Residential Proximity to Traffic and Adverse Birth Outcomes in Los Angeles County, California, 1994–1996

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We reported previously that increases in ambient air pollution in the Los Angeles basin increased the risk of low weight and premature birth. However, ambient concentrations measured at monitoring stations may not take into account differential exposure to pollutants found in elevated concentrations near heavy-traffic roadways. Therefore, we used an epidemiologic case–control study design to examine whether residential proximity to heavy-traffic roadways influenced the occurrence of low birth weight (LBW) and/or preterm birth in Los Angeles County between 1994 and 1996. We mapped subject home locations at birth and estimated exposure to traffic-related air pollution using a distance-weighted traffic density (DWTD) measure. This measure takes into account residential proximity to and level of traffic on roadways surrounding homes. We calculated odds ratios (ORs) and risk ratios (RRs) for being LBW and/or preterm per quintile of DWTD. The clearest exposure-response pattern was observed for preterm birth, with an RR of 1.08 [95% confidence interval (CI), 1.01–1.15] for infants in the highest DWTD quintile. Although higher risks were observed for LBW infants, exposure-response relations were less consistent. Examining the influence of season, we found elevated risks primarily for women whose third trimester fell during fall/winter months ($OR_{term\ LBW}$ = 1.39; 95% CI, 1.16–1.67; $OR_{preterm\ and\ LBW}$ = 1.24; 95% CI = 1.03–1.48; $RR_{all\ preterm}$ = 1.15; 95% CI, 1.05–1.26), and exposure-response relations were stronger for all outcomes. This result is consistent with elevated pollution in proximity to sources during more stagnant air conditions present in winter months. Our previous research and these latest results suggest exposure to traffic-related pollutants may be important. *Key words:* air pollution, epidemiology, low birth weight, preterm birth, traffic density. *Environ Health Perspect* 111:207–216 (2003). [Online 4 November 2002] doi:10.1289/ehp.5688 available via *http://dx.doi.org/*

Epidemiologic studies addressing the relationship between ambient air pollution and fetal development are accumulating worldwide. Studies conducted in China (Wang et al. 1997; Xu et al. 1995), Brazil (Pereira et al. 1998), the Czech Republic (Bobak and Leon 1999; Dejmek et al. 1999; Perera et al. 1999), Mexico (Loomis et al. 1999), Korea (Ha et al. 2001), and the United States (Woodruff et al. 1997) linked ambient air pollution exposure during pregnancy with term low birth weight (LBW), intrauterine growth retardation (IUGR), preterm birth, and perinatal mortality. We recently reported that increases in carbon monoxide, particulate matter < 10 µm in aerodynamic diameter (PM_{10}), and ozone concentrations during vulnerable pregnancy periods increased the risk of term LBW (Ritz and Yu 1999), preterm delivery (Ritz et al. 2000), and certain cardiac malformations, such as ventricular septal defects (Ritz et al. 2002). CO is released directly in motor vehicle exhaust and does not react readily in the atmosphere to form other compounds. Fine (< 2.5 µm) and ultrafine (< 0.1 µm) particles are also released directly in vehicle exhaust but undergo physical and chemical transformations in the atmosphere as they disperse from the roadway (Zhu et al. 2002). The consistently observed associations between ambient CO concentrations and adverse birth outcomes in our previous studies suggest that compounds in motor vehicle exhaust (either CO or associated compounds such as fine and ultrafine particles) may affect fetal development.

In our previous studies (Ritz and Yu 1999; Ritz et al. 2000, 2002), air pollution exposure assessment was based on measurements taken at ambient monitoring stations during specific pregnancy periods. Although such measures may adequately reflect average exposure of pregnant women to background air pollution concentrations in their neighborhood, they may not take into account differential exposure within neighborhoods due to proximity to heavy-traffic roadways and freeways. Women residing closer to these sources may experience greater exposure to potentially toxic compounds released directly in vehicle exhaust or formed in the atmosphere adjacent to roadways. Therefore, we examined whether residential proximity to heavy-traffic roadways, such as freeways and major arterials, during pregnancy was associated with the risk of term LBW and preterm birth in infants born to women living in Los Angeles County, California, between 1994–1996 using a case–control study design.

Methods

Subjects. We used birth certificates, provided by the California Department of Health Services (Sacramento, CA), to identify study subjects and to determine their gestational age, birth weight, and values for covariates included in our analyses. We included infants born to women living in the 28 Los Angeles County zip codes evaluated in earlier work (Ritz and Yu 1999; Ritz et al. 2000) and 84 additional zip codes selected to capture areas intersected by freeways and major arterials and collectors (Figure 1). Overall we included 112 of the 269 zip code areas in Los Angeles County (42%).

From the 1994–1996 cohort of all children born in the selected zip codes, we identified all term low weight (< 2,500 g at ≥ 37 weeks gestation) and preterm (< 37 weeks gestation) infants and randomly selected an approximately equal number of controls from all normal birth weight children born at term in the same year and in the same set of zip code areas (*n* = 65,379). We were able to estimate exposure values for 50,933 of the selected 65,379 cases and controls. In analyses, we excluded very low birth weight babies (< 500 g; *n* = 265), very heavy babies (> 5,000 g; *n* = 84), and 684 births for whom gestational age was most likely misreported (delivery occurred < 90 days (*n* = 89) or > 320 days gestation (*n* = 595)). Study subjects also may have been excluded from analyses because of missing data for individual-level covariates such as maternal age, infant sex, maternal race/ethnicity, prenatal care information, and maternal education (total of 997 subjects) or census-level covariates such as median household income, per capita income, median age of structure, proportion of children in poverty, median gross rent, and median home value (total of 3,854 subjects). Although a large number of subjects were missing data for

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We thank C. Miller of the South Coast Air Quality Management District for providing air monitoring data and K. Farnsworth of the California Department of Transportation for providing traffic count data. We thank Z. Iqbal for help with traffic data mapping. We also thank F. Yu, D. Stram, and J. Kim for their helpful comments on draft versions of the manuscript.

This work was supported by the UCLA Center for Occupational and Environmental Health, the Southern California Particle Center and Supersite, and the National Institute of Environmental Health Sciences (NIEHS Grant R01 ES010960-01).

Received 9 September 2002; accepted 19 November 2002.

median home value (n = 2,765), our results for variables of interest differed minimally when including and excluding the census-level variables in our models. We generated odds ratio (OR) or risk ratio (RR) estimates for term LBW and preterm birth both including and excluding multiple births (n = 48,132 subjects after excluding twins and triplets) and for preterm birth, including and excluding deliveries by cesarean section (n = 37,433 subjects after both exclusions). This research was approved by the UCLA Office for Protection of Research Subjects and the California State Committee for the Protection of Human Subjects.

Exposure assessment. Los Angeles County Department of Health records provided address information for the selected subjects. On the basis of these records, we were able to determine the address for 56,695 of the selected 65,379 cases and controls (87%) and geocoded them using ArcView GIS software (Version 3.2; Environmental Systems Research Institute [ESRI], Redlands, CA) and the ESRI StreetMap. We mapped 51,592 subject homes using this geocoding procedure (91% of homes that could be address matched); mapping was unsuccessful because of address errors or an inability to match recorded house numbers to street segments in the StreetMap.

We obtained 1994–1996 annual average daily traffic counts (AADTs) for freeways, state highways, and primary and secondary arterials and collectors and corresponding electronic street maps for Los Angeles County from the California Department of Transportation (Caltrans). As part of its Highway Performance Monitoring System (HPMS) program, Caltrans estimates AADT values using a "typical" 48-hr traffic count (i.e., holiday and atypical counts are excluded) that is adjusted to represent annual average daily traffic using applicable day-of-week, monthly/seasonal, and growth factors. These adjustment factors are based on measurements taken at representative continuous count stations (Caltrans 2000). Each 48-hr sample location is counted at least once every 3 years and during noncount years the AADT is extrapolated to reflect the traffic growth trend for that location. We used the Caltrans AADT values to generate our traffic density measures. To eliminate some spatial mismatch between the Caltrans electronic street map and the ESRI StreetMap, we electronically and/or manually transferred the Caltrans AADT data on to the commercial StreetMap.

We calculated a distance-weighted traffic density (DWTD) value for each subject using a method similar to Pearson et al. (2000) and English et al. (1999). Specifically, we constructed a 750-ft (228.6-m) radius buffer around each subject home and employed a simple model to estimate the dispersion of motor vehicle exhaust from the roadways within this region. This model was originally developed and applied by Pearson et al. (2000) and is based on a Gaussian probability distribution assuming 96% of all motor vehicle exhaust pollutants disperse at 500 ft (152.4 m) from the roadway according to the following equation:

$$Y = \left(\frac{1}{0.4\sqrt{2\pi}}\right) \times \exp\left[\left(\frac{(0.5)\left(\frac{D}{500}\right)^2}{(0.4)^2}\right)\right]$$

where D is the shortest distance from the subject home to the street and Y is the value used to weight the AADT count on each street within a subject's buffer. The resulting weighted AADT values for all streets within the buffer were then summed for each subject. The "96% decay within 500 ft" criterion was selected because previous studies indicated substantial dispersion of motor vehicle exhaust pollutants within approximately this distance from roadways, although exact dispersion distances varied by study and pollutant measured (Hitchins et al. 2000; Kuhler et al. 1988; Nitta et al. 1993; Ott 1977; Rodes and Holland 1981; Roorda-Knape et al. 1998; Sistla et al. 1979; Sivacoumar and Thanasekaran 1999; Wrobel et al. 2000; Zhu et al. 2002). We assigned a default DWTD value of 50 to 1,344 mapped homes (3%) with only small, uncounted local roads within the 750-ft buffer. After excluding homes with buffer areas extending into adjacent counties, we were able to estimate DWTD values for 50,933 of the 51,592 mapped homes (99%). In addition, we created a dichotomous indicator for having a buffer containing one or more freeways to explore the relative importance of freeway versus street traffic contributions. Last, we obtained ambient air pollution data from the SCAQMD to determine annual average background concentrations of CO, PM_{10}, O_3, and NO_2 measured at air monitoring stations throughout the basin. Subject homes were assigned to the nearest "best" monitoring station taking into account geographic and meteorologic factors that influence air pollution dispersion in the basin.

Statistical methods. We examined three dichotomous outcome categories: all preterm births (births at < 37 weeks gestation), low birth weight (< 2,500 g) infants born at term, and preterm births that were also low birth weight (a subgroup of the first category). We grouped the DWTD values into quintiles derived from the DWTD distribution for all subjects and evaluated their association with each outcome using logistic regression analyses. ORs for preterm birth (normal and low weight) were converted to risk ratios using case and control sampling fractions to adjust intercept values in regression models.

We adjusted for several known risk factors for LBW and preterm birth that could potentially confound the relationship between these outcomes and DWTD. For all outcomes, we adjusted for maternal age (< 20, 20–29, 30–34, 35–39, ≥ 40 years),

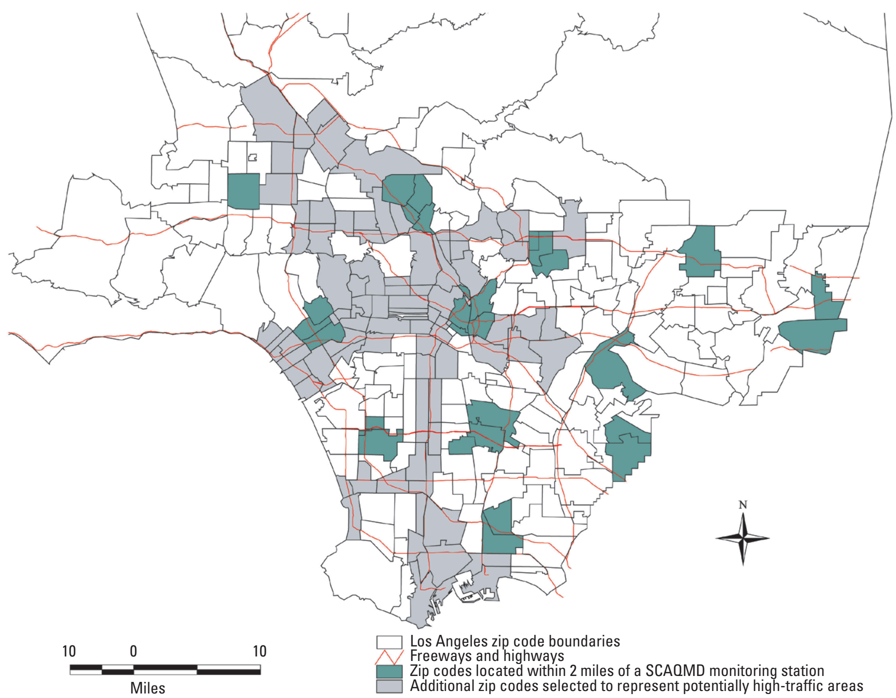

Figure 1. Location of zip codes included in DWTD analysis, Los Angeles County, California.

Table 1. Percent of subjects in each outcome group by individual-level demographic characteristics.[a]

Parameter	Term LBW[b] (*n* = 3,771)	Controls[b] (*n* = 26,351)	Preterm and LBW[c] (*n* = 3,509)	All preterm[c] (*n* = 13,464)	Controls[c] (*n* = 21,124)
Mean gestational age, days (SD)	274.4 (11.6)	280.2 (10.7)	230.3 (25.5)	241.3 (20.2)	280.2 (10.6)
Mean birth weight, grams (SD)	2264.2 (262.5)	3448.7 (439.0)	1932.9 (520.6)	2869.6 (721.8)	3425.8 (424.3)
Infant sex					
Male	43.8	51.2	51.8	53.5	50.3
Female	56.2	48.8	48.2	46.5	49.7
Prenatal care					
None	1.8	0.5	2.6	2.1	0.5
During first trimester	76.0	79.2	75.7	72.5	78.3
After first trimester	22.2	20.3	21.7	25.5	21.2
Parity					
First birth	48.3	39.4	47.0	39.2	37.8
Second or subsequent birth	51.7	60.6	53.0	60.8	62.2
Time since previous live birth					
≤ 12 months	2.6	1.4	4.0	3.6	1.5
> 12 months	97.4	98.6	96.0	96.4	98.5
Maternal race/ethnicity					
White	12.1	15.4	11.7	10.4	14.7
Hispanic	61.3	68.8	63.5	70.8	70.1
African American	16.0	7.4	16.6	11.8	7.2
Asian	5.3	5.1	4.1	3.4	4.9
Other	5.3	3.3	4.2	3.5	3.2
Maternal education (years)					
< 9	21.1	24.3	21.4	27.9	25.1
9–11	27.2	24.3	27.8	27.7	25.0
12	27.0	25.2	26.6	24.5	25.2
13–15	14.3	13.8	14.6	11.8	13.1
≥ 16	10.4	12.3	9.6	8.1	11.7
Maternal age (years)					
< 20	17.1	12.7	18.3	18.5	13.7
20–29	50.7	53.5	47.0	50.2	54.8
30–34	18.9	21.4	20.7	18.8	20.3
35–39	10.0	10.0	11.2	10.2	9.2
≥ 40	3.3	2.4	2.8	2.3	2.0
Previous LBW or preterm infant					
1 or more	2.9	0.8	2.7	1.4	0.6
None	97.1	99.2	97.3	98.6	99.4
Year of birth					
1994	34.9	32.0	35.0	34.7	32.5
1995	32.7	36.8	32.8	32.7	36.5
1996	32.4	31.1	32.2	32.6	30.9
Birth season					
Spring	23.4	24.8	23.2	25.6	24.7
Summer	27.1	26.0	26.8	24.7	26.0
Fall	24.3	24.8	24.3	24.7	24.8
Winter	25.1	24.4	25.7	25.1	24.5
Background annual average CO concentration (ppm)[d]					
< 1.34	21.3	23.9	22.0	21.9	23.5
1.34–1.73	24.0	23.9	23.8	23.5	24.2
1.74–2.06	37.2	35.7	38.6	37.9	36.1
≥ 2.07	17.6	16.5	15.6	16.8	16.2
Background annual average PM_{10} concentration (µg/m^3)[d]					
< 36.19	34.8	33.1	34.7	33.9	33.0
36.19–41.11	20.7	20.5	21.9	21.1	20.7
41.12–42.78	24.9	27.5	23.5	24.9	27.2
≥ 42.79	19.7	18.8	19.9	20.1	19.1
Background annual average NO_2 concentration (pphm)[d]					
< 3.22	23.7	26.4	24.9	24.2	26.2
3.22–4.35	22.8	20.1	21.7	21.3	20.0
4.36–4.55	27.3	29.7	27.5	28.3	29.7
≥ 4.56	26.2	23.7	26.0	26.2	24.1
Background annual average O_3 concentration (pphm)[d]					
< 1.77	24.8	23.0	23.9	24.7	23.0
1.77–1.80	25.6	25.0	27.1	27.2	25.6
1.81–2.37	27.1	27.5	25.9	25.7	27.3
≥ 2.38	22.6	24.5	23.2	22.4	24.2
DWTD[e]					
< 1,524	18.3	20.6	19.2	19.5	20.6
1,524–5,266	20.5	20.3	19.5	19.3	20.4
5,267–11,568	20.5	19.9	19.6	20.0	20.0
11,569–24,579	20.6	19.7	21.1	20.6	19.5
≥ 24,580	20.2	19.6	20.6	20.7	19.5

[a]Multiple births (twins, triplets, etc.) were excluded from the data set for all three outcomes. [b]Births delivered by cesarean section were included in the data set used to evaluate term LBW infants. [c]Births delivered by cesarean section were excluded from the data set used to evaluate preterm birth. [d]Values listed are the < 25th, 25–50th, 50–75th, and > 75th percentiles of the annual average background concentrations for 48,132 subjects (all subjects with DWTD values excluding multiple births). Only one percentile differed for the 37,433 subjects used to evaluate the relationship between DWTD and preterm birth (i.e., all subjects with DWTD values excluding multiple births and infants delivered by cesarean section); the 75th percentile for NO_2 was 4.61 pphm (vs. 4.56 pphm). [e]Values listed are the < 20th, 20–40th, 40–60th, 60–80th, and > 80th percentiles of the DWTD values for 48,132 subjects (all subjects with DWTD values excluding multiple births). The percentiles for the 37,433 subjects used to evaluate the relationship between DWTD and preterm birth are 1,537; 1,537– 5,338; 5,339–11,722; 11,723–24,711; and ≥ 24,712.

maternal race/ethnicity (African American, white, Hispanic, Asian, other races), maternal education (0–8, 9–11, 12, 13–15, ≥ 16 years), parity (first birth vs. second or subsequent birth), interval since the previous live birth (≤ 12 months vs. > 12 months), level of prenatal care (none, during first trimester, after first trimester), infant sex, previous LBW or preterm infant (one or more vs. none), birth season, and year of birth (Table 1). For birth weight, we also adjusted for gestational age (measured in weeks), entering a linear and quadratic term into the model to capture the leveling-off of the slope for weight gain during the last weeks of pregnancy (Ritz and Yu 1999).

To further evaluate potential confounding by socioeconomic status (SES) beyond maternal education, we obtained 1990 U.S. Census data (U.S. Census Bureau 2001) at the block group level for the following variables: median household income, median per capita income, median age of structures, proportion of children (≤ 17 years old) in poverty, median gross rent, and median home value (Table 2). We evaluated changes in regression estimates and confidence intervals when including these variables in the model (continuous variables). Additionally, some analyses included an indicator term for having one or more freeways in the buffer and/or annual average background pollutant (CO, NO_2, O_3, PM_{10}) concentrations measured at the nearest "best" air monitoring station (continuous variables). Finally, we conducted stratified analyses by birth season (i.e., whether the third trimester of pregnancy occurred during fall/winter versus spring/summer months) and according to percentiles of annual average background pollutant concentrations or census block-group–level SES indicators.

Results

The mean weight and gestational age for term LBW infants were 2,264 g and 274 days, respectively, compared to means of 3,449 g and 280 days for controls (Table 1). Premature and premature and LBW (premature–LBW) infants weighed on average 2,870 and 1,933 g at birth, respectively, and had mean gestational ages of 241 and 230 days, respectively (vs. 3,426 g and 280 days for controls). (Different controls groups were used for term LBW and preterm births because for the latter we excluded births by cesarean section.) In multivariate models, all three outcomes were positively associated with low level of prenatal care, low parity (i.e., no live siblings), younger (≤ 19 years) and older (≥ 40 years) maternal ages, and having given birth to one or more LBW or preterm infants previously (Table 3). African-American and Asian women and women of other races had a higher risk of term LBW than whites or Hispanics. Similarly, white women had a lower risk of preterm birth than Hispanics, African Americans, Asians, and women of other races. Female infant sex was positively associated with term LBW, but negatively associated with preterm birth. A longer time interval since a previous live birth (> 12 months) was negatively associated with all three outcomes, as was higher maternal education level (≥ 13 years of education compared to 12 years). Risk of term LBW and preterm birth increased as the median household income, per capita income, median gross rent, and median home value in the census-block group of residence decreased and as the proportion of children (≤ 17 years) living below the poverty level increased.

Based on our models, the clearest exposure-response pattern was observed for the RR relating DWTD to all preterm births (excluding births by cesarean section), with an 8% increase in risk observed for infants in the highest DWTD quintile, after adjustment for all covariates, background air pollution concentrations, and SES variables [RR = 1.08; 95% confidence interval (CI), 1.01–1.15] (Table 4). The OR for preterm–LBW birth in general increased with DWTD quintiles and in the highest quintile we observed a 12% increase in risk for this outcome, after adjustment for all covariates, background air pollution concentrations, and SES variables (OR = 1.12; 95% CI, 0.98–1.27) (Table 5). We observed a 10–17% increase in risk of term LBW for infants with DWTD values above the 20th percentile, but no exposure-response pattern was apparent (Table 6). Adjusting for background air pollution concentrations, presence of one of more freeways near the residence, and all measured SES variables changed effect estimates minimally. Risk of term LBW and preterm birth increased by 19% and 11%, respectively, per 1 ppm increase in annual average background CO concentration in fully adjusted models.

Women whose third trimester occurred during the fall/winter months and who were in the highest DWTD quintile experienced a 39% increased risk of giving birth to a term low weight infant compared to women in the lowest DWTD quintile, whereas no effect was found for women with spring/summer third trimesters at any DWTD level.

Table 2. Percent of subjects in each outcome group by census tract-level demographic characteristics.[a]

Parameter	Term LBW[b] (*n* = 3,771)	Controls[b] (*n* = 26,351)	Preterm and LBW[c] (*n* = 3,509)	All preterm[c] (*n* = 13,464)	Controls[c] (*n* = 21,124)
Median household income (US$)[d]					
< 19,668	25.7	23.5	27.0	27.1	23.4
19,668–25,385	25.4	24.3	25.1	26.1	24.3
25,386–33,699	25.2	25.5	24.7	24.4	25.3
≥ 33,700	23.7	26.7	23.3	22.4	26.9
Per capita income (US$)[d]					
< 6,409	25.9	23.7	26.3	26.9	23.6
6,409–8,640	24.2	24.2	24.9	26.0	24.4
8,641–13,839	25.6	24.8	24.9	25.1	24.8
≥ 13,840	24.3	27.3	24.0	22.0	27.2
Median age of structure (years)[d]					
< 37	23.0	23.7	21.9	22.7	23.4
37–44	25.3	24.6	24.8	24.5	24.5
45–50	24.8	25.0	24.6	25.3	25.2
≥ 51	26.9	26.7	28.7	27.6	27.0
Proportion of children in poverty[d]					
< 0.14	22.8	25.9	24.0	22.9	26.8
0.14–0.27	25.1	25.5	25.3	26.0	26.0
0.28–0.40	25.7	24.8	24.2	25.0	24.9
≥ 0.41	26.4	23.8	26.5	26.1	22.3
Median gross rent (US$)[d]					
< 492	24.6	23.6	26.7	27.0	23.7
492–562	25.8	24.4	25.3	25.7	24.1
563–669	26.4	25.0	25.2	25.1	25.2
≥ 670	23.2	27.0	22.8	22.3	27.0
Median home value (US$)[d]					
< 132,500	28.0	23.6	26.7	26.6	23.5
132,500–169,299	23.7	25.0	23.6	25.5	24.8
169,300–231,399	25.6	24.9	25.5	24.9	25.1
≥ 231,400	22.7	26.6	24.2	23.0	26.6

[a]Multiple births (twins, triplets, etc.) were excluded from the data set for all three outcomes. [b]Births delivered by cesarean section were included in the data set used to evaluate term LBW infants. [c]Births delivered by cesarean section were excluded from the data set used to evaluate preterm birth. [d]Values listed are the < 25th, 25–50th, 50–75th, and ≥ 75th percentiles of the SES data for 48,132 subjects (all subjects with DWTD values excluding multiple births). The percentiles for the 37,433 subjects used to evaluate the relationship between DWTD and preterm birth are median household income (US$) < 19,354, 19,354– < 25,213, 25,213–< 33,333, and ≥ 33,333; per capita income (US$): < 6,359, 6,359–8,517, 8,518–13,563, and ≥ 13,564; mean age of structure (years): < 37, 37–44, 45–50, and ≥ 51; proportion of children in poverty: < 0.15, 0.15–0.28, 0.29–0.41, and ≥ 0.42; median gross rent (US$): < 490, 490–559, 560–665, and ≥ 666; median home value (US$): < 130,000, 130,000–168,199, 168,200–227,299, and ≥ 227,300.

Similarly, we estimated a 24% increase in risk of preterm–LBW birth for infants born to women in the highest exposure category and who had their third trimester in fall/winter months (OR = 1.24; 95% CI, 1.03–1.48), whereas a maximum excess risk of 12% (OR = 1.12; 95% CI, 0.95–1.33) was observed for women with spring/summer third trimesters. Risk of preterm birth also increased for women whose last trimester of gestation occurred in the fall/winter (RR = 1.15; 95% CI, 1.05-1.26 for subjects in the highest DWTD category).

Additional stratified analyses showed that in zip code areas where annual average concentrations of CO, NO_2, and PM_{10} were above the 75th percentile, the DWTD effects were higher for preterm birth (results not shown). Specifically, women in the highest DWTD quintile and residing in areas with high background CO levels had a risk of 15% (RR = 1.15; 95% CI, 0.97–1.36) compared to an excess risk of approximately 5% for women in the highest DWTD quintile but residing in low background CO areas (RR = 1.05; 95% CI, 0.97–1.13). Similar differences in risk were observed for women living in areas with high versus low background NO_2 levels, but no such pattern was observed for PM_{10}, and an opposite pattern was observed for O_3. The same general patterns were observed for term LBW and preterm-LBW, but confidence intervals were fairly wide due to smaller sample sizes in these groups.

Stratification on median values for census block-group–level SES indicators showed that the effects observed for DWTD were stronger for women residing in lower SES areas (results not shown), with the greatest differences in effect estimates observed when stratifying on the median proportion of children in poverty. In areas where the proportion of children in poverty was above the median value, women exposed at the highest DWTD quintile had a 25% greater risk of delivering a term LBW infant (OR = 1.25; 95% CI, 1.03–1.51), whereas the excess risk was only 7% for women residing in areas with a lower proportion of children below the poverty level (OR = 1.07; 95% CI, 0.90–1.27). A similar pattern was observed for preterm birth [RR= 1.15 (95% CI, 1.03–1.27) vs. 1.03 (95% CI, 0.95–1.11) for low vs. high SES areas, respectively] and preterm–LBW [OR = 1.18 (95% CI, 0.97–1.43) vs. 1.07 (95% CI, 0.90–1.27) for low vs. high SES areas, respectively].

Table 3. ORs and 95% CIs for three outcome groups for each covariate included in the adjusted model.[a]

Parameter	Term LBW[b] (*n* = 3,771)	Preterm and LBW[c] (*n* = 3,509)	All preterm[c] (*n* = 13,464)
Gestational week	< 0.001	—	—
Gestational week squared	1.10 (1.09–1.11)	—	—
Female child	1.44 (1.34–1.55)	0.94 (0.87–1.01)	0.87 (0.84–0.91)
Prenatal care			
During first trimester (referent)	1.0	1.0	1.0
None	3.26 (2.33–4.56)	4.78 (3.56–6.43)	3.70 (2.95–4.64)
After first trimester	1.14 (1.04–1.24)	1.03 (0.94–1.12)	1.20 (1.14–1.26)
Parity			
No siblings	1.65 (1.52–1.79)	1.75 (1.61–1.91)	1.17 (1.11–1.23)
Time since previous live birth			
> 12 months	0.51 (0.40–0.65)	0.29 (0.24–0.37)	0.40 (0.35–0.47)
Maternal race/ethnicity			
White (referent)	1.0	1.0	1.0
Hispanic	0.95 (0.83–1.07)	1.14 (1.00–1.30	1.16 (1.07–1.25)
African American	2.41 (2.08–2.78)	2.82 (2.43–3.28)	2.02 (1.83–2.23)
Asian	1.24 (1.03–1.49)	1.08 (0.88–1.32)	0.98 (0.86–1.12)
Other	1.83 (1.52–2.21)	1.60 (1.30–1.97)	1.49 (1.30–1.70)
Maternal education (years)			
12 (referent)	1.0	1.0	1.0
< 9	1.00 (0.89–1.12)	0.93 (0.83–1.04)	1.20 (1.12–1.28)
9–11	1.12 (1.01–1.24)	1.12 (1.01–1.25)	1.12 (1.05–1.19)
13–15	0.89 (0.79–1.00)	0.96 (0.85–1.09)	0.92 (0.85–1.00)
≥ 16	0.74 (0.64–0.85)	0.71 (0.61–0.83)	0.78 (0.71–0.86)
Maternal age (years)			
20–29 (referent)	1.0	1.0	1.0
< 20	1.12 (1.00–1.25)	1.12 (1.00–1.25)	1.26 (1.17–1.34)
30–34	1.03 (0.93–1.14)	1.42 (1.28–1.57)	1.13 (1.06–1.20)
35–39	0.76 (0.60–0.96)	0.79 (0.61–1.02)	0.96 (0.81–1.13)
≥ 40	1.52 (1.23–1.90)	2.18 (1.72–2.76)	1.41 (1.21–1.65)
Previous LBW or preterm infant			
1 or more	3.18 (2.46–4.11)	4.25 (3.22–5.62)	2.30 (1.83–2.90)
Year of birth			
1994 (referent)	1.0	1.0	1.0
1995	0.84 (0.77–0.92)	0.84 (0.77–0.92)	0.85 (0.81–0.90)
1996	1.01 (0.91–1.12)	0.99 (0.89–1.10)	1.02 (0.96–1.09)
Birth season			
Summer (referent)	1.0	1.0	1.0
Spring	0.93 (0.84–1.04)	0.92 (0.82–1.02)	1.02 (0.96–1.09)
Fall	0.97 (0.88–1.07)	0.97 (0.87–1.08)	1.07 (1.00–1.14)
Winter	1.00 (0.91–1.11)	1.01 (0.91–1.12)	1.07 (1.01–1.14)
Freeway within 750 ft of house	1.02 (0.91–1.14)	1.01 (0.90–1.13)	0.96 (0.89–1.02)
Annual average CO concentration (per ppm)	1.22 (1.03–1.44)	1.01 (0.85–1.21)	1.11 (1.00–1.23)
Annual average PM_{10} concentration (per 10 μg/m^3)	1.07 (0.92–1.24)	1.02 (0.87–1.19)	1.03 (0.94–1.14)
Annual average NO_2 concentration (per pphm)	0.93 (0.79–1.08)	1.01 (0.86–1.19)	0.94 (0.85–1.03)
Annual average O_3 concentration (per pphm)	0.95 (0.80–1.13)	0.95 (0.80–1.14)	0.99 (0.89–1.10)

[a]Multiple births (twins, triplets, etc.) were excluded from the data set for all three outcomes. [b]Births delivered by cesarean section were included in the data set used to evaluate term LBW infants. [c]Births delivered by cesarean section were excluded from the data set used to evaluate preterm births.

Discussion

To our knowledge, this is the first study to evaluate the relationship between maternal residential proximity to heavy-traffic roadways and risk of adverse birth outcomes. We observed an approximately 10–20% increase in risk of term LBW and preterm birth in infants born to women living close to heavy-traffic roadways and therefore potentially exposed to higher levels of motor vehicle exhaust. Stronger effects were observed for women whose third trimesters fell during fall/winter months, lived in high background air pollution areas, and/or lived in more impoverished areas according to census block-group indicators of SES. We used a relatively simple measure of motor vehicle air pollution exposure that could be derived from traffic data readily available for this large population. This approach, however, may have resulted in substantial exposure misclassification. Using existing data and applying GIS methods, we estimated the DWTD measures without knowledge of disease status. Therefore, we do not expect errors in DWTD measurement to be differentially distributed between cases and controls. Assuming that the DWTD measurement errors are also independent of errors in other variables used in the analysis, the strengths of our reported associations are most likely underestimated.

Our exposure model is much cruder than mobile source air dispersion models such as Caltran's CALINE model, which also estimates dispersion of vehicle exhaust based on a Gaussian diffusion equation, but taking meteorologic factors, roadway geometry, and vehicle emission rates into account (Benson 1984). We selected the crude but less data and modeling intensive approach so that values could be estimated for a large population and the method could be potentially applied in other populations and settings. Although the DWTD model may be less accurate than complex air dispersion models, its interpretation is quite straightforward, allowing us to evaluate the relative importance of residential proximity to vehicular emissions. Several studies that measured traffic-related pollutants (CO, NO_2, black smoke, fine and ultrafine particles) with increasing distances from freeways and roadways showed that concentrations tended to follow an exponential decay curve, especially in downwind directions (Hitchins et al. 2000; Rodes and Holland 1981; Roorda-Knape et al. 1998; Sistla et al. 1979; Sivacoumar and Thanasekaran 1999; Zhu et al. 2002). Other studies have shown that concentrations of traffic-related pollutants near freeways and roadways are correlated with traffic counts (Kinney et al. 2000; Momas et al. 1999; Pikhart et al. 1999) and/or, more generally, are higher than background levels near heavy-traffic roadways (Fischer et al. 2000; Janssen et al. 1997, 2001; Kingham et al. 2000; Kuhler et al. 1988; Monn et al. 1997; Morawska et al. 1999; Nakai et al. 1995; Nitta et al. 1993; Ott 1977; Pfeffer 1994; Roemer and van Wijnen 2001; Shi et al. 1999; Wrobel et al. 2000; Wjst et al. 1993). These data support the use of a purely distance- and traffic-based DWTD-type model to estimate exposure to traffic-related pollutants in large epidemiologic studies.

There are several potential sources of exposure misclassification related to address mapping and estimation of DWTD values. We used addresses reported on birth certificates and assumed that mothers did not move during pregnancy. We had no information on residential mobility, but data from Santa Clara, California, showed that although 25% of women move during pregnancy (Shaw and Malcoe 1992), residential addresses reported on birth certificates reflect location during the last months of pregnancy more accurately (Schulman et al. 1993). We previously found exposures during the third trimester of pregnancy to be most relevant for term LBW and preterm birth (Ritz and Yu 1999; Ritz et al. 2000). In Western societies, birth weight is generally determined by factors affecting pregnancy after the 28th week of gestation (Kline et al. 1989). Although the biologic mechanisms whereby air pollution may cause preterm birth remain to be determined, elevated exposures near the end of gestation may cause disturbances of the pituitary–adrenocortico–placental system, disturbances of uterine blood flow, and/or increased maternal susceptibility to infections, with these pathogenic processes subsequently triggering premature contractions and/or premature rupture of membranes. Assuming that the last trimester of pregnancy is the most important period for the outcomes investigated, residential mobility is expected to affect our estimates minimally.

We relied on address data reported on birth certificates and a GIS map of Los Angeles County to locate subject homes without being able to check the accuracy of this geocoding method for 50,000 residences. Because the geocoding process was automated and blinded to disease status, we expect mapping errors to introduce nondifferential misclassification only.

We relied on existing data and maps to determine the number and type of streets and corresponding traffic counts within 750 ft from a residence. Caltrans provides counts on freeways and major arterials and collectors, but smaller residential streets with little traffic are typically not counted. Traffic on such small residential streets is likely to have a negligible impact on our measure. The Caltrans HPMS database covers about 40% of the total

Table 4. Association (RR point estimate, 95% CI)[a] between residential DWTD and risk of preterm birth for infants born between 1994 and 1996 to mothers living in 112 zip codes located in Los Angeles County, California.[b,c]

Parameter	Single-parameter models	Models including covariates,[d] background concentrations,[e] and freeway indicator[f]	Models including covariates,[d] background concentrations,[e] freeway indicator,[f] and all census-block-group–level SES variables[e]
Quintile of distance-weighted traffic density (DWTD)			
< 20th percentile	1.0	1.0	1.0
20th–39th percentile	1.00 (0.94–1.07)	0.99 (0.93–1.05)	0.98 (0.92–1.04)
40th–59th percentile	1.05 (0.98–1.11)	1.02 (0.96–1.09)	1.02 (0.95–1.08)
60th–79th percentile	1.10 (1.04–1.17)	1.07 (1.01–1.13)	1.06 (0.99–1.12)
≥ 80th percentile	1.11 (1.04–1.18)	1.08 (1.01–1.15)	1.08 (1.01–1.15)
			(p = 0.0037)[g]; (p = 0.0025)[h]
One or more freeways in buffer	0.99 (0.93–1.05)	0.96 (0.91–1.02)	0.96 (0.90–1.02)
Annual average background concentration			
CO (per 1 ppm)	1.12 (1.08–1.17)	1.09 (1.00–1.19)	1.11 (1.01–1.22)
NO_2 (per 1 pphm)	1.05 (1.02–1.08)	0.95 (0.87–1.03)	0.94 (0.86–1.02)
O_3 (per 1 pphm)	0.89 (0.85–0.93)	0.99 (0.91–1.09)	1.05 (0.95–1.16)
PM_{10} (per 10 ug/m^3)	0.96 (0.92–1.00)	1.03 (0.95–1.12)	1.02 (0.94–1.11)
Fall/winter third trimester (birth month January–June)[i]			
< 20th percentile	1.0	1.0	1.0
20th–39th percentile	0.99 (0.91–1.09)	0.99 (0.90–1.07)	0.97 (0.89–1.06)
40th–59th percentile	1.05 (0.97–1.15)	1.04 (0.95–1.13)	1.04 (0.95–1.13)
60th–79th percentile	1.11 (1.02–1.21)	1.08 (1.00–1.18)	1.08 (0.99–1.18)
≥ 80th percentile	1.18 (1.08–1.28)	1.15 (1.06–1.26)	1.15 (1.05–1.26)
			(p = 0.0001)[g]; (p = 0.0001)[h]
Spring/summer third trimester (birth month July–December)[i]			
< 20th percentile	1.0	1.0	1.0
20th–39th percentile	1.01 (0.92–1.10)	0.99 (0.91–1.08)	0.98 (0.90–1.07)
40th–59th percentile	1.04 (0.95–1.13)	1.01 (0.92–1.10)	0.99 (0.91–1.09)
60th–79th percentile	1.10 (1.00–1.20)	1.05 (0.97–1.15)	1.03 (0.94–1.12)
≥ 80th percentile	1.04 (0.96–1.14)	1.01 (0.92–1.10)	1.00 (0.91–1.10)
			(p = 0.7750)[g]; (p = 0.7084)[h]

[a]ORs were converted to RRs using the case and control sampling fractions to adjust intercept values. [b]Multiple births (twins, triplets, etc.) and births delivered by cesarean section were excluded from the analysis. [c]Cases = 13,464; controls = 21,124; sample sizes for multiple-parameter models are slightly smaller due to missing covariate data for some subjects. [d]The model includes the following covariates: infant sex, maternal age, maternal race/ethnicity, maternal education, interval since previous live birth, parity, level of prenatal care, year of analysis, birth season. [e]Background air pollution concentrations and census-level SES variables were entered into the model as continuous variables. [f]One or more freeways located within a 750-ft buffer. [g]Chi-square p-value for test of trend using category means as score values. [h]Chi-square p-value for test of trend using category medians as score values. [i]RR estimates stratified on birth month do not include adjustment for birth season. Fall/winter third trimesters fell predominantly during the months of November–May, whereas spring/summer third trimesters fell predominantly during the months of May–November.

road mileage in Los Angeles County, but this accounts for approximately 92% of all vehicular travel—i.e., the most frequently used roads have AADT values attributed to them (Caltrans. Personal communication). The traffic counts provided by Caltrans reflect an annual average 24-hr traffic count—i.e., daily, monthly, and seasonal fluctuations in traffic flows are disregarded. Therefore, our estimated DWTD values based on these counts reflect annual average measures only. Although the DWTD value attributed to a woman's third trimester may be over- or underestimated by the annual averages, monthly factors used to adjust 48-hr counts to annual average daily traffic values usually vary by < 10% in urban areas (Caltrans 2000).

The DWTD values take into account only the total number of vehicles passing by a residence and do not differentiate among gasoline and diesel-fueled vehicles, vehicle speeds, and the typical age of vehicles that frequent a given street. These factors are important because gasoline engines emit amounts and types of gaseous and particulate compounds different from diesel engines, emissions vary by speed, and older vehicles with less efficient emission control systems emit more pollutants. Studies have shown ambient CO concentrations in a given urban area to be heavily influenced by a relatively small percentage of high emitting, older or badly maintained cars (Lawson et al. 1990; Stephens and Cadle 1991). Therefore, women living near high-traffic roadways traveled by newer vehicles may be less exposed than women living near streets traveled by a smaller number of older vehicles. Similarly, women living near roadways frequented by diesel-fueled vehicles may experience greater exposure to particles or other toxics found in diesel engine exhaust, regardless of total vehicle counts.

Our model assumed that motor vehicle exhaust dispersion followed a Gaussian curve centered on a given roadway with 96% decay occurring at 500 ft (152.4 m). Such a curve may not adequately represent dispersion conditions because meteorologic factors such as wind direction, wind speed, and presence of inversion layers may be important. For example, in our study, it did not appear to be important whether subjects had one or more freeways within 750 ft of their residence (based on a dichotomous yes/no variable). These findings could result from exposure misclassification because women who lived primarily upwind of freeways during pregnancy may have been less exposed than women who lived primarily downwind. Wind direction may be less important for streets, since urban homes are typically surrounded by streets while freeways typically run along just one side of a home. Alternatively, these findings may suggest that cumulative traffic on all streets surrounding a home may be more important than proximity to freeways.

We explored differences in adverse birth outcome risks caused by close proximity to heavy-traffic roadways based on the assumption that women residing closer to these sources might receive greater exposure to motor vehicle related air pollution. Although we accounted for background air pollution exposures using ambient monitoring station data, we had no data on exposures to indoor (e.g., passive tobacco smoke, gas stoves and/or heaters, attached garages), occupational, or commuting sources. Our measures assumed that pregnant women spent a substantial amount of time at home and that a significant portion of traffic exhaust infiltrated these homes. A recent study in four Los Angeles County communities reported that adults spend an average of 90% of their time indoors, with approximately 70% of this indoor time at home, 15% at work, and 5% at other locations (Jones et al. Unpublished

Table 5. Association (OR point estimate, 95% CI) between residential DWTD and risk of LBW and preterm birth for infants born between 1994 and 1996 to mothers living in 112 zip codes located in Los Angeles County, California.[a,b]

Parameter	Single-parameter models	Models including covariates,[c] background concentrations,[d] and freeway indicator[e]	Models including covariates,[c] background concentrations,[d] freeway indicator,[e] and all census-block-group–level SES variables[d]
Quintile of distance-weighted traffic density (DWTD)			
< 20th percentile	1.0	1.0	1.0
20th–39th percentile	1.02 (0.91–1.15)	1.01 (0.90 –1.14)	0.98 (0.87–1.11)
40th–59th percentile	1.05 (0.93–1.17)	1.05 (0.93 –1.18)	1.03 (0.91–1.17)
60th–79th percentile	1.16 (1.04–1.30)	1.14 (1.01 –1.28)	1.12 (0.99–1.26)
≥ 80th percentile	1.13 (1.01–1.26)	1.12 (0.99 –1.26)	1.12 (0.98–1.27)
			(p = 0.0340)[f]; (p = 0.0232)[g]
One or more freeways in buffer	1.06 (0.96–1.18)	1.01 (0.90 –1.13)	1.00 (0.89–1.12)
Annual average background concentration			
CO (per 1 ppm)	1.08 (1.00–1.16)	1.01 (0.85 –1.21)	1.06 (0.88–1.27)
NO_2 (per 1 pphm)	1.02 (0.97–1.07)	1.01 (0.86 –1.19)	0.99 (0.83–1.17)
O_3 (per 1 pphm)	0.91 (0.84–0.99)	0.95 (0.80 –1.14)	1.08 (0.90–1.31)
PM_{10} (per 10 ug/m^3)	0.90 (0.83–0.98)	1.02 (0.87 –1.19)	1.00 (0.85–1.18)
Fall/winter third trimester (birth month January–June)[h]			
< 20th percentile	1.0	1.0	1.0
20th–39th percentile	0.96 (0.82–1.14)	0.96 (0.81 –1.14)	0.93 (0.78–1.11)
40th–59th percentile	0.99 (0.84–1.17)	0.99 (0.83 –1.17)	0.98 (0.82–1.17)
60th–79th percentile	1.14 (0.97–1.34)	1.12 (0.95 –1.33)	1.11 (0.93–1.33)
≥ 80th percentile	1.24 (1.06–1.45)	1.24 (1.04 –1.47)	1.24 (1.03–1.48)
			(p = 0.0011)[f]; (p = 0.0010)[g]
Spring/summer third trimester (birth month July–December)[h]			
< 20th percentile	1.0	1.0	1.0
20th–39th percentile	1.08 (0.92–1.27)	1.06 (0.90 –1.25)	1.04 (0.88–1.23)
40th–59th percentile	1.10 (0.94–1.29)	1.11 (0.94 –1.31)	1.08 (0.91–1.28)
60th–79th percentile	1.17 (1.00–1.38)	1.16 (0.98 –1.36)	1.12 (0.95–1.33)
≥ 80th percentile	1.03 (0.87–1.20)	1.01 (0.85 –1.20)	1.00 (0.84–1.20)
			(p = 0.7733)[f]; (p = 0.9115)[g]

[a]Multiple births (twins, triplets, etc.) and births delivered by cesarean section were excluded from the analysis. [b]Cases = 3,509; controls = 21,124; sample sizes for multiple-parameter models are slightly smaller due to missing covariate data for some subjects. [c]The model includes the following covariates: infant sex, maternal age, maternal race/ethnicity, maternal education, interval since previous live birth, parity, level of prenatal care, year of analysis, birth season. [d]Background air pollution concentrations and census-level SES variables were entered into the model as continuous variables. [e]One or more freeways located within a 750-ft buffer. [f]Chi-square p-value for test of trend using category means as score values. [g]Chi-square p-value for test of trend using category medians as score values. [h]OR estimates stratified on birth month do not include adjustment for birth season. Fall/winter third trimesters fell predominantly during the months of November–May, whereas spring/summer third trimesters fell predominantly during the months of May–November.

data). This is similar to data from a representative sample of Californians that indicated adults spend approximately 15 hr per day indoors at home, making this the most frequently occupied location (Jenkins et al. 1992; Wiley et al. 1991). Time spent at home may be even greater for women in their last trimester of pregnancy.

The fraction of outdoor pollution that penetrates indoors is a function of housing characteristics including air exchange rates, building surface to volume ratios, use of air conditioning, and use of windows for ventilation. Residential air exchange rates are higher in the metropolitan Los Angeles basin than in other areas of California (northern California and San Diego) and the United States, presumably because of greater use of open windows and doors in the relatively warm climate (Wilson et al. 1996). Poorer-quality housing (e.g., less tightly sealed windows, lack of air conditioning, and more open windows) in lower SES areas may result in greater penetration of traffic-related pollutants indoors. There is some suggestion of such an effect in our study because the relationship between DWTD and adverse birth outcomes was greater in lower SES areas. Alternatively, this could be caused by greater vulnerability to air pollution exposures resulting from SES-related factors such as poorer nutrition during pregnancy or perhaps a greater percentage of older, high-emitting gasoline or diesel vehicles frequenting streets in these areas. Stronger effects for women in low SES areas may also be caused by an increased reliance on public transit, with greater times spent outdoors waiting for buses and greater transit times in buses, resulting in higher commuting exposures.

Not all of the 65,379 cases and controls originally selected could be included in the analyses because we were unable to match 13% of these births to an address in the county-level birth certificate data. Furthermore, 10% of the subjects who could be matched to an address could not be geocoded due to errors in address data or an inability to match an address to a street segment. We found that subjects who could not be address matched and/or mapped were more likely to be cases than controls; for example, of the preterm births that could be address matched, 45% were cases and 55% were controls, whereas 47% and 53% of the subjects who could not be address matched were cases and controls, respectively. If unmapped subjects were also more likely to be exposed, perhaps because individuals with missing or incorrect address data are of lower SES and as a result live in high traffic areas, then our estimates could be biased toward the null. Although DWTD values were only weakly correlated with census block-group–level SES indicators (Pearson correlation coefficients ranged from –0.06 to 0.05) and with years of maternal education (r = –0.03), background air pollution concentrations were related to the census SES variables (correlation coefficients ranged from –0.42 to 0.46 depending on pollutant) and maternal education (r = 0.20).

Finally, we cannot rule out potential residual confounding by risk factors for which we lacked data or by risk factors that were measured with error (e.g., census block-group–level SES variables). However, even adjustment for relatively strong risk factors (e.g., lack of prenatal care, maternal race/ethnicity, previous LBW or preterm infant) did not change effect estimates substantially (by a maximum of 7%, but in most cases by 1–3%). Similarly, inclusion of census-block-group–level variables in the models changed estimates by a maximum of 6% (but mostly by 0–2%). We did not have information on maternal active and

Table 6. Association (OR point estimate, 95% CI) between residential DWTD and risk of term LBW for infants born between 1994 and 1996 to mothers living in 112 zip codes located in Los Angeles County, California.[a,b]

Parameter	Single-parameter models	Models including covariates,[c] background concentrations,[d] and freeway indicator[e]	Models including covariates,[c] background concentrations,[d] freeway indicator,[e] and all census-block-group–level SES variables[d]
Quintile of DWTD			
< 20th percentile	1.0	1.0	1.0
20th–39th percentile	1.13 (1.02–1.27)	1.11 (0.99–1.25)	1.10 (0.98–1.24)
40th–59th percentile	1.16 (1.04–1.29)	1.16 (1.03–1.30)	1.17 (1.04–1.32)
60th–79th percentile	1.18 (1.05–1.31)	1.15 (1.02–1.29)	1.16 (1.02–1.31)
≥ 80th percentile	1.16 (1.04–1.30)	1.11 (0.99–1.26)	1.14 (1.00–1.29)
			(p = 0.2379)[f]; (p = 0.1672)[g]
One or more freeways in buffer	1.01 (0.91–1.11)	1.02 (0.91–1.14)	1.00 (0.89–1.12)
Annual average background concentration			
CO (per 1 ppm)	1.16 (1.08–1.24)	1.22 (1.03–1.44)	1.19 (1.00–1.42)
NO_2 (per 1 pphm)	1.06 (1.01–1.11)	0.93 (0.79–1.08)	0.93 (0.79–1.09)
O_3 (per 1 pphm)	0.87 (0.81–0.95)	0.95 (0.80–1.13)	1.01 (0.84–1.21)
PM_{10} (per 10 ug/m^3)	0.92 (0.84–0.99)	1.07 (0.92–1.24)	1.04 (0.89–1.22)
Fall/winter third trimester (birth month January–June)[h]			
< 20th percentile	1.0	1.0	1.0
20th–39th percentile	1.18 (1.00–1.38)	1.20 (1.01–1.42)	1.20 (1.01–1.43)
40th–59th percentile	1.26 (1.08–1.48)	1.33 (1.12–1.58)	1.36 (1.14–1.62)
60th–79th percentile	1.29 (1.10–1.51)	1.33 (1.12–1.57)	1.35 (1.13–1.61)
≥ 80th percentile	1.33 (1.13–1.55)	1.33 (1.11–1.58)	1.39 (1.16–1.67)
			(p = 0.0094)[f]; (p = 0.0044)[g]
Spring/summer third trimester (birth month July–December)[h]			
< 20th percentile	1.0	1.0	1.0
20th–39th percentile	1.10 (0.95–1.28)	1.04 (0.89–1.22)	1.03 (0.87–1.22)
40th–59th percentile	1.07 (0.92–1.24)	1.02 (0.87–1.20)	1.03 (0.87–1.21)
60th–79th percentile	1.08 (0.93–1.26)	1.01 (0.86–1.18)	1.01 (0.85–1.19)
≥ 80th percentile	1.03 (0.88–1.20)	0.96 (0.81–1.13)	0.96 (0.81–1.14)
			(p = 0 0.4336)[f]; (p = 0.4547)[g]

[a]Multiple births (twins, triplets, etc.) were excluded from the analysis; births delivered by cesarean section were included in the analysis. [b]Cases = 3,771; controls = 26,351; sample sizes for multiple-parameter models are slightly smaller due to missing covariate data for some subjects. [c]The model includes the following covariates: infant sex, maternal age, maternal race/ethnicity, maternal education, interval since previous live birth, parity, level of prenatal care, gestational age, gestational age squared, year of analysis, birth season. [d]Background air pollution concentrations and census-level SES variables were entered into the model as continuous variables. [e]One or more freeways located within a 750-ft buffer. [f]Chi-square p-value for test of trend using category means as score values. [g]Chi-square p-value for test of trend using category medians as score values. [h]OR estimates stratified on birth month do not include adjustment for birth season. Fall/winter third trimesters fell predominantly during the months of November–May, whereas spring/summer third trimesters fell predominantly during the months of May–November.

passive smoking, diet, weight gain during pregnancy, and maternal height and prepregnancy weight. Such factors could potentially be correlated with living near heavy-traffic roadways (e.g., if individuals in lower SES areas tend to live closer to freeways and other high traffic streets and also have poorer nutrition during pregnancy). But these factors would also be related to the SES indicators we included in our models, such as maternal education, prenatal care, median household income, and thus were accounted for in our analyses. Other neighborhood-level factors, such as high noise levels, could also be correlated with living near heavy-traffic roadways and adverse birth outcomes and therefore are a potential source of residual confounding. However, we observed effects mainly for women whose third trimester fell during fall/winter months when greater atmospheric stability tends to limit pollutant dispersion. Although unmeasured risk factors may vary spatially, they would also have to vary seasonally to confound the observed associations. For example, for smoking to confound the observed relationships between DWTD and adverse birth outcomes, parental smoking would not only have to increase as one moves closer to heavy-traffic roadways, but this smoking pattern would also have to affect a woman's pregnancy mostly during fall/winter months. The fact that we see the most pronounced and strongest effects for DWTD in low SES census blocks seems to confirm that women in these neighborhoods are more highly exposed (older cars and older, less insulated houses) and/or are more susceptible (less prenatal care and poorer nutrition). It also suggests that while SES differences between neighborhoods may be effect measure modifiers, SES differences within neighborhoods are less likely to be as pronounced and thus a strong confounder.

Despite the limitations of our research discussed above, we believe our results provide useful information. This was the first study to evaluate the relationship between exposure to motor vehicle exhaust (measured by DWTD) and adverse birth outcomes in a large urbanized area. Because of the large population and number of annual births in Los Angeles County, we had fairly good statistical power to detect small to moderate effects while controlling for other risk factors. Our results are consistent with our previous work. We observed a 19% and 11% increase in risk of term LBW and preterm birth, respectively, per 1 ppm increase in CO based on annual average concentrations for this more recent time period (1994–1996). These results are remarkably similar to our previous studies (based on 1989–1993 data) despite using annual exposure averages and more zip codes at longer distances from ambient monitoring stations. We observed exposure-response relations between DWTD and preterm birth, the outcome group for which we had the largest sample size; similar trends were seen for preterm–LBW and term LBW but results were less stable. Furthermore, we observed an increase in the effect estimates relating DWTD to prematurity and LBW for women whose third trimester fell during fall/winter months, again similar to what our previous research showed and consistent with expectations based on meteorologic conditions in the Los Angeles basin. Ambient levels of CO and PM_{10} are higher during winter months due to seasonal lower average wind speeds and lower temperatures that reduce surface vertical mixing and cause near-surface inversions to be stronger and last longer (Flachsbart 1995). These factors act to limit dilution and dispersion of emissions resulting in increased pollution levels in proximity to sources during such winter conditions.

Potential biologic mechanisms for the effect of exposure to CO and PM_{10} on term LBW and preterm birth have been discussed previously (Ritz and Yu 1999; Ritz et al. 2000). Additional toxicologic data are needed to determine whether certain toxics emitted in motor vehicle exhaust, for which CO and/or particles are potential markers (e.g., polycyclic aromatic hydrocarbons), may be responsible for these adverse birth outcomes.

Conclusions

We observed an approximately 10–20% increase in risk of preterm birth (both normal and low weight) and term LBW in infants born to women potentially exposed to high levels of traffic-related air pollution, as represented by distance-weighted traffic density (DWTD). These risks appeared to be strongest for women whose third trimesters fell during fall/winter months, who lived in high background air pollution areas, and/or who lived in more impoverished areas according to census block-group–level indicators of SES. The consistently observed associations between adverse birth outcomes and ambient CO in our previous studies and these latest results suggest motor vehicle exhaust exposures may be important for these outcomes. In subsequent studies we plan to refine our DWTD measure further by incorporating meteorologic factors and possibly estimates of gasoline and diesel-fueled vehicle percentages on roadways. We are currently conducting a survey of mothers living in Los Angeles County who have recently given birth to collect information on residential mobility during pregnancy, unmeasured risk factors, and exposure to other sources of air pollution, including indoor and occupational exposures.

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