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

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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; Srám et al. 2005). However, estimated associations between these outcomes and air pollutant exposures over the whole pregnancy and during specific time windows (e.g., trimester of pregnancy) 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 Outcomes (ICAPPO) (Woodruff et al. 2010). The primary objective of ICAPPO is to help 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 analyze existing study data sets that were created to answer similar but not identical research questions. A workshop was held in Dublin (25–29 August 2009) to share and discuss the initial results of the feasibility study. In this report, we describe the common research protocol and participating studies. Throughout this article, study results from each research group are referred to by name (e.g., EDEN study [Etude des Déterminants pré et post nataux du développement et de la santé de l’Enfant]) if necessary. Address correspondence to J.D. Parker, National Center for Health Statistics, 3311 Toledo Rd., Room 6107, Hyattsville, MD 20782 USA; Telephone: (301) 458-4419; Fax: (301) 458-4038; E-mail: djparker@cdc.gov. Supplemental Material is available online (doi:10.1289/ehp.1002725 via http://dx.doi.org/).

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available, otherwise by location (e.g., Seattle study). Additionally, we present estimated odds ratios (ORs) for the association between low birth weight (LBW) 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 (J.D.P., D.Q.R., S.V.G., J.H.L.), 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 (LBW 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 (SES)], dates of birth and conception (often based on last menstrual period), and ambient PM concentrations, as described below, during pregnancy. The primary outcome was term LBW, 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 PM (≤ 2.5 µm in aerodynamic diameter (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$_{1}$ (< 4 µm in diameter) (Muir and Laxen 1995); results for black smoke are presented alongside the PM$_{10}$ results for the PAMPER (Particulate Matter and Perinatal Events Research) study (Newcastle upon Tyne, UK). The methods for modeling the PAMPER black smoke exposures are described elsewhere (Fanhawse et al. 2008).

**Socioeconomic status.** ICAPPO participants identified 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 differ 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 ORs per 10-µg/m$^3$ increase in average concentration during pregnancy to facilitate synthesis of results. Results from two models were examined: Model 1 covariates were PM$_{10}$ and study-specific maternal education or other SES measure; model 2 covariates were PM$_{10}$, maternal education or other SES measure, plus other study location-specific covariates as described above.

**Secondary statistical analyses.** For these 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.

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**Table 1. Birth years, number of births, percent term LBW, and measure of SES used in model 1 (adjusted for SES only), by study.**

<table>
<thead>
<tr>
<th>Study and location</th>
<th>Birth years</th>
<th>No. of births</th>
<th>Percent term LBW</th>
<th>Measure</th>
<th>SES measure used in model 1 of feasibility study</th>
<th>Descriptive statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlanta, Georgia, USA (Darlow et al. 2009a, 2009b)</td>
<td>1996–2004</td>
<td>325,221</td>
<td>2.62</td>
<td>Attained maternal education</td>
<td>Years: 19.8% &lt; 12, 24.7% 12, 55.5% &gt; 12</td>
<td></td>
</tr>
<tr>
<td>California, USA (Monello-Frosh et al. 2010)</td>
<td>1996–2006</td>
<td>1,714,509</td>
<td>2.43</td>
<td>Attained maternal education</td>
<td>Years: 31.5% &lt; 12, 28.0% 12, 40.5% &gt; 12</td>
<td></td>
</tr>
<tr>
<td>Connecticut and Massachusetts, USA (Bell et al. 2007, 2008)</td>
<td>1999–2002</td>
<td>173,042</td>
<td>2.16</td>
<td>Attained maternal education</td>
<td>Mean ± SD, 13.6 ± 2.6 years</td>
<td></td>
</tr>
<tr>
<td>EDEN, Poitiers and Nancy, France (Lepeule et al. 2010)</td>
<td>2003–2006</td>
<td>1,233</td>
<td>2.11</td>
<td>Age at completion of education</td>
<td>Years: 17.7% &lt; 19, 61.7% 19–24, 20.6% &gt; 24</td>
<td></td>
</tr>
<tr>
<td>Lombardy, Italy (Pesatori et al. 2008)</td>
<td>2004–2006</td>
<td>213,542</td>
<td>2.71</td>
<td>Attained maternal education</td>
<td>Degree: 33.3% high school, 45.8% high school, 3.6% bachelor, 17.6% graduate</td>
<td></td>
</tr>
<tr>
<td>PAMPER, Newcastle upon Tyne, UK (Glinaia et al. 2008; Pearce et al. 2010)</td>
<td>1982–1992</td>
<td>81,953</td>
<td>3.19</td>
<td>Area-level indicator: Townsend Deprivation Score</td>
<td>Quintile cut-points: −1.2, 2.4, 4.7, 6.6</td>
<td></td>
</tr>
<tr>
<td>New Jersey, USA (Rich et al. 2009)</td>
<td>1999–2003</td>
<td>87,281</td>
<td>2.75</td>
<td>Attained maternal education</td>
<td>Years: 20.6% &lt; 12, 36.5% 12, 42.9% &gt; 12</td>
<td></td>
</tr>
<tr>
<td>PIAMA, the Netherlands (Gehring et al. 2011)</td>
<td>1996–1997</td>
<td>3,471</td>
<td>1.15</td>
<td>Attained maternal education</td>
<td>Degree: 22.8% low, 41.6% medium, 35.6% high</td>
<td></td>
</tr>
<tr>
<td>Generation R, Rotterdam, the Netherlands (van den Hooven et al. 2009)</td>
<td>2002–2006</td>
<td>7,296</td>
<td>2.26</td>
<td>Attained maternal education</td>
<td>Degree: 10.9% none/low, 44.7% secondary, 44.3% higher</td>
<td></td>
</tr>
<tr>
<td>São Paulo, Brazil (Gouveia et al. 2004)</td>
<td>2005</td>
<td>158,791</td>
<td>3.77</td>
<td>Attained maternal education</td>
<td>Years: 23.3% &lt; 12, 50.7% 8–11, 19.9% &gt; 11</td>
<td></td>
</tr>
<tr>
<td>Seoul, Republic of Korea (Ha et al. 2004)</td>
<td>1998–2000</td>
<td>372,319</td>
<td>1.45</td>
<td>Attained maternal education</td>
<td>Degree: 4.1% high school, 52.7% high school, 42.3% ≤ bachelor</td>
<td></td>
</tr>
<tr>
<td>Seattle, Washington, USA (Sathyanarayana S, Carr C, unpublished data)</td>
<td>1998–2005</td>
<td>301,880</td>
<td>1.56</td>
<td>Attained maternal education</td>
<td>Years: 12.8% &lt; 12, 26.1% 12, 60.0% &gt; 12</td>
<td></td>
</tr>
<tr>
<td>Sydney, Australia (Jalaludin et al. 2007)</td>
<td>1998–2004</td>
<td>279,015</td>
<td>1.62</td>
<td>Area-level indicator: Index of Relative Socioeconomic Disadvantage</td>
<td>Quintile cut-points: ≤ 945.1, 1010.7, 1072.7</td>
<td></td>
</tr>
<tr>
<td>Vancouver, British Columbia, Canada (Brauer et al. 2008)</td>
<td>1999–2002</td>
<td>66,467</td>
<td>1.35</td>
<td>Area level indicator: percentage of women with postsecondary education</td>
<td>Quintile cut-points: 28.8, 36.3, 44.1</td>
<td></td>
</tr>
</tbody>
</table>

*Data sets 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. *Births used in model 1: singleton, term infants with known birth weight, maternal SES, gestational age, and ambient PM$_{10}$ or black smoke concentrations. *Collection of maternal education changed during the study period. *The Townsend Deprivation Score is an area-based measure of material deprivation (Townsend et al. 1988), calculated for each enumeration district (~200 households) based on 1981, 1991, and 1981 census data. *The Australian Bureau of Statistics (2001) Index of Relative Socio-economic Disadvantage uses a range of census factors and is assigned to each census collection district (~200 households).
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 for both PM$_{10}$ and PM$_{2.5}$, one 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 > 1,000 in the EDEN study, Nancy and Poitiers, France to > 1 million in the California study, although there was some variability within studies depending on the exposure measure and covariates. The percentage of LBW among term births ranged from 1.15% in the PIAMA (Prevention and Incidence of Asthma and Mite Allergy) study (Netherlands) to 3.77% in the São Paulo study (Table 1).

By design, data sets 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 data sets (Bell et al. 2007, 2008; Brauer et al. 2008; Darrow et al. 2009a, 2009b; Gehring et al. 2011; Glinianaia et al. 2008; Gouveia et al. 2008; 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 of 14; 79%) used routinely collected monitoring network data to estimate exposures (Table 2), although its use differed 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 (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 data set was 32.8 µg/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 14 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 2 and in secondary analyses (see Supplemental Material, Table 1 (doi:10.1289/ehp.1002725)). For example, maternal 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 that may correlate with SES: maternal age, race, ethnicity, indigenous status, and country of birth.

### Birth weight

Figure 1 shows the relative odds of term LBW per 10-µg/m$^3$ increase in mean PM$_{10}$ concentration during pregnancy, adjusted for SES (model 1) by location. Associations differed among study locations ($p$-value from test for heterogeneity < 0.001).

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**Table 2.** PM$_{10}$ distribution, method of exposure estimation, area, and source of exposure variability, by study.

<table>
<thead>
<tr>
<th>Study</th>
<th>PM$_{10}$ distribution (µg/m$^3$)</th>
<th>Method of exposure estimation</th>
<th>Approximate area$^a$ (km$^2$)</th>
<th>Exposure contrast$^b$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Study</strong></td>
<td><strong>Median</strong></td>
<td><strong>25th percentile</strong></td>
<td><strong>75th percentile</strong></td>
<td>Monitoring network; population-weighted spatial average over city (Ivy et al. 2008)</td>
</tr>
<tr>
<td>Atlanta</td>
<td>23.5</td>
<td>22.3</td>
<td>25.4</td>
<td>4,538</td>
</tr>
<tr>
<td>California</td>
<td>28.9</td>
<td>22.6</td>
<td>38.7</td>
<td>423.970$^c$</td>
</tr>
<tr>
<td>Connecticut and Massachusetts</td>
<td>22.0</td>
<td>18.1</td>
<td>25.5</td>
<td>41,892</td>
</tr>
<tr>
<td>EDEN</td>
<td>19.0</td>
<td>18</td>
<td>21</td>
<td>480</td>
</tr>
<tr>
<td>Lombardy</td>
<td>49</td>
<td>44</td>
<td>54</td>
<td>23,865</td>
</tr>
<tr>
<td>PAMPER$^e$ (PM$_{10}$ not available)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Jersey</td>
<td>28.0</td>
<td>24.8</td>
<td>31.7</td>
<td>63</td>
</tr>
<tr>
<td>PIAMA</td>
<td>40.5</td>
<td>36.7</td>
<td>43.4</td>
<td>12,000</td>
</tr>
<tr>
<td>Generation R</td>
<td>32.8</td>
<td>32.2</td>
<td>33.3</td>
<td>150</td>
</tr>
<tr>
<td>São Paulo</td>
<td>40.3</td>
<td>39.2</td>
<td>42.1</td>
<td>1,500</td>
</tr>
<tr>
<td>Seattle$^f$ (PM$_{10}$ not available)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seoul</td>
<td>66.45</td>
<td>59.63</td>
<td>69.72</td>
<td>17,000</td>
</tr>
<tr>
<td>Sydney</td>
<td>16.50</td>
<td>12.8</td>
<td>21.0</td>
<td>605</td>
</tr>
<tr>
<td>Vancouver</td>
<td>12.5</td>
<td>11.7</td>
<td>13.1</td>
<td>12,145</td>
</tr>
</tbody>
</table>

$^a$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. $^c$Black smoke is a historic measure of airborne PM, − PM$_{2.5}$ shown to be a reasonable predictor of daily average PM$_{10}$(Muir and Laxen 1998). $^d$PM$_{10}$ estimated from PM$_{2.5}$ LUR model results. $^e$PM$_{10}$ available. $^f$PM$_{2.5}$ exposure also derived from LUR (see "PM concentration estimation").
Six studies indicated a statistically significant positive (adverse) association (Atlanta, California, Connecticut and Massachusetts, PAMPER, São Paulo, and Seoul), whereas 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 ORs from model 2 [models fitted with additional covariates; see Supplemental Material, Table 1 (doi:10.1289/ehp.1002725)]. Additional covariates varied among studies and included maternal age and transformations of age, parity, antenatal visits, country of birth, sex, 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 SES. About half of model 2 ORs suggest slightly stronger associations between air pollution and term LBW compared with model 1 ORs, whereas other model 2 ORs were either very similar or attenuated compared with model 1 (for a direct comparison of estimates, see Supplemental Material, Table 2 (doi:10.1289/ehp.1002725)). Associations differed among study locations (p-value from test for heterogeneity < 0.001).

Figure 3 shows changes in mean birth weight associated with each 10-µg/m³ increase in PM$_{10}$ 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 of 11) indicating a 2- to 20-g lower birth weight associated with each 10-µg/m³ increase in PM$_{10}$ exposure. Of the 11 studies, six reported a statistically significant adverse effect of PM$_{10}$; whereas two (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 (doi:10.1289/ehp.1002725)).

Figure 4 shows estimated relative odds of LBW associated with each 10-µg/m³ 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 mean birth weight associated with each 10-µg/m³ increase in PM$_{2.5}$ exposure. Additional ORs were either very similar or attenuated compared with model 1 ORs (see “Methods”).

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**Figure 1.** ORs (95% CIs) for LBW among term births in association with a 10-µg/m³ increase in estimated average PM$_{10}$, or black smoke (PAMPER), concentration during the entire pregnancy, adjusted for SES (model 1), by study.

**Figure 2.** ORs (95% CIs) for LBW among term births in association with a 10-µg/m³ increase in estimated average PM$_{10}$, or black smoke (PAMPER), concentration during the entire pregnancy, adjusted for SES and study-specific variables (model 2), by study.

**Figure 3.** Change in mean birth weight (95% CIs) among term births in association with a 10-µg/m³ increase in estimated average PM$_{10}$, or black smoke (PAMPER), concentration during the entire pregnancy, adjusted for SES (model 1), by study.

**Figure 4.** ORs (95% CIs) for LBW among term births in association with a 10-µg/m³ increase in estimated average PM$_{2.5}$ concentration during the entire pregnancy, adjusted for SES, by study.
in the relative odds of LBW, whereas others indicated no association. The Vancouver study reported different results using different PM2.5 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 PM10 and mean birth weight and between PM2.5 and LBW. After controlling for SES, the reduction in mean birth weight associated with a PM10 increase of 10 μg/m³ was between 2 and 20 g for 9 of 11 locations. Although based on fewer studies than those for PM10, the initial tests of homogeneity for PM2.5 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 (see Appendix), participants concluded that the method used to estimate PM10 exposures may be the most critical design difference among the studies. Some prior studies from California (Basu et al. 2004; Wilhelm and Ritz 2005), 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 PM2.5 estimates from LUR and monitor data (IDW) and concluded that their moderate correlation could be attributable 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 PM10 levels and concentration ranges among study locations. In the Vancouver study, for example, the 10-μg/m³ increase used to derive ORs is nearly an order of magnitude greater than the interquartile range (11.7–13.1; Table 2) of exposures. Similarly, in the Atlanta study, the 10-μg/m³ reporting unit represents nearly the entire range of PM10 concentrations (18.6–29.6 μg/m³). The analytical methods used in the common framework assume no threshold level below which PM is not associated with health. Although evidence supports 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. We did not directly examine nonlinear relationships in this feasibility study, but they may contribute to heterogeneity among studies; a more fully coordinated analysis should improve our ability to assess nonlinear relationships.

**Appendix**

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Covariates likely to affect the relationship between PM10 and LBW 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, although 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). Although 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 models using SES only and those using SES plus covariates 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. Although 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 (Ballester 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 spatially averaged exposure 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, data sets, 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.

**References**


