Association of Long-term Exposure to Airborne Particulate Matter of 1 μm or Less With Preterm Birth in China

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IMPORTANCE  Airborne particulate matter pollution has been associated with preterm birth (PTB) in some studies. However, most of these studies assessed only populations living near monitoring stations, and the association of airborne particulate matter having a median diameter of 1 μm or less (PM1) with PTB has not been studied.

OBJECTIVE  To evaluate whether PM1 concentrations are associated with the risk of PTB.

DESIGN, SETTING, AND PARTICIPANTS  This national cohort study used National Free Preconception Health Examination Project data collected in 324 of 344 prefecture-level cities from 30 provinces of mainland China. In total, 1,300,342 healthy singleton pregnancies were included from women who were in labor from December 1, 2013, through November 30, 2014. Data analysis was conducted between December 1, 2016, and April 1, 2017.

EXPOSURES  Predicted weekly PM1 concentration data collected using satellite remote sensing, meteorologic, and land use information matched with the home addresses of pregnant women.

MAIN OUTCOMES AND MEASURES  Preterm birth (≤37 gestational weeks). Gestational age was assessed using the time since the first day of the last menstrual period. Cox proportional hazards regression analysis was used to examine the associations between trimester-specific PM1 concentrations and PTB after controlling for temperature, seasonality, spatial variation, and individual covariates.

RESULTS  Of the 1,300,342 singleton live births at the gestational age of 20 to 45 weeks included in this study, 104,585 (8.0%) were preterm. In fully adjusted models, a PM1 concentration increase of 10 μg/m3 over the entire pregnancy was significantly associated with increased risk of PTB (hazard ratio [HR], 1.09; 95% CI, 1.09-1.10), very PTB as defined as gestational age from 28 through 31 weeks (HR, 1.20; 95% CI, 1.18-1.23), and extremely PTB as defined as 20 through 27 weeks’ gestation (HR, 1.29; 95% CI, 1.25-1.34). Pregnant women who were older (30-50 years) at conception (HR, 1.13; 95% CI, 1.11-1.14), were overweight before pregnancy (HR, 1.13; 95% CI, 1.11-1.15), had a rural household registration (HR, 1.09; 95% CI, 1.09-1.10), worked as farmers (HR, 1.10; 95% CI, 1.09-1.11), and conceived in autumn (HR, 1.48; 95% CI, 1.46-1.50) appeared to be more sensitive to PM1 exposure than their counterparts.

CONCLUSIONS AND RELEVANCE  Results from this national cohort study examining more than 1.3 million births indicated that exposure to PM1 air pollution was associated with an increased risk of PTB in China. These findings will provide evidence to inform future research studies, public health interventions, and environmental policies.
The World Health Organization reported in 2010 that there were 12.9 million preterm births (PTBs) per year worldwide (9.6% of total births), and PTB has become the leading cause of perinatal mortality and morbidity. Preterm birth can lead to not only neonatal mortality but also lifelong disabilities that negatively contribute to a range of pulmonary, circulatory, and neurologic outcomes, resulting in $26.2 billion in medical costs per year in the United States alone. The etiology of PTB remains unclear, although biological, psychological, social, and environmental factors are thought to play significant roles.

An increasing number of studies have examined the association between particulate matter air pollution and PTB, including studies in Australia, Canada, England, the United States, South Korea, Spain, and China. However, those previous studies have primarily focused on airborne particulate matter with diameters of 10 μm (PM_{10}) or less or of 2.5 μm (PM_{2.5}) and greater. Compared with PM_{2.5} or PM_{10}, PM_{1} (ie, an airborne particulate diameter of 1.0 μm or less) has a higher surface area to mass ratio and can reach the lung alveoli. Particulate matter of this size has been shown to activate multiple pathophysiological processes, which may in turn contribute to PTB. Although PM_{1} contributes to nearly 80% of PM_{2.5}, no epidemiological study has examined the association between PM_{1} and PTB to our knowledge. Thus, there is a critical need to investigate the association between PM_{1} exposure during pregnancy and PTB.

In addition, even in those studies examining PM_{2.5} and PM_{10}, variability in the exposure estimates and analysis methods has led to inconsistent results. Because most of the studies have been conducted in developed countries with relatively lower levels of PM air pollution and smaller exposure ranges, the power to generate robust results may have been restricted. Furthermore, most studies have been based on birth record data, meaning that the studies were unable to take into account the mother’s socioeconomic and behavioral characteristics, which can contribute to the estimates of the effects of PM air pollution. Most previous studies have treated PTB as a binary variable instead of using multiple categories, raising some limitations when trying to associate PTB with each degree of prematurity. The resulting gap in evidence limits the formulation of effective policies regulating air pollution, especially in areas with a wide range of PM pollution.

In the present study, we obtained estimated concentrations of PM_{1} by using satellite-based aerosol optical depth data, land use information, and meteorologic data and applied these to a national birth cohort across mainland China that included both urban and rural areas. The primary objective was to evaluate whether PM_{1} pollution levels were associated with the risk of PTB in a cohort of 1300342 births in China from December 1, 2013, to November 30, 2014. We also aimed to identify subgroups of pregnant women vulnerable to PM_{1}.

**Methods**

**Study Design and Participants**

Data for this national cohort study were extracted from the National Free Preconception Health Examination Project (NFPHEP), which was launched by the Chinese National Health and Family Planning Commission and Ministry of Finance in 2010 to provide free preconception health examinations and follow-up of pregnancy outcomes for couples of childbearing age throughout China. The detailed study design, organization, and implementation have been described elsewhere. We collected NFPHEP database data regarding the preconception examination, early gestation follow-up, and postpartum follow-up for all of the 1.535 545 nulliparous women who were in labor from December 1, 2013, through November 30, 2014. A flowchart (eFigure 1 in the Supplement) of the exclusion criteria for the birth cohort is provided in the Supplement (see eTable 1 in the Supplement for additional information on PTB rates). The final analyses included 1 300 342 singleton live births and was conducted between December 1, 2016, and April 1, 2017. The institutional review board of the National Research Institute for Family Planning, Beijing, China, approved this study. All participants provided written informed consent.

**Outcome Definition**

As recommended by the World Health Organization, PTB was defined as a gestational age from 20 through 36 completed weeks. We also categorized very PTB as a gestational age from 28 through 31 weeks and extremely PTB as 20 through 27 weeks. The time since the first day of the last menstrual period was used to assess gestational age. Women’s responses to inquiries about the date were recorded during the early gestation follow-up visit (conducted no later than 12 weeks after conception) by an obstetrician. After delivery, each woman was asked again about the date of the last menstrual period, after which gestational age was determined at the postpartum follow-up visit (conducted no later than 6 weeks after delivery).

**Exposure Assessment**

Weekly PM_{1} concentrations were predicted at a 0.1° × 0.1° spatial resolution for mainland China during the research period by using satellite remote sensing, meteorologic, and land use information (see the eAppendix in the Supplement for more detailed information). Each woman’s address information at the township level was collected during the preconception examination, early gestation follow-up, and postpartum follow-up records. The 3 addresses were compared, and those women who moved during pregnancy were excluded. In total, 24 444 township-level locations were geocoded, including both...
Long-term Exposure to Airborne Particulate Matter and Preterm Birth in China

Table 1. Maternal and Fetal Characteristics of the Included Term and Preterm Births

Table 1. Maternal and Fetal Characteristics of the Included Term and Preterm Births (continued)

urban and rural areas (41,636 township-level units existed in China during the study period). Each woman's address information was geocoded into longitude and latitude and matched to the centroid of the nearest 0.1° × 0.1° grid cell location of predicted PM1. Trimester-specific mean PM1 concentrations were calculated using the weekly concentration. The data were categorized as trimester 1 (1-13 weeks’ gestation), trimester 2 (14-26 weeks’ gestation), trimester 3 (27 weeks to delivery), and the entire pregnancy (see eTable 2 in the Supplement for additional information).

Statistical Analysis

Cox proportional hazards regression analyses were conducted by using generalized additive mixed models to estimate the association of trimester-specific PM1 exposure with PTB.15 Gestational age was fitted as the time scale, and the event was defined as PTB (medically induced labor data were removed from the analysis). Trimester-specific PM1 levels were fitted as time-independent variables. A literature review was conducted, and a directed acyclic graph was used to create a least biased estimate of the association.1,10,18 The data in the model were adjusted for the following individual variables: maternal age from 16 to 50 years by 5-year intervals; household registration19 (rural, urban); completed educational level (primary school or below, junior high school, senior high school, or college or higher); occupation (farmers, workers, or others); body mass index calculated as the weight in kilograms divided by height in meters squared (≤18.5, 18.6-23.9, or ≥24); organic solvent, heavy metal, or pesticide exposure after conception (yes, no); alcohol consumption and cigarette smoking of mother or partner (still, quit, or never); mode of delivery (vaginal, cesarean); sex of the neonate (male, female); and season of conception (summer, June through August; fall, September through November; winter, December through February; or spring, March through May). A spline with 4 df was used to control for trimester-specific mean temperature.20 A random contribution of province was fitted to control for potential spatial variation.15 Only PM1 and the random contribution of province were included in the crude models. All the aforementioned covariates were then used to build the adjusted models. The restricted maximum likelihood method was used to fit the models, and hazard ratios (HRs) associated with a 10-μg/m3 increase in PM1 were reported.

Trimester-specific associations between very PTB, extremely PTB, and exposure were also assessed using the same approach. A potential association of dose was explored by fitting PM1 as a spline function with 4 df in the models. The

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Exposures during the entire pregnancy were categorized into 4 quartiles, and the HRs for each higher exposure group compared with the lowest exposure group were reported. In addition, because previous studies have shown that the socioeconomic status of women and the season of conception can modify the effects of PM pollution, subgroupanalyses were conducted to assess which subgroups were associated with increased risk of PTB.

Sensitivity analyses were conducted by fitting a random contribution of city. A single model adjusted for exposures during each trimester was created as a sensitivity analysis for trimester-specific contributions. All analyses were performed using R, version 3.3.3 (R Core Team). All statistical tests were 2-sided, and P values <.05 were considered statistically significant.

Results

In total, 1300 342 singleton live births at the gestational ages of 20 to 45 weeks were included in this study that covered 324 of 344 prefecture-level cities from the 30 provinces in mainland China (eFigure 2 in the Supplement). Among the live births, 104 585 (8.0%) were PTBs (eTable 3 in the Supplement). The demographic profiles of women with preterm deliveries differed from those with term deliveries (Table 1). Women with preterm deliveries were more likely to be younger than 20 years at conception (11.0%), come from rural areas (8.1%), have primary school or below educational attainment (9.1%), and be farmers (8.3%). Women who were overweight before their pregnancy (9.1%), smoked cigarettes (9.1%) or consumed alcohol after conception (8.6%), underwent cesarean delivery (8.3%), delivered a boy (8.4%), or conceived in winter (9.1%) were more likely to deliver preterm.

The median PM1 exposure over the entire pregnancy for all mothers was 46.0 μg/m3 with a wide interquartile range (14.3-127.6 μg/m3) (eTable 4 in the Supplement). Figure 1 shows the distribution of quartered mean PM1 exposure over the entire pregnancy for each prefecture-level city in mainland China. We found that women living in the Beijing, Tianjin, and Hebei regions, the Yangtze River delta, the Sichuan Basin, and the Pearl River delta experienced relatively high PM1 exposure (>52.7 μg/m3) over the entire pregnancy.

Table 2 provides the crude and adjusted HRs (and 95% CIs) of PTB associated with maternal exposure to PM1. In the crude models, we found that an increase in PM1 exposure in each trimester and over the entire pregnancy was significantly associated with an increased risk of PTB. In the adjusted analyses, a PM1 exposure increase of 10 μg/m3 in trimester 1 (HR, 1.07; 95% CI, 1.06-1.07), trimester 2 (HR, 1.10; 95% CI, 1.09-1.10), trimester 3 (HR, 1.04; 95% CI, 1.03-1.04), and over the entire pregnancy (HR, 1.09; 95% CI, 1.09-1.10) was significantly associated with an increased risk of PTB. The risks associated with PM1 for very and extremely PTBs were higher than those for PTB. For very PTB, an increased PM1 exposure of 10 μg/m3 over the entire pregnancy provided an HR of 1.20 (95% CI, 1.18-1.23), reaching 1.29 (95% CI, 1.25-1.34) for extremely PTB. The HRs associated with PM1 exposure during the first and second trimester were greater than those of the third trimester.

After fitting the contribution of PM1 exposure over the entire pregnancy as a spline function, the association between PM1 exposure and risk of PTB was log linear (eFigure 3 in the Supplement). When we compared the risk of PTB associated...
Table 2. Crude and Adjusted Preterm Birth Hazard Ratios for Increases in PM$_1$ Concentrations of 10 μg/m$^3$

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Hazard Ratio (95% CI)</th>
<th>First Trimester</th>
<th>Second Trimester</th>
<th>Third Trimester</th>
<th>Entire Pregnancy</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTB</td>
<td>1.03 (1.03-1.03)</td>
<td>1.05 (1.04-1.05)</td>
<td>1.01 (1.01-1.02)</td>
<td>1.06 (1.05-1.07)</td>
<td></td>
</tr>
<tr>
<td>VPTB</td>
<td>1.08 (1.07-1.09)</td>
<td>1.10 (1.09-1.11)</td>
<td>1.02 (1.01-1.03)</td>
<td>1.13 (1.12-1.15)</td>
<td></td>
</tr>
<tr>
<td>ExPTB</td>
<td>1.11 (1.09-1.14)</td>
<td>1.13 (1.11-1.15)</td>
<td>0.99 (0.95-1.04)</td>
<td>1.16 (1.15-1.22)</td>
<td></td>
</tr>
</tbody>
</table>

### Adjusted model b

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Hazard Ratio (95% CI)</th>
<th>First Trimester</th>
<th>Second Trimester</th>
<th>Third Trimester</th>
<th>Entire Pregnancy</th>
</tr>
</thead>
<tbody>
<tr>
<td>PTB</td>
<td>1.07 (1.06-1.07)</td>
<td>1.10 (1.09-1.10)</td>
<td>1.04 (1.03-1.04)</td>
<td>1.09 (1.09-1.10)</td>
<td></td>
</tr>
<tr>
<td>VPTB</td>
<td>1.13 (1.12-1.15)</td>
<td>1.13 (1.12-1.15)</td>
<td>1.06 (1.05-1.08)</td>
<td>1.20 (1.18-1.23)</td>
<td></td>
</tr>
<tr>
<td>ExPTB</td>
<td>1.11 (1.09-1.14)</td>
<td>1.13 (1.10-1.16)</td>
<td>1.06 (0.99-1.12)</td>
<td>1.29 (1.25-1.34)</td>
<td></td>
</tr>
</tbody>
</table>

Abbreviations: PM$_1$, airborne particulate matter with a median diameter of 1 μm or less; ExPTB, extremely preterm birth; PTB, preterm birth; VPTB, very preterm birth.

* Generalized additive model with Cox proportional hazards regression analysis, including the random contribution of province.

b Adjusted for maternal age, household registration, educational level, occupation, prepregnancy body mass index, organic solvent exposure, heavy metal exposure, pesticide exposure, maternal or partner cigarette smoking, alcohol consumption, mode of delivery, neonate’s sex, season, nonlinear association with temperature, and the random contribution of province.

Discussion

The present cohort study of 1.3 million births in China from December 1, 2013, through November 30, 2014, provides compelling evidence that exposure to PM$_1$ air pollution is associated with increased risk of PTB. To our knowledge, no study has reported associations between PM$_1$, and suspended particulates and the risk of PTB. Two national-level studies also used estimated or satellite-based estimates of PM$_2.5$, exposures to examine pregnancy outcomes, although their results were inconsistent. Stieb et al$^{3}$ reported negative associations between satellite-derived PM$_2.5$ and PTB in Canada for an unadjusted model (odds ratio [OR], 0.96; 95% CI, 0.93-0.98) and a model adjusted for the maternal demographic characteristics and socioeconomic status (OR, 0.96; 95% CI, 0.93-0.99). Fleischer et al$^{4}$ found that PM$_2.5$ was not associated with PTB when using a global sample, but the highest quartile of exposure in China was associated with PTB. This result indicates that the difference in exposure range could be a reason for the inconsistent results. In addition, some studies conducted in small areas (eg, at the city level) have also reported positive associations between PTB and PM$_2.5$ or PM$_1$, based on data from Asian populations.$^{6,0,11}$

A previous study reported that PM$_1$ contributed to nearly 80% of PM$_2.5$ in China,$^{14}$ and PM$_1$ and PM$_2.5$ have similar components. But few studies worldwide have focused on airborne PM$_1$ owing to the unavailability of air monitoring data. Thus, few studies have estimated the health effects of PM$_1$. Previous studies examining PM$_2.5$ have suggested that it results in inflammation and oxidative stress.$^{1,2,3}$ However, another previous study$^{22}$ has indicated that inflammation may be related to the creation of reactive oxygen species. Reactive oxygen species can lead to DNA damage, cell damage, irreversible protein modifications, disruption of cellular processes, or alterations in cellular signaling.$^{23}$ Whether these alterations

Figure 2. Adjusted Hazard Ratios of Preterm Birth Associated With Categorized Exposure to Airborne Particulate Matter With Median Diameter of 1 μm or Less Over the Entire Pregnancy

Generalized additive model with Cox proportional hazards regression analysis adjusted for maternal age, household registration, educational level, occupation, prepregnancy body mass index, organic solvent exposure, heavy metal exposure, pesticide exposure, cigarette smoking by mother or partner, alcohol consumption, mode of delivery, neonate’s sex, season, nonlinear association with temperature, and the random contribution of province. Group 1 is the reference group. The hazard ratio for group 2 is 1.03 (95% CI, 1.01-1.05), group 3 is 1.13 (95% CI, 1.10-1.15), and group 4 is 1.36 (95% CI, 1.33-1.39).

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would lead to PTB is not clear, but they may disrupt normal gestational processes. Studies have reported that the mean concentration of PM1 in Australia is 16 μg/m³, in Athens is 18.5 μg/m³, and in Milan is 16.4 μg/m³, which are lower than the PM1 exposure in our study.21,24,25 Although, to our knowledge, no study to date has investigated the association between PM1 exposure and pregnancy outcomes, the present study found significant positive associations between PM1 exposure and pregnancy outcomes, and resulting in enormous annual medical costs worldwide.32,33 In the present study, we found an increased PTB risk of 9% associated with an increase in PM1 concentration of 10 μg/m³ over the entire pregnancy. Compared with less polluted areas (PM1 <38.4 μg/m³), an increased PTB risk of 36% was found in areas with higher levels of air pollution (PM1 >52.7 μg/m³) in China. To our knowledge, the present air pollution standards in both the United States and China do not include regulations for PM1; thus, there is an urgent need to improve these related policies. Effective strategies, such as improving indoor air quality or wearing a mask outdoors, should be considered in protecting mothers from the risks associated with PM pollution.

Strengths and Limitations

Our study has important clinical and public health implications. Preterm birth not only is the leading cause of death throughout the world for neonates, infants, and children younger than 5 years30,31 but also has long-term consequences. Numerous studies have shown that individuals born prematurely can have lifelong health problems in multiple organs or systems, including asthma and metabolic disorders, causing tremendous strain on families and the medical system and resulting in enormous annual medical costs worldwide.32,33 In the present study, we found an increased PTB risk of 9% associated with an increase in PM1 concentration of 10 μg/m³ over the entire pregnancy. Compared with less polluted areas (PM1 <38.4 μg/m³), an increased PTB risk of 36% was found in areas with higher levels of air pollution (PM1 >52.7 μg/m³) in China. To our knowledge, the present air pollution standards in both the United States and China do not include regulations for PM1; thus, there is an urgent need to improve these related policies. Effective strategies, such as improving indoor air quality or wearing a mask outdoors, should be considered in protecting mothers from the risks associated with PM pollution.

Figure 3. Adjusted Hazard Ratios of Preterm Birth for Each Increase in Airborne Particulate Matter With Median Diameter of 1 μm or Less Exposure of 10 μg/m³ Over the Entire Pregnancy in Each Subgroup

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>No. of Births</th>
<th>Hazard Ratio (95% CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maternal age, y</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16-24</td>
<td>453 357</td>
<td>1.08 (1.07-1.10)</td>
</tr>
<tr>
<td>25-29</td>
<td>624 279</td>
<td>1.09 (1.08-1.10)</td>
</tr>
<tr>
<td>30-50</td>
<td>222 706</td>
<td>1.13 (1.11-1.14)</td>
</tr>
<tr>
<td>Household registration</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rural</td>
<td>1225 464</td>
<td>1.09 (1.09-1.10)</td>
</tr>
<tr>
<td>Urban</td>
<td>74 878</td>
<td>1.04 (1.02-1.07)</td>
</tr>
<tr>
<td>Educational level</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Primary school or below</td>
<td>37 123</td>
<td>1.05 (1.01-1.09)</td>
</tr>
<tr>
<td>Junior high school</td>
<td>787 163</td>
<td>1.09 (1.08-1.10)</td>
</tr>
<tr>
<td>Senior high school</td>
<td>260 495</td>
<td>1.10 (1.08-1.12)</td>
</tr>
<tr>
<td>College or higher</td>
<td>193 042</td>
<td>1.06 (1.05-1.08)</td>
</tr>
<tr>
<td>Occupation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Farmer</td>
<td>962 458</td>
<td>1.10 (1.09-1.11)</td>
</tr>
<tr>
<td>Worker</td>
<td>222 653</td>
<td>1.06 (1.04-1.07)</td>
</tr>
<tr>
<td>Other*</td>
<td>88 961</td>
<td>1.04 (1.02-1.07)</td>
</tr>
<tr>
<td>Prepregnancy BMI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;18.5</td>
<td>962 456</td>
<td>1.09 (1.08-1.10)</td>
</tr>
<tr>
<td>18.6-23.9</td>
<td>222 654</td>
<td>1.09 (1.07-1.11)</td>
</tr>
<tr>
<td>&gt;24</td>
<td>88 962</td>
<td>1.13 (1.11-1.15)</td>
</tr>
<tr>
<td>Season of conception</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Spring</td>
<td>331 432</td>
<td>1.07 (1.06-1.08)</td>
</tr>
<tr>
<td>Summer</td>
<td>329 918</td>
<td>1.05 (1.03-1.06)</td>
</tr>
<tr>
<td>Autumn</td>
<td>331 165</td>
<td>1.48 (1.46-1.50)</td>
</tr>
<tr>
<td>Winter</td>
<td>307 027</td>
<td>1.09 (1.08-1.11)</td>
</tr>
<tr>
<td>Overall</td>
<td>1300 342</td>
<td>1.09 (1.09-1.10)</td>
</tr>
</tbody>
</table>

Generalized additive model with Cox proportional hazards regression analysis adjusted for maternal age, household registration, educational level, occupation, prepregnancy body mass index (BMI) (calculated as the weight in kilograms divided by height in meters squared), organic solvent exposure, heavy metal exposure, pesticide exposure, mother or partner smoking of cigarettes, alcohol consumption, mode of delivery, neonate’s sex, season, nonlinear association of temperature, and random contribution of province.

* Other occupations included housewife, individual business, or other.
home addresses recorded from preconception, early gestation follow-up, and postpartum follow-up records, which minimized potential exposure misclassification resulting from residential mobility. By contrast, most previous studies have used residence at birth to assign exposure for the entire pregnancy. Finally, because this was a prospective cohort study, we minimized recall bias for the dates of the last menstrual period and birth, which helped ensure the accuracies of gestational age and PTB assessments.

The study also had several limitations. Although we used a satellite-based comprehensive model and assigned exposures according to the mothers’ addresses at the township level, there could have been misclassification of the exposure. The pollutant levels at microenvironmental levels (eg, indoor, outdoor, or associated with commuting) or maternal activity patterns may have contributed to a misclassification. In addition, specific components and their proportions could not be considered separately but rather were grouped as PM1. The specific components might have had different chemical structures and might be associated with different health concerns. Future studies are needed to investigate PM components and their sources.

Conclusions
Exposure to PM1 air pollution during pregnancy was associated with an increased risk of PTB. The mothers who were older at conception, were overweight before pregnancy, were registered as a rural household, worked as farmers, or conceived in autumn had a greater risk of PTB associated with PM1 exposure. Further studies to examine the mechanisms accounting for increased vulnerability to PM1 are warranted. Public policies and guidelines should be improved to protect pregnant women from risks associated with PM1 air pollution.

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Correction: This article was corrected on March 5, 2018, to correct the degree for Qin Li from PhD to MMSc in the Byline, revise how Mr Li is addressed in the Author Contributions and Funding/Support sections, and replace the maps of China in Figure 1 as well as figure 2 in the Supplement to fix a portion of the country’s western border.

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Study supervision: H.-J. Wang, Ma.

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