.83	0.69 to 0.99
>0.93	−8.4	−32.2 to 15.3	0.90	0.75 to 1.10

* Adjusted for maternal factors (maternal race and Hispanic origin, maternal education, marital status, maternal age, primiparity, and season of delivery) concurrent with trimester exposure of CO ($PM_{2.5}$ models) or $PM_{2.5}$ (CO models).

ern California, even after controlling for TSP. Design or temporal differences in our 2 studies, such as differing measures of CO exposure and control for $PM_{2.5}$ in our study instead of TSP in the Ritz study,[3] may have contributed to the discrepancy.

This study is limited by several factors that impede definitive conclusions about air quality and health. Deciding on the appropriate measure of pollution exposure is challenging. Although we averaged air pollution measurements that were taken over the pregnancy or trimester of pregnancy, which is likely the best general indicator of exposure, the distribution of the exposure during pregnancy was not considered. For example, consistently moderate pollution levels and low pollution levels with occasional high levels both may lead to a similar average measure of exposure. Furthermore, not surprising, models were unstable with the simultaneous inclusion of exposures from all 3 trimesters or with the inclusion of both a particular trimester exposure and the 9-month exposure, making conclusions about the relative importance of exposure during a particular trimester difficult.

Similarly, the effect of geographic unit of exposure measurements on inferences is unclear. On the one hand, assigning exposure to each mother from measurements taken within 5 miles of her house is 1 way to capture exposure; on the other hand, mothers are not likely to spend their time at their homes, suggesting that averaging over larger distances or other geographic units, such as counties, might be a more accurate way to measure "average" exposure. Exposure for a particular birth has been measured differently across studies; for example, the northeastern US study used city-specific pollution exposures,[5] whereas Ritz et al[3] defined exposure using monitoring data within 2 miles of a mother's zip code of residence. Ritz et al[3] examined the possible effect of geography by limiting their study to women who had already had 1 live birth under the assumption that they might be more likely to spend their days closer to home; they found that the association between CO and birth weight was stronger in this subgroup of mothers. When we similarly limited our study to multiparous or adolescent mothers, the associations in this study did not change much. Basu et al[23] reported greater associations between birth weight and $PM_{2.5}$ when $PM_{2.5}$ was averaged over counties rather than using monitors closer to a mother's house; however, the reasons for this difference were not identified. Finally, the underlying populations are often homogeneous within studies and differ between studies, especially between countries but also within the United States; the study from Georgia enrolled primarily black mothers,[6] whereas studies from Southern California have a large proportion of Mexican births.[2–4] We adjusted for a variety of maternal demographic factors in this study, although the effect of those adjustments on our findings was minimal. Maternal smoking was not available on these California birth records. Although its inclusion in our study could potentially change our conclusion, a preliminary examination of the effect of maternal smoking on the association between particulate matter and birth weight using birth records for Arizona and Florida found minimal change in the association between particulate matter and infant birth weight after controlling for maternal smoking.[30]

Despite these limitations, our work shows a consistent, if weak, association between birth weight and $PM_{2.5}$. The ability to examine exposure measures using measurements within 5 miles of each mother's home may be better than broader geographic units, particularly for mothers who live in large counties. The sizable number of California infants enabled us to limit the study to births at 40 weeks, reducing the effect of gestational age on both the calculation of exposure and its effect on birth weight. The use of both a continuous and a dichotomous outcome enabled us to examine both the central and the tail components of the birth weight distribution.

Our study is consistent with the growing number of studies published each year documenting an increased likelihood of adverse birth outcomes among mothers with the highest levels of pollution exposure. Even in California, where the average levels of $PM_{2.5}$ and CO are low relative to many other countries, the average birth weight for infants with mothers who are exposed to the highest levels of pollution was lower than it was for infants with mothers who lived in areas with lower exposure levels.

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AGING PARENTS OF DISABLED OFFSPRING

"After a lifetime of caring for their developmentally disabled children, a generation of parents is reaching the same painful crossroads, realizing that they can't do this much longer. During the 1950s and 1960s, these pioneering mothers and fathers were among the first to shun institutional care, insisting on a place for their children in society rather than on its fringes. They were a major force behind laws requiring schools to allow disabled children into mainstream classrooms or to set up special programs for them. In raising their children at home, these parents had little support from outside organizations, leaving them largely on their own to be parent, nurse, and teacher for children with then-baffling conditions. They saved the government hundreds of millions of dollars in expensive care. They also set the standard that subsequent generations of parents have embraced. Today, about 76% of the 4.3 million people with developmental disabilities live at home; a quarter of them are cared for by a family member who is ≥60 years old. Most of the rest live in supervised settings or on their own. That dedication enriched lives and created a symbiosis between parent and child that strengthened over time, but that time likewise makes untenable. Now in their 60s, 70s, and 80s, some with weak hearts or limbs and others coming off bypass surgery or chemotherapy, these aging parents are realizing that carrying a disabled adult child down the steps is dangerous. Tending to breathing tubes throughout the night is exhausting. These parents' lifelong concern with their child's mortality is coupled with a growing awareness of their own."

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