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The International Collaboration on Air Pollution and Pregnancy Outcomes: Initial Results.

Jennifer Parker[1], David Q. Rich[2], Svetlana V. Glinianaia[3], Jong Han Leem[4], Daniel Wartenberg[5], Michelle L. Bell[6], Matteo Bonzini[7], Michael Brauer[8], Lyndsey Darrow[9], Ulrike Gehring[10], Nelson Gouveia[11], Paolo Grillo[12], Eunhee Ha[13], Edith H. van den Hooven[14,15], Bin Jalaludin[16, 17], Bill M. Jesdale[18], Johanna Lepeule[19,20], Rachel Morello-Frosch[18,21], Geoffrey G. Morgan[16,22], Rémy Slama[19,20], Frank H. Pierik[15], Angela Cecilia Pesatori[23], Sheela Sathyanarayana[24], Juhee Seo[13], Matthew Strickland[9], Lillian Tamburic[25], and Tracey J. Woodruff[26]

[1]National Center for Health Statistics, Centers for Disease Control and Prevention, Hyattsville, MD

[2]University of Rochester School of Medicine and Dentistry, Department of Community and Preventive Medicine, Rochester, NY, USA

[3]Institute of Health and Society, Newcastle University, Newcastle upon Tyne, England, UK

[4]Department of Occupational & Environmental Medicine, Inha University. Incheon, Republic of Korea

[5]UMDNJ-Robert Wood Johnson Medical School, NJ, USA

[6]Yale University, New Haven, CT, USA

[7]Department of Experimental Medicine, University of Insubria, Varese, Italy

[8]The University of British Columbia, Vancouver, BC Canada

[9]Department of Environmental Health, Emory University, Atlanta GA, USA

[10]Institute for Risk Assessment Sciences, Utrecht University, Utrecht, Netherlands

[11]Department of Preventive Medicine, School of Medicine of the University of São Paulo, São Paulo Brasil

[12]Epidemiology Unite, "Fondazione IRCCS Ca'Granda – Ospedale Maggiore Policlinico", Milan, Italy

[13] Department of Preventive Medicine, Ewha Womans University, Seoul, Republic of Korea

[14]The Generation R Study Group, Erasmus Medical Center, Rotterdam, The Netherlands.

[15]Department of Environment and Health, Netherlands Organisation for Applied Scientific Research (TNO), Delft, The Netherlands.

[16]North Coast Area Health Service, New South Wales, Australia

[17]Centre for Research, Evidence Management and Surveillance, Sydney South West Area Health Service, and School of Public Health and Community Medicine, University of New South Wales, Australia

[18]Department of Environmental Science, Policy and Management University of California, Berkeley, CA USA

[19]Inserm, National Institute of Health and Medical Research, Avenir Team "Environmental Epidemiology Applied to Fecundity and Reproduction", Institut Albert Bonniot, U823, Grenoble, France

[20]University J. Fourier Grenoble, Grenoble, France.

[21]School of Public Health, University of California, Berkeley, CA USA

[22]Northern Rivers University Department of Rural Health, University of Sydney, New South Wales, Australia

[23]Department of Occupational and Environmental Health, Università di Milano, Milan, Italy

[24]Seattle Children's Research Institute, University of Washington, WA USA

[25]University of British Columbia, Centre for Health Services and Policy Research, Vancouver, Canada

[26]Center for Reproductive Health and the Environment. University of California, San Francisco, USA

Corresponding author:

Jennifer D. Parker
National Center for Health Statistics
3311 Toledo Road, room 6107
Hyattsville, MD 20782
jdparker@cdc.gov
T. (301) 458-4419
F. (301) 458-4038

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CDC disclaimer

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Abbreviations:

ICAPPO = International Collaboration on Air Pollution and Pregnancy Outcome

IDW = Inverse Distance Weighted

IRSED = Index of Relative Socio-economic Disadvantage

LBW = Low birth weight

LMP = Last menstrual period

LUR= Land Use Regression

PAMPER = Particulate Matter and Perinatal Events Research

PM = Particulate matter

SES = Socioeconomic Status

UK = United Kingdom

USA = United States of America

Abstract

Background. The findings of prior studies of air pollution effects on adverse birth outcomes are difficult to synthesize due to differences in study design.

Objectives. The International Collaboration on Air Pollution and Pregnancy Outcome was formed to understand how differences in research methods contribute to variations in findings. We initiated a feasibility study to: 1) assess the ability of geographically diverse research groups to analyze their datasets using a common protocol and 2) perform location-specific analyses of air pollution effects on birth weight using a standardized statistical approach.

Results. Fourteen research groups from nine countries participated. We developed a protocol to estimate odds ratios (OR) for the association between particulate matter (PM_{10}) and low birthweight (LBW) among term births, adjusted first for socioeconomic status and second for additional location-specific variables. Among locations with data for the PM_{10} analysis, ORs estimating the relative risk of term-LBW associated with a 10 $\mu g/m^3$ increase in average PM_{10} concentration during pregnancy adjusted for socioeconomic status ranged from 0.63 (95% confidence interval, CI= 0.30, 1.35, the Netherlands) to 1.15 (CI=0.61, 2.18, Vancouver), with 6 research groups reporting statistically significant adverse associations. We found evidence of statistically significant heterogeneity in estimated effects among locations.

Conclusions. Variability in PM_{10}-LBW relationships among study locations remained, despite use of a common statistical approach. A more detailed meta-analysis and use of more complex protocols for future analysis may uncover reasons for heterogeneity across locations. However, our findings confirm the potential for a diverse group of researchers to analyze their data in a standardized way to improve understanding of air pollution effects on birth outcomes.

Introduction

Evidence that poor air quality can adversely affect birth outcomes is increasing. A small number of review articles have summarized existing studies and concluded that there is likely an adverse effect of air pollution on pregnancy outcome (Glinianaia et al. 2004; Ritz and Wilhelm, 2008; Sram et al. 2005). However, estimated associations between these outcomes and air pollutant exposures over the whole pregnancy and during specific time windows (according to trimester of pregnancy, for example) have been inconsistent, making definitive conclusions difficult (Glinianaia et al., 2004; Slama et al. 2008; Woodruff et al. 2009).

Comparisons of findings across different geographic locations are hindered, in part, by differences in research designs. Although most published studies have reported adverse pregnancy outcomes in association with prenatal exposure to air pollution, inconsistent findings reported by some studies prompted a series of workshops to discuss this relatively new area of investigation (Slama et al. 2008; Woodruff et al. 2009) and the formation of the International Collaboration on Air Pollution and Pregnancy Outcome (ICAPPO) (Woodruff et al. 2010). The primary objective of ICAPPO is to understand how differences in research design and methods contribute to variations in findings.

As part of this effort, a feasibility study was developed to determine whether it would be possible to use a common protocol to re-analyse existing datasets that were created to answer similar but not identical research questions. In this report, we describe the common research protocol and participating studies. Throughout this manuscript, study results from each research group are referred to by name (e.g. EDEN study) if available, otherwise by location (e.g. Seattle study). Additionally, we present estimated odds ratios for the association between low birth

weight among term births and exposure to ambient particulate matter with an aerodynamic diameter < 10 µm (PM_{10}) during pregnancy.

METHODS

Through discussion with the larger group of ICAPPO participants and detailed planning by a smaller group (JP, DR, SVG, JHL), a protocol for the feasibility study was developed, agreed upon and distributed to a geographically diverse group of researchers. To maximize the number of participating groups, we deliberately simplified the protocol by restricting the primary statistical analysis to one outcome (low birth weight in term births) and the air pollution exposure (PM_{10}) available for the largest number locations (Woodruff et al 2010).

Cohort restrictions. We limited the study to live-born, singleton, term (37-42 complete weeks of gestation) infants with known birth weight, maternal education (or another measure of socioeconomic status), dates of birth and conception (often based on last menstrual period (LMP)), and ambient PM concentrations, as described below, during pregnancy. The primary outcome was term low birth weight (LBW); LBW was defined as birth weight <2,500 g.

Air pollution exposure. The primary exposure variable was the ambient concentration of PM_{10} averaged over the entire pregnancy. PM_{10} concentrations were assigned to each subject using the approach employed by each research group in their original work. Although we focused on PM_{10}, investigators also were encouraged to provide results for fine particulate matter ($PM_{2.5}$) if available. Studies without PM_{10} data provided effect estimates for $PM_{2.5}$ or black smoke exposures during pregnancy.

Black smoke approximates PM less than 4 microns in diameter (Muir and Laxon, 1995); results for black smoke are presented alongside the PM_{10} results for the PAMPER study (Newcastle upon Tyne, UK). The methods for modeling the PAMPER black smoke exposures are described elsewhere (Fanshawe et al. 2008).

Socioeconomic status. ICAPPO participants identified socioeconomic status (SES) as a potentially important control variable when assessing pollution and birth outcomes (Slama et al. 2008; Woodruff et al. 2009), and agreed to use maternal education as the primary measure of SES in the feasibility study. Maternal education is commonly used as an SES measure in perinatal studies, and has been shown to be related, albeit imperfectly, with other measures of SES (Kaufman et al. 2008; Parker et al. 1994; Pickett et al. 2002). If maternal education was unavailable, using different individual or area-level SES measures was allowed. Because the collection and meaning of maternal education for these studies differs among the study locations, its form as an analytic covariate differed among the study locations.

Other covariates. Participants also were encouraged to provide estimates adjusted for additional covariates as described below. Although additional variables make comparisons of results across locations more challenging, they allowed us to examine how additional adjustments specific to each location might influence estimates reported by each study.

Primary statistical analysis. We used logistic regression, with term-LBW as the dependent variable and PM_{10}as a continuous explanatory variable; black smoke was used in the PAMPER study, as described above. Results are reported as odds ratios per 10 $\mu g/m^3$ increase in average concentration during pregnancy to facilitate synthesis of results. Results from two models were examined:

Model 1 covariates: PM_{10} and study-specific maternal education or other SES measure

Model 2 covariates: PM_{10}, maternal education or other SES measure, plus other study-location specific covariates as described above

For the ***secondary analyses***, we suggested modeling continuous term birth weight as an outcome (using linear regression) and/or using $PM_{2.5}$ as an exposure measure. In addition, results from models describing associations after controlling for different SES measures were contributed. Secondary analyses were encouraged but not required for participation, so results of secondary analyses were not reported by all investigators.

Although full meta-analyses were not performed, in our examination of results, initial tests of homogeneity across study locations were conducted using fixed effects models (Sterne et al. 2001). In these tests, the null hypothesis of homogeneity was rejected with p-values < 0.05.

RESULTS

Locations. Fourteen research groups from nine countries participated (Table 1). Of these, six reported results for PM_{10} only, six reported results for both PM_{10} and $PM_{2.5}$, one reported results for $PM_{2.5}$ only (Seattle study), and one for black smoke only (PAMPER study). Most data were from the late 1990s to the mid 2000s. However, the PAMPER study comprised births from 1962 through 1992. The number of eligible births ranged from slightly over one thousand in the EDEN study (Nancy and Poitiers, France) to over one million in the California

study, although there was some variability within studies depending on the exposure measure and covariates. The percent of LBW among term births ranged from 1.15% in the PIAMA study (the Netherlands) to 3.77% in the São Paulo study (Table 1)

By design, datasets used in the feasibility study have been used for previous studies of pollution and pregnancy outcomes, or are intended for such use. However, these are not necessarily studies of PM_{10} or term-LBW, and previously published results may have been based on earlier versions of study datasets (Bell et al. 2007; Bell et al. 2008; Brauer et al. 2008; Darrow et al. 2009a; Darrow et al. 2009b; Glinianaia et al. 2008; Gehring et al. 2011; Gouveia et al. 2004; Ha et al. 2004, Jalaludin et al. 2007; Lepeule et al. 2010; Mannes et al. 2005; Pearce et al. 2010; Pesatori et al. 2008; Rich et al. 2009; Slama et al. 2009; van den Hooven et al. 2009).

PM concentration estimation. PM concentration estimates and estimation methods differed among the studies (Table 2). Some research groups relied on temporal variability in PM to estimate effects, where exposure was calculated by averaging all measurements over the entire study area for the pregnancy interval; for these studies, exposure estimates differed for pregnancies occurring at different times, but not by maternal residence, within the study area. Other studies estimated effects based on both temporal and spatial PM contrasts, where estimates were calculated for multiple geographic administrative units or at each maternal address; in these studies, exposures differed both by maternal address and by timing of the pregnancies within the study period. Most research groups (11) used routinely collected monitoring network data to estimate exposures (Table 2), although its use differs among studies (e.g. averages over geographic areas; nearest monitor measurement, or inverse distance weighted (IDW) averages from multiple monitors, from residence).

Two research groups used models to estimate PM_{10} exposure (Table 2), although modeling methods differed. The Generation R study (Rotterdam, the Netherlands) used dispersion modeling (combination of monitoring data with modeling techniques) (Wesseling et al. 2002) whereas the PIAMA study (the Netherlands) used temporally adjusted land use regression (LUR) (Gehring et al. 2011) and estimated residential PM_{10} from modeled $PM_{2.5}$ concentration (Cyrys et al. 2003). PAMPER used modeled estimates, as described above; the median modeled black smoke concentration in the PAMPER dataset was 32.8 $\mu g/m^3$ with an interquartile range of 17.1-104.9, reflecting, in part, the long time spanned. The Vancouver study used monitoring network data for PM_{10} but used both LUR models and monitoring network data (IDW) to estimate $PM_{2.5}$ exposures (Brauer et al. 2008); results for both Vancouver $PM_{2.5}$ estimates are shown below.

Socioeconomic status. Eleven of the research groups used maternal education as the indicator of SES for Model 1 (Table 1). However, the maternal education measure varied in form and meaning across studies. Three studies relied on contextual information based on neighborhood characteristics to define maternal SES for Model 1 of the primary analysis (Table 1). Some research groups included additional individual level socioeconomic measures for Model 2 and in secondary analyses (See Supplemental Material, Table 1). For example, paternal occupation was used in the Lombardy study. The California study added area-level socioeconomic measures. Similarly, the Vancouver study added an additional area-level income variable. Some research groups included individual-level characteristics which may correlate with socioeconomic status: maternal age, race, ethnicity, indigenous status, and country of birth.

Birthweight

The relative odds of term-LBW per 10 μg/m^3 increase in mean PM_{10} concentration during pregnancy, adjusted for SES (Model 1) are shown by location in Figure 1. Associations differed among study locations (p-value from test for heterogeneity < 0.001). Six studies indicated a statistically significant positive (adverse) association (Atlanta, California, Connecticut/Massachusetts, PAMPER, São Paulo, and Seoul) while the Sydney and Vancouver studies indicated an adverse, albeit not significant, association (Figure 1). Little or no association was reported by seven studies; no research group reported significant inverse (protective) associations.

Figure 2 shows estimated odds ratios from Model 2 (models fitted with additional covariates; see Supplemental Material, Table 1). Additional covariates varied among studies and included maternal age and transformations of age, parity, antenatal visits, country of birth, gender, maternal smoking, maternal alcohol, maternal hypertension, maternal diabetes, season of conception, year of birth, marital status, race/ethnicity, indigenous status, gestational age, and contextual measures of socioeconomic status. About half of Model 2 ORs suggest slightly stronger associations between air pollution and term-LBW than Model 1 ORs while other Model 2 ORs were either very similar or attenuated compared with Model 1 (see Supplemental Material Table 2 for a direct comparison of estimates). Associations differed among study locations (p-value from test for heterogeneity < 0.05).

Changes in mean term birth weight associated with each 10 μg/m^3 increase in PM_{10} are shown in Figure 3 for the 11 locations reporting continuous birth weight results. The mean estimated change ranged from a 42.2 g decrease (Generation R) to an increase of about 20 g (the

Atlanta study), with most estimates (9 out of 11) indicating a 2 to 20 g lower birth weight associated with each 10 μg/m^3 increase in PM_{10} exposure. Of the 11 studies, 6 reported a statistically significant adverse effect of PM_{10}, while 2 (the Atlanta and Lombardy studies) indicated a significant protective effect. These associations differed among study locations (p-value from test for heterogeneity < 0.001). After controlling for study-specific factors, model coefficients, often, although not always, suggested larger decreases in birth weight with increases in PM_{10} (see Supplemental Material, Table 3). In the Atlanta study, the estimate changed from an apparent mean increase of 20 g to a mean decrease of -28.8 g (-49.6,-8.1) whereas PIAMA's estimate changed to an apparent increase (47.0 g (-10.5, 104.6)) after controlling for location-specific confounders.

Figure 4 shows estimated relative odds of low birth weight associated with each 10 μg/m^3 increase in $PM_{2.5}$ concentration, after controlling for SES, for a subset of studies. As for PM_{10}, some studies indicated a significant increase in the relative odds of LBW while others indicated no association. The Vancouver study reported different results using different $PM_{2.5}$ estimates. P-values from separate heterogeneity tests, each including one Vancouver estimate, were 0.06 (LUR) and 0.18 (IDW).

DISCUSSION

Despite the deliberately simple protocol and the heterogeneity in study designs and locations, we found some consistency across studies, particularly for the relationships between PM_{10} and mean birth weight and $PM_{2.5}$ and low birth weight. After controlling for SES, the reduction in mean birth weight associated with a PM_{10} increase of 10μg/m^3 was between 2 and

20 g, for 9 of 11 locations. Although based on fewer studies than those for PM_{10}, the initial tests of homogeneity for $PM_{2.5}$ results were not statistically significant. More detailed meta-analysis of the initial results, considering alternative models, influential locations, and differences in location-specific covariates and exposures may improve our understanding of these relationships and lead to improved summary estimates.

Based on a discussion of initial feasibility study results at the 2009 workshop in Dublin, Ireland, participants concluded that the method used to estimate PM_{10} exposures may be the most critical design difference among the studies. Some prior studies from California (Basu et al. 2004; Wilhelm and Ritz 2003), Vancouver (Brauer et al. 2008), Sydney (Mannes et al. 2005), and Atlanta (Darrow et al. 2009a) have examined the consequences of different methods for calculating pollution metrics in the same study but from different perspectives. For example, as in the results presented in Figure 4, Brauer et al. (2008) compared $PM_{2.5}$ estimates from LUR and monitor data (IDW) and concluded that their moderate correlation could be due to different aspects of variability being captured by each method. Basu et al. (2004) found stronger associations for exposures estimated over larger geographic areas than over smaller geographic areas, but did not speculate on the reasons for the discrepancy; however, Basu et al (2004) cautioned that studies using different methods for exposure assessment may not be comparable.

Importantly, there is large variation in PM_{10} levels and concentration ranges among study locations. In the Vancouver study, for example, the 10 $\mu g/m^3$ increase used to derive odds ratios is nearly an order of magnitude greater than the interquartile range (11.7 to 13.1, Table 2) of exposures. Similarly, in the Atlanta study, the 10 $\mu g/m^3$ reporting unit represents more than the entire range of PM_{10} concentrations18.6 to 29.6). The analytical methods used in the common framework assume no threshold level below which PM is not associated with health. While

evidence supporting the hypothesis that no threshold exists for PM relationships and overall population mortality (Daniels et al 2000), threshold assumptions have not been fully explored for adverse reproductive outcomes, including birth weight. Non-linear relationships were not directly examined in this feasibility study, however, they may contribute to heterogeneity among studies; a more fully coordinated analysis should improve our ability to assess non-linear relationships.

Covariates likely to affect the relationship between PM_{10} and low birth weight differ among study locations for many reasons (Strickland et al. 2009). For studies that estimate effects based on spatial contrasts, controlling for SES can be important because it may be spatially correlated with exposure concentrations (O'Neill et al. 2003). However, SES measures and their relationships with both birth outcomes and air pollution are not consistent. For example, while mothers with lower SES generally tend to have poorer birth outcomes, the strength of the relationship differs depending on which birth outcome (birth weight, preterm birth) and which measures of SES (maternal education, occupation) are used (Parker et al. 1994; Pickett et al. 2002). While in some places, mothers with higher SES live in less polluted areas (Woodruff et al. 2003), in others, the opposite relationship holds (Slama et al. 2007). Because participating studies rely on exposure estimates with differing spatial and temporal components, critical confounders may differ among studies (Strickland et al. 2009). Changes between results for the SES-only and SES plus covariates models varied among studies, suggesting that other statistical approaches, possibly hierarchical models, that allow for different types of confounding factors could be informative for understanding apparent variations among locations.

Finally, other methods of analysis could be used. While logistic regression is commonly applied, alternative approaches have considered spatial correlations (Jerrett et al. 2005), time-

varying exposures (Suh et al. 2009), generalized additive models (Ballaster et al. 2010) and hierarchical structures (Yi et al. 2010). Bell et al. (2007) proposed a method for handling correlated exposures across trimesters. Because both model-based and spatial averaged exposures estimates are calculated with error, considering their precision would provide more accurate confidence intervals (Woodruff et al. 2009).

The ICAPPO feasibility project successfully coordinated analyses of the association between ambient PM concentrations and term-LBW, across multiple locations, datasets, and research teams worldwide. These initial results and the participation of multiple research groups, even without external funding, support the continuation of this effort to increase our understanding of the human reproductive consequences of adverse air quality.

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Appendix

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Table 1: Birth years, number of births, percent term low birth weight (LBW) and measure of socioeconomic status (SES) used in Model 1 (adjusted for SES only), by study

				SES measure used in Model 1 of feasibility study	
Study and location[a]	Birth years	Number of births[b]	Percent term LBW	Measure	Descriptive statistics
Atlanta, Georgia, USA (Darrow et al. 2009a, 2009b)	1996-2004	325,221	2.62	Attained maternal education	Years: 19.8% < 12, 24.7% 12, 55.5% >12
California, USA (Morello-Frosh et al. 2010)	1996-2006	1,714,509	2.43	Attained maternal education[c]	Years: 31.5% < 12, 28.0% 12, 40.5% > 12
Connecticut and Massachusetts, USA (Bell et al. 2007, 2008)	1999-2002	173,042	2.16	Attained maternal education	Mean 13.6 years (SD 2.6)
EDEN, Poitiers and Nancy, France (Lepeule et al. 2010)	2003-2006	1,233	2.11	Age at completion of education	Age, years: 17.7 % <19, 61.7% 19-24, 20.6% >24
Lombardy, Italy (Pesatori et al. 2008)	2004-2006	213,542	2.71	Attained maternal education	Degree: 33.3% < high school degree, 45.8 % high school degree, 3.6% bachelor degree, 17.6% graduate degree

Table 1: (continued)

Study and location[a]	Birth years	Number of births[b]	Percent term LBW	SES measure used in Model 1 of feasibility study	
				Measure	Descriptive statistics
PAMPER, Newcastle upon Tyne, UK (Glinianaia et al. 2008; Pearce et al. 2010)	1962-1992	81,953	3.19	Area level indicator: Townsend Deprivation Score[d]	Quintiles cut-points: -1.2, 2.4, 4.7, 6.6
New Jersey, USA (Rich et al. 2009)	1999-2003	87,281	2.75	Attained maternal education	Years: 20.6% < 12, 36.5% 12, 42.9% > 12
PIAMA, the Netherlands (Gehring et al. 2011)	1996-1997	3,471	1.15	Attained maternal education	Degree: 22.8% low ; 41.6% medium; 35.6% high
Generation R Rotterdam, the Netherlands (van den Hooven et al. 2009)	2002-2006	7,296	2.26	Attained maternal education	Degree: 10.9% none/low; 44.7% secondary; 44.3 % higher
São Paulo, Brazil (Gouveia et al. 2004)	2005	158,791	3.77	Attained maternal education	Years: 29.3% < 7, 50.7% 8-11, 19.9% > 11
Seoul, Republic of Korea (Ha et al. 2004)	1998-2000	372,319	1.45	Attained maternal education	Degree: 4.1% < high school degree, 52.7% high school degree, 43.2% <=bachelor degree

Table 1: (continued)

				SES measure used in Model 1 of feasibility study	
Study and location[a]	Birth years	Number of births[b]	Percent term LBW	Measure	Descriptive statistics
Seattle, Washington USA	1998-2005	301,880	1.56	Attained maternal education[c]	Years: 12.8% < 12, 26.1% 12, 60.0% > 12
Sydney, Australia (Jalaludin et al, 2007)	1998-2004	279,015	1.62	Area level indicator: Index of Relative Socioeconomic Disadvantage[e]	Quartiles cut-points**:** ≤945.1; 945.1 to ≤1010.7, 1010.7 to ≤1072.7, >1072.7
Vancouver, British Columbia Canada (Brauer et al. 2008)	1999-2002	66,467	1.35	Area level indicator: % women with post-secondary education	Quartiles cut-points: 28.8, 36.3, 44.1

[a]Datasets have been used for other studies, although not necessarily studies of PM_{10} or term-LBW; cited analyses sometimes used different versions of the data.

[b]Births used in Model 1: Singleton, term infants with known birth weight, maternal socioeconomic status, gestational age, and ambient PM_{10} or black smoke concentrations.

[c]Collection of maternal education changed during the study period.

[d]The Townsend deprivation score is an area-based measure of material deprivation (Townsend et al. 1988), calculated for each enumeration district (approximately 200 households) based on 1971, 1981 and 1991 Census data.

[e]The Australian Bureau of Statistics' Index of Relative Socio-economic Disadvantage (IRSED) (Australian Bureau of statistics 2001) uses a range of census factors and is assigned to each Census Collection District (approximately 200 households).

Table 2. PM_{10} distribution, method of exposure estimation, area, and source of exposure variability, by study

Study	PM_{10} distribution, ($\mu g/m^3$) Median	25th	75th	Method of exposure estimation	Approx-imate area[a] (km^2)	Exposure contrast[b]
Atlanta	23.5	22.3	25.4	Monitoring network. Population-weighted spatial average over city. (Ivy et al. 2008)	4,538	temporal
California	28.9	22.6	38.7	Monitoring network. Nearest monitor within 10 km of residence.	423,970[a]	spatial and temporal
Connecticut and Massachusetts	22.0	18.1	25.5	Monitoring network. Spatial average over county of residence.	41,692	spatial and temporal
EDEN	19.0	18	21	Monitoring network. Nearest monitor within 20 km of residence.	480	spatial and temporal
Lombardy	49	44	54	Monitoring network. Average of monitoring stations located in 9 regional areas (Baccarelli et al. 2007)	23,865	spatial and temporal
PAMPER[c]	(PM_{10} not available)			Spatial-temporal model for black smoke (Fanshawe et al. 2008)	63	spatial and temporal
New Jersey	28.0	24.8	31.7	Monitoring network. Nearest monitor within 10 km of residence.	22,592[a]	spatial and temporal
PIAMA	40.5	36.7	43.4	Land use regression (LUR) model (Gehring et al. 2011) with temporal adjustment using air monitoring network data[d]	12,000	spatial and temporal

Table 2: (continued)

Study	PM_{10} distribution, ($\mu g/m^3$) Median	25th	75th	Method of exposure estimation	Approx-imate area[a] (km^2)	Exposure contrast[b]
Generation R	32.8	32.2	33.3	Dispersion model (Wesseling et al. 2002)	150	spatial
São Paulo	40.3	39.2	42.1	Monitoring network. Average from 14 monitors throughout city.	1,500	temporal
Seattle[e]	(PM_{10} not available)			Monitoring network. Population-weighted spatial average of $PM_{2.5}$ for monitors within 20 km of residence (Ivy et al. 2008)		spatial and temporal
Seoul	66.45	59.63	69.72	Monitoring network. Average from 27 monitors throughout city.	605	spatial and temporal
Sydney	16.50	12.8	21.0	Monitoring network. Average from 8 monitors throughout city.	12,145	temporal
Vancouver	12.5	11.7	13.1	Monitoring network. Inverse distance weighting of up to 3 monitors within 50 km of residence.[f]	3,300	spatial and temporal

[a]Approximate geographic area in which mothers reside; in California and New Jersey, the geographic area includes maternal addresses too far from a PM_{10} or $PM_{2.5}$ monitoring site to be included in the study.
[b]Temporal contrast is used to describe studies where exposure estimates differ among mothers based on the timing of their pregnancy; spatial contrast is used to describe studies where exposure estimates differ among mothers based on their residence.
[c]Only Black Smoke available (Black smoke is a historic measure of airborne PM, an approximate equivalent to PM_4 (black smoke ~ PM_4), shown to be a reasonable predictor of daily average PM_{10}) (Muir and Laxon, 1995).
[d]PM_{10} estimated from $PM_{2.5}$ LUR model results (see text).
[e]Only $PM_{2.5}$ available. [f] $PM_{2.5}$ exposure also derived from LUR (see text).

Figure Legends

Figure 1. Odds ratios (and 95% confidence intervals) for low birth weight among term births in association with a 10 μg/m^3 increase in estimated average PM_{10}, or black smoke (PAMPER), concentration during the entire pregnancy, adjusted for socioeconomic status (Model 1), by study.

Figure 2. Odds ratios (and 95% confidence intervals) for low birth weight among term births in association with a 10 μg/m^3 increase in estimated average PM_{10}, or black smoke (PAMPER), concentration during the entire pregnancy, adjusted for socioeconomic status and study-specific variables (Model 2), by study.

Figure 3. Change in mean birth weight (and 95% confidence intervals) among term births in association with a 10 μg/m^3 increase in estimated average PM_{10}, or black smoke (PAMPER), concentration during the entire pregnancy, adjusted for socioeconomic status, by study.

Figure 4. Odds ratios (and 95% confidence intervals) for low birth weight among term births in association with a 10 μg/m^3 increase in estimated average $PM_{2.5}$ concentration[a] during the entire pregnancy, adjusted for socioeconomic status, by study.

[a]Results for the Vancouver study are from two different $PM_{2.5}$ estimation methods, land use regression (LUR) and inverse distance weighing (IDW) of monitor measurements (see text)

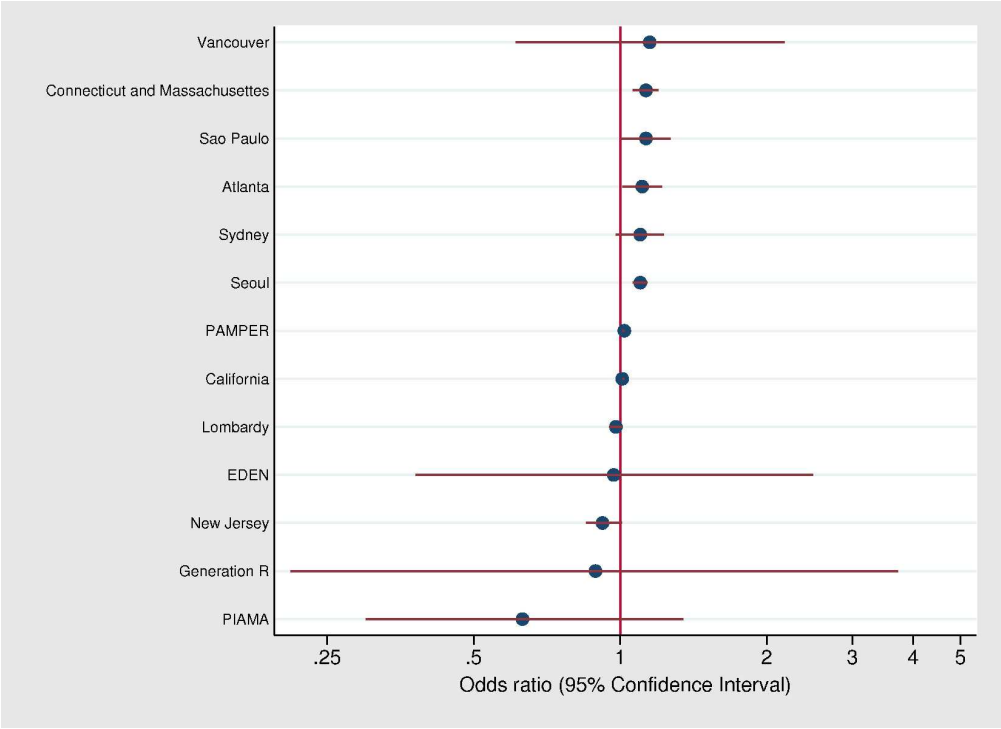

Figure 1. Odds ratios (and 95% confidence intervals) for low birth weight among term births in association with a 10 µg/m3 increase in estimated average PM10, or black smoke (PAMPER), concentration during the entire pregnancy, adjusted for socioeconomic status (Model 1), by study.
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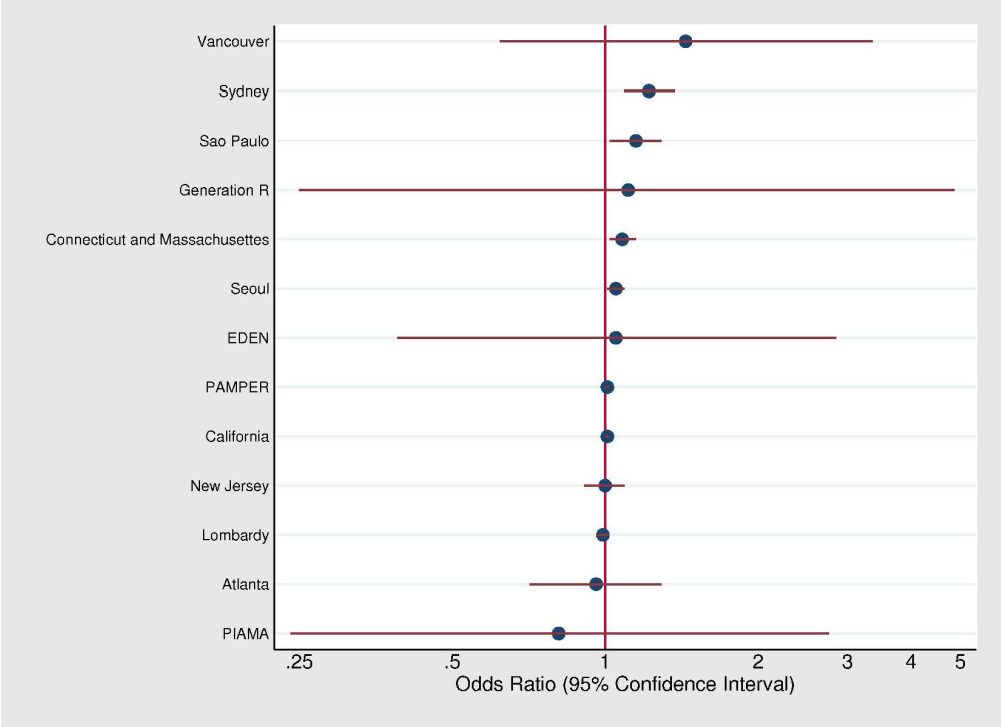

Figure 2. Odds ratios (and 95% confidence intervals) for low birth weight among term births in association with a 10 µg/m3 increase in estimated average PM10, or black smoke (PAMPER), concentration during the entire pregnancy, adjusted for socioeconomic status and study-specific variables (Model 2), by study.
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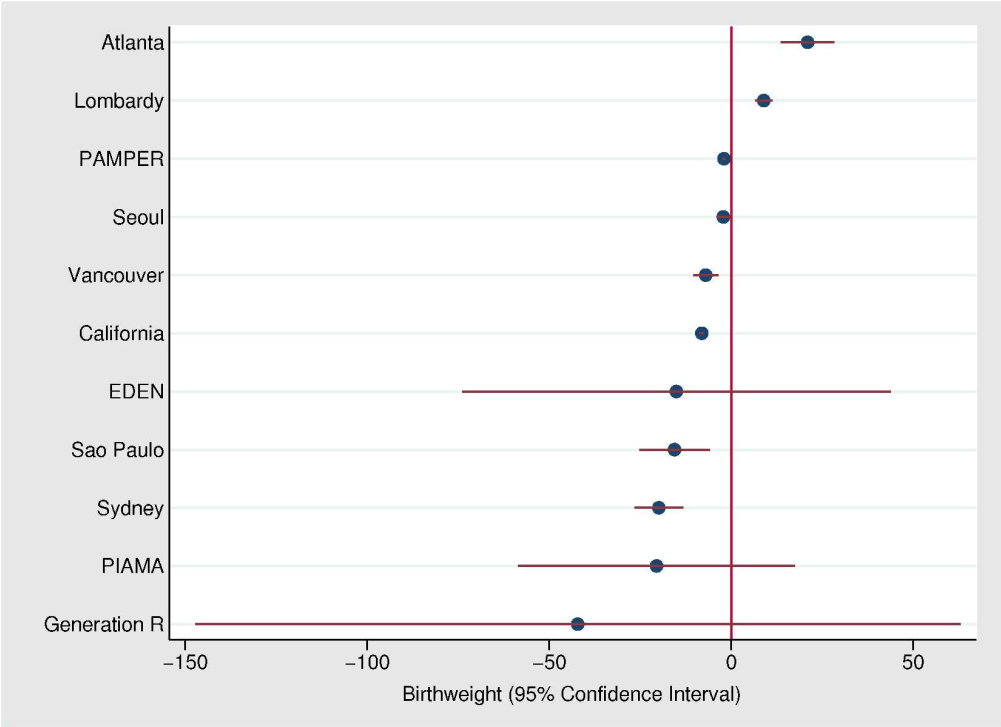

Figure 3. Change in mean birth weight (and 95% confidence intervals) among term births in association with a 10 µg/m3 increase in estimated average PM10, or black smoke (PAMPER), concentration during the entire pregnancy, adjusted for socioeconomic status, by study.
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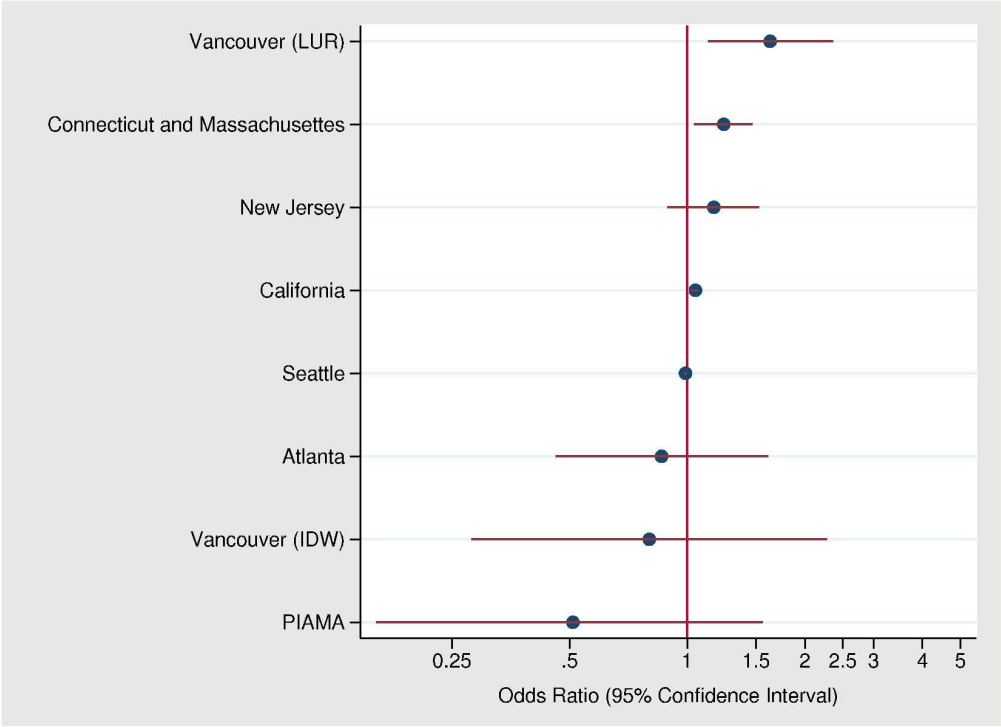

Figure 4. Odds ratios (and 95% confidence intervals) for low birth weight among term births in association with a 10 µg/m3 increase in estimated average PM2.5 concentrationa during the entire pregnancy, adjusted for socioeconomic status, by study.
aResults for the Vancouver study are from two different PM2.5 estimation methods, land use regression (LUR) and inverse distance weighing (IDW) of monitor measurements (see text)

139x101mm (600 x 600 DPI)