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Air pollution associated hypertension and increased blood pressure may be reduced by breastfeeding in Chinese children: The Seven Northeastern Cities Chinese Children's Study☆

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ABSTRACT

Background: Little is known about the association between air pollution and hypertension among children, and no studies report whether breastfeeding modifies this association in children.
Methods: Nine thousand three hundred fifty-four Chinese children, ages 5–17 years old, from 24 elementary schools and 24 middle schools in the Seven Northeastern Cities during 2012–2013 were evaluated. The weight, height, and BP were measured. Four-year average concentrations of particles with an aerodynamic diameter of ≤10 μm (PM_{10}), sulfur dioxide (SO_2), nitrogen dioxides (NO_2), ozone (O_3), and carbon monoxide (CO) were calculated from monitoring stations. Two-level regression analysis was used to examine the effects, controlling for covariates.
Results: The results showed that associations existed between hypertension and pollutants. The odds ratios for hypertension ranged from 1.12 per 46.3 μg/m^3 increase for O_3 (95% confidence interval [CI], 1.10–1.13) to 1.68 per 30.6 μg/m^3 increase for PM_{10} (95% CI, 1.53–1.86). The increases in mean diastolic BP ranged from 0.58 mm Hg per 46.3 μg/m^3 increase for O_3 (95% CI, 0.52–0.63 mm Hg) to 2.89 mm Hg per 563.4 μg/m^3 increase for CO (95% CI: 2.53–3.24 mm Hg). The increase in systolic BP ranged from 0.50 mm Hg per 46.3 μg/m^3 increase for O_3 (95% CI: 0.43–0.57 mm Hg) to 2.10 mm Hg per 30.6 μg/m^3 increase for PM_{10} (95% CI, 1.73–2.47 mm Hg). Compared with children who had been breastfed, non-breastfed children exhibited consistently stronger effects.
Conclusion: Study findings indicate that high levels of PM_{10}, SO_2, NO_2, O_3, and CO are associated with increased arterial BP and hypertension among the children. Breastfeeding may reduce the risk.

1. Introduction

Almost one billion people worldwide have hypertension, a major risk factor for cardiovascular disease. Blood pressure (BP), on average, has slightly decreased worldwide between 1980 and 2008. However, many populations in developing countries have experienced an increase in BP, and an increased prevalence of hypertension [1]. Kearney et al. estimate that by 2025 approximately 1.17 billion people in developing countries will have hypertension, nearly three-fourths of the worldwide population with hypertension [2]. While genetic factors, changing lifestyles, and dietary shifts are contributing factors, environmental factors such as ambient air pollution may increase the risk for hypertension [3–6].

Evidence shows that ambient air pollution [4–6] and breastfeeding [7–11] are associated with hypertension among child'ren. Breast milk contains long-chain polyunsaturated fatty acids (LCPUFAs), which are important structural components of tissue membrane systems, including the vascular endothelium, which is responsible for the reduction of vasoconstriction and platelet aggregation [12]. In particular, breastfeeding can influence the programming of neonatal sodium restriction, degrade insulin resistance, and promote lipid metabolism that persists into adolescence and adulthood [13–15]. Previous studies suggest that

Abbreviations: PM_{10}, Particulate matter with an aerodynamic diameter ≤10 μm; SO_2, Sulfur dioxide; NO_2, Nitrogen dioxide; O_3, Ozone; ORs, Odds ratios; 95% CI, 95% Confidence interval; BP, Blood pressure; SNECCS, Seven Northeastern Cities Chinese Children's Study.

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breastfeeding is associated with decreased effects of other environmental toxicants on children's health [16]. Our own study also reported that breastfeeding is a modifier of the respiratory effects of air pollution in Chinese children [17]. To test the hypothesis that breastfeeding decreases the adverse BP response to ambient air pollution exposure among children may provide insight into the effects of co-exposure to ambient air pollution and breastfeeding on hypertension and blood pressure in children, which in turn may provide the benefit of predicting and controlling BP later in life.

Using data from the Seven Northeastern Cities Chinese Children's Study, we investigated two hypotheses: (1) populations with long-term exposure to ambient air pollution experience higher BP and a higher prevalence of hypertension among children, and (2) breastfeeding decreases the adverse BP response to ambient air pollution exposure among children. We tested these two hypotheses by analyzing data from the Seven Northeastern Cities Chinese Children's Study. This cross-sectional study evaluated air pollution and child health in a large, well-characterized population-based sample of children residing in northeast China, where there are wide differences in inter- and intra-city pollution ranges and high ambient pollutant levels, thus offering an opportunity to assess the associations between exposure and response.

2. Methods

2.1. Study cities selection and subject recruitment

The Seven Northeastern Cities Chinese Children's Study (SNECCS) is a cross-sectional study of children's health outcomes based on exposure to ambient air pollutants. This region encompasses more than 20 million people residing in 14 cities in Liaoning province in Northeastern China. To maximize the inter- and intra-city gradients of the pollutants of interest and also to minimize the correlation between district-specific ambient pollutants, in April 2012 the seven cities of Shenyang, Dalian, Anshan, Fushun, Benxi, Liaoyang, and Dandong in Liaoning province were selected as study sites, based on air pollution measurements taken between 2009 and 2011. In each of the seven cities, we selected all urban districts for the study. There are five districts in Shenyang, four districts in Dalian and Fushun, three districts in Anshan, Benxi, and Dandong, and two districts in Liaoyang. In each of the 24 study districts, one elementary school and one middle school within one mile of air monitoring sites were randomly selected, and then one or two classrooms were randomly selected from each grade of the selected schools. In any classroom targeted for participation, all children who had lived in the district for at least 2 years before the start of study were included in the study. The design and conduct of this investigation was in accordance with the World Medical Association Declaration of Helsinki-Ethical Principles for Medical Research Involving Human Subjects and ethical approval was obtained from Human Studies Committee of China Medical University. Before data collection, a written informed consent form was obtained from each participant and their parents.

2.2. BP measurements

All investigators and staff of the study were required to successfully complete a training program based on procedures formulated by the American Academy of Pediatrics [18], designed to facilitate the administration of the study questionnaire and a standardized protocol to measure BP. At the end of the training program, each trainee was required to take a qualifying examination and those who passed were given a BP observer certificate. Participants were advised not to smoke, drink alcohol, coffee, or tea, and to abstain from exercise for at least 30 min before having their BP measured.

Measurements were performed in a quiet and temperate room. The BP measurements were performed by a team of four carefully trained nurses whose adherence to the measurement protocol was assessed regularly. After 5 min of rest, sitting BP was measured three times by using standardized mercuric-column sphygmomanometer, with the use of an appropriate cuff size adapted to arm circumference according to standardized procedural guidelines. The time interval between successive pairs of BP measurements was 2 min. The average of the three BP measurements was used to identify hypertension. The hypertension status of the participants was assessed based on the fourth report on the diagnosis, evaluation, and treatment of high blood pressure in children and adolescents [18]. Hypertension in children was defined as average SBP and DBP that is ≥95th percentile for gender, age and height. This definition of the BP threshold has gained worldwide support and has been used in the vast majority of studies on pediatric hypertension [18].

2.3. Anthropometric measurements and data collection

Children were measured without shoes in light garments. Weight and height were measured with the use of electronic scales (at 0.1 kg) and fixed stadiometers (at 0.1 cm). The body mass index (BMI) was calculated as weight divided by height squared (kg/m^2). Parental education was defined as the highest education level completed by either parent. Passive smoking exposure was defined as living with someone who smokes cigarettes daily in the home. Breastfeeding exposure, based on parental report, was defined as mainly breastfed for 3 months or more. In present study, new mothers had a 3-month pregnancy leave after delivery. After 3 months, most of the new mothers had to return to work and many of them stopped breastfeeding at that time. Therefore, we designed the question to collect only 3-month breastfeeding information. The early diet of children not breastfed includes animal milk, juice, and soups made from egg, rice, chicken, pork, beef, fish, or vegetables [17].

2.4. Ambient air pollution

In each of the selected study districts, there was one municipal air monitoring station located 1 km from the study participants' homes. Measurements of PM_{10}, SO_2, NO_2, and O_3 concentrations from 2009 to 2012 were obtained at the stations, using uniform methods and quality assurance. These stations were separated by specified distances from major roads, industrial sources, buildings, or residential sources of emissions from the combustion of coal, waste, or oil, assuring that the air pollution measurements were more likely to reflect the background air pollution levels. These measurements were used to estimate long-term exposures for the participants. Measurements strictly followed the methodological standards set by the State Environmental Protection Administration of China [19].

Concentrations of each pollutant were assessed continuously and reported hourly: PM_{10} by beta-attenuation, SO_2 by ultraviolet fluorescence, NO_2 by chemiluminescence, O_3 by ultraviolet photometry, and CO by non-dispersive infrared spectrometry [20]. We calculated average daily concentrations of PM_{10}, SO_2, NO_2, O_3, and CO (averaged over eight hours). These data were based on days for which at least 75% of the 1-h values were available, after excluding abnormal values in the hourly data collected from each monitoring station. Exposure parameters in the present study were 4-year averages (2009–2012) for concentrations calculated from the 24-h PM_{10}, SO_2, NO_2, and CO concentrations, and 10:00 AM to 6:00 PM 8-h O_3 concentrations in each district.

2.5. Statistical analysis

Data were tested for homogeneity (using Bartlett's unequal variances test) and normality (using Shapiro–Wilks W-test). For each group, the values of mean ± standard deviation were calculated for continuous variables. Relative frequencies were calculated for categorical variables. Contingency tables and χ^2-tests were used to calculate the relationship associations between categorical variables. We assessed the association of ambient air pollutants with BP using generalized additive models. To investigate the relationship between hypertension and ambient air pollution, we considered a two-level binary logistic regression model with participants being the first-level units and districts being the second-level units. At the child level, we predicted the logit of the hypertension's prevalence rate by breastfeeding (BF) and k covariates (X1, …, Xk) as follows:

$$\text{logit}\,[P(\text{symptomij})] = \alpha j + \lambda jBFij + \beta 1X1ij + \ldots + \beta kX1ij + eij \quad (1)$$

where the subscript j is for districts (j = 1,…, 24), the subscript i is for children (i = 1…, nj), αj is the intercept at the district level, λj is the regression coefficient for breastfeeding, β1, …, βk are the regression coefficients of covariates, and eij is the random error, assumed to have means of zero and constant variance. The αj and λj are random coefficients as they are assumed to vary across districts. In general, a district with a high αj is predicted to have higher prevalence rates than a district with a low αj. Similarly, differences in λj indicate that the relationship between breastfeeding and prevalence rates is not the same in all districts. In districts with a high (low) λj, breastfeeding has a large (small) effect on prevalence rates or the difference between breastfed children and non-breastfed children is relatively large (small).

At the district level, we regressed the district-specific intercepts αj and coefficients λj on the district-specific pollutant level (Zj) to explain the variations of αj and λj, as follows:

$$\alpha j = \alpha + \gamma 1\,Zj + u1j \quad (2)$$

$$\lambda j = \lambda + \gamma 2\,Zj + u2j. \quad (3)$$

Eq. (2) predicts the prevalence rates in a district by Zj. If γ1 is positive, then, adjusting for covariates, the districts with higher pollutant levels have a higher prevalence rate. Conversely, if γ1 is negative, then, adjusting for covariates, the prevalence rates are lower in districts with a higher pollutant level. Eq. (3) states that, adjusting for covariates, the relationship between prevalence rates and breastfeeding in a district depends on the district's pollutant level Zj. If γ2 is positive, then, adjusting for covariates, the breastfeeding effect on prevalence rates is larger with a higher pollutant level. Conversely, if γ2 is negative, then adjusting for covariates, the breastfeeding effect on prevalence rates is smaller with a higher pollutant level. The u-terms u1j and u2j are random errors at the district level, assumed to be independent and have mean of zero and constant variance. These random errors characterize the variation between districts and are assumed to be independent from eij at the child level. Note that α, λ, β1 ,…, βk, γ1 and γ2 are not assumed to vary across districts. Therefore, they have no subscript j to indicate to which district they belong; they are referred to as fixed effects as they apply to all districts.