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Chemical constituents of fine particulate air pollution and pulmonary function in healthy adults: The Healthy Volunteer Natural Relocation study

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HIGHLIGHTS

- Study subjects relocated between areas with different air pollution contents.
- $PM_{2.5}$ showed the most consistent inverse associations with pulmonary function.
- Cu, Cd, As and Sn were consistently associated with reduced pulmonary function.
- Carbonaceous fractions, $SO_4{}^{2-}$ and Sb were also associated with pulmonary function.
- Sources may include traffic, industry, coal burning, and long range transported dust.

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ABSTRACT

The study examined the associations of 32 chemical constituents of particulate matter with an aerodynamic diameter $\leq 2.5\,\mu m$ ($PM_{2.5}$) with pulmonary function in a panel of 21 college students. Study subjects relocated from a suburban area to an urban area with changing ambient air pollution levels and contents in Beijing, China, and provided daily morning/evening peak expiratory flow (PEF) and forced expiratory volume in 1 s (FEV_1) measurements over 6 months in three study periods. There were significant reductions in evening PEF and morning/evening FEV_1 associated with various air pollutants and $PM_{2.5}$ constituents. Four $PM_{2.5}$ constituents (copper, cadmium, arsenic and stannum) were found to be most consistently associated with the reductions in these pulmonary function measures. These findings provide clues for the respiratory effects of specific particulate chemical constituents in the context of urban air pollution.

1. Introduction

Ambient air pollution has been associated with increased respiratory events and impaired pulmonary function in many previous studies [1–6]. Among the air pollutants, particulate matter (PM), especially the PM with an aerodynamic diameter $\leq 2.5\,\mu m$ ($PM_{2.5}$), has received increasing attention in recent years due to its stronger ability to cause adverse health impact [3,7–9]. However, ambient PM is a mixture of various chemical constituents with different potentials to cause health effects [10]. Although previous studies assessing the respiratory health effects of PM pollution have looked into the effects of different PM chemical constituents, most of them only examined a limited number of PM constituents, such as black carbon/elemental carbon (EC) [2,4,11,12] and some metals [12–14]. It is recommended that air pollution research measures a rich array of air pollutants, and thus may lead to a better understanding of the features of a complex air pollution

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Abbreviations: Al, aluminum; As, arsenic; Ba, barium; BIT, Beijing Institute of Technology; BMI, body mass index; Ca, calcium; Cd, cadmium; Cl^-, chloride; CI, confidence interval; CO, carbon monoxide; Co, cobalt; Cr, chromium; Cu, copper; EC, elemental carbon; F^-, fluoride; Fe, iron; FEV_1, forced expiratory volume in 1 s; HVNR study, Healthy Volunteer Natural Relocation study; IQR, interquartile range; K, potassium; Mg, magnesium; Mn, manganese; Mo, molybdenum; Na, sodium; Ni, nickel; NO, nitric oxide; NO_2, nitrogen dioxide; $NO_3{}^-$, nitrate; NO_X, nitrogen oxides; OC, organic carbon; Pb, lead; PEF, peak expiratory flow; PM, particulate matter; $PM_{2.5}$, particulate matter with aerodynamic diameter $\leq 2.5\,\mu m$; $PM_{2.5-10}$, particulate matter with aerodynamic diameter between 2.5 and $10\,\mu m$; PM_{10}, particulate matter with aerodynamic diameter $\leq 10\,\mu m$; POC, primary organic carbon; POM, particulate organic matter; Sb, antimony; SD, standard deviation; Se, selenium; Sn, stannum; $SO_4{}^{2-}$, sulfate; SOC, secondary organic carbon; Sr, strontium; Ti, titanium; V, vanadium; Zn, zinc.

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mixture that are most deleterious to health [15]. In addition, PM chemical constituents originate from various air pollution sources such as motor vehicles, industry, road dust, secondary, coal burning and incineration [16]. A better understanding of the responsible constituents and related sources is important and could potentially lead to more targeted and effective regulations [17]. Therefore, it is important to investigate the roles of different PM constituents and related sources behind the PM-related health effects.

In order to investigate the respiratory health effects of various PM chemical constituents, a group of young healthy college students were followed before and after their natural relocation from a suburban area to an urban area with changing ambient air pollution levels and contents in Beijing, China. They provided daily morning/evening peak expiratory flow (PEF, a person's maximum speed of expiration) and forced expiratory volume in 1 s (FEV_1, the amount of air which can be forcibly exhaled from the lungs in the first second of a forced exhalation) over 6 months in three study periods. Beijing is a megacity with about 20,000,000 residents and more than 5,000,000 motor vehicles in 2011. Traffic emissions are the major source of ambient air pollution in Beijing urban area [18]. In contrast, ambient air pollution in Beijing suburban area also has several other major pollution sources (e.g., construction activities and industry) in addition to the traffic emissions. As a result, study subjects experienced two different air pollution scenarios associated with local pollution sources and then facilitated the investigation of the health effects of different $PM_{2.5}$ chemical constituents.

2. Materials and methods

2.1. Study subjects and design

The Healthy Volunteer Natural Relocation (HVNR) study was a panel study designed to investigate the short-term pulmonary and cardiovascular effects of ambient PM pollution in a group of healthy adults in the context of urban air pollution [19]. In the present study, study subjects were 21 male college students between 19 and 21 years of age living in school dormitories of Beijing Institute of Technology (BIT). BIT has 2 campuses about 30 km apart, one (BIT Liangxiang campus) is located in the southwest suburban area and the other one (BIT main campus) is located in the northern urban area of Beijing (see Fig. A.1). Local air pollution sources around these two campuses were quite different during the three study periods. The BIT Liangxiang campus is about 2000 meters from the nearest freeway and is surrounded by substantive construction activities and a certain number of plants and factories. The BIT main campus is located in the downtown area along the northwest inner side of the 3rd ring road that circles the city. There are no substantive construction activities or industrial facilities near the BIT main campus. Students completed their first two years of undergraduate training in the BIT Liangxiang campus from September 2008 to July 2010 and then relocated to the BIT main campus for the next two years of undergraduate training from August 2010 to July 2012. They provided daily self-monitored PEF/FEV_1 measurements on two different time points (morning/evening) over the following three study periods: Suburban Period from 22 April to 20 June 2010 in the BIT Liangxiang campus, Urban Period 1 from 3 September to 8 November 2010 and Urban Period 2 from 10 April to 12 June 2011 in the BIT main campus. The Institutional Review Board of Peking University Health Science Center approved the study, and a written informed consent was obtained from each participant before the study began.

2.2. Pulmonary health measurement

Trained technicians instructed the study subjects to measure their daily PEF/FEV_1 levels using an electronic PEF/FEV_1 diary meter (Model 2110; Vitalograph Ltd., Buckingham, UK) at the beginning of the study. Study subjects were asked to perform the measurements in a standing position after getting up in the morning (0600–1100 h) and before going to sleep in the evening (2100–0100 h). Each measurement included two blows which were automatically recorded into the electronic meter with a time point annotation. A supervised PEF/FEV_1 maneuver was performed for each subject biweekly during the study to insure the quality of self-monitoring by trained technicians. PEF/FEV_1 data in the electronic meters were extracted using the Software for PEF/FEV_1 Diary (Version 2.03) installed in a working computer. The better reading of the two blows for each measurement was selected and used in final data analysis. The PEF/FEV_1 data of the first 3 d in each study period were excluded from analysis because a training period would be necessary for learning PEF/FEV_1 measuring technique [14]. Study subjects used a symptom/medication diary to record any onset of respiratory symptoms (e.g., cough, wheeze, chest tightness, and shortness of breath) and related medication use throughout the study. Weight and height were measured in each study period, and body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared.

2.3. Air pollution measurement

Daily levels of air pollutants (from 12:00 PM the previous day to 12:00 PM the present day) were monitored at a central air-monitoring station located within 300 meters of school dormitories in each campus. SKC sampling systems were used to collect $PM_{2.5}$ mass on quartz-fiber filters and polytetrafluoroethylene filters (SKC Inc., Eighty Four, PA, USA). A model T15n enhanced carbon monoxide (CO) measurer was used for CO measurement (Langan Products Inc., San Francisco, CA, USA), and Ogawa passive samplers were used for nitrogen oxides (NO_X) and nitrogen dioxide (NO_2) collection on cellulose fiber filters (Ogawa Air Inc., Osaka, Japan). A HOBO Pro V2 logger (Onset Corp., Pocasset, MA, USA) was used for temperature and relative humidity measurements. Data on PM with aerodynamic diameter $\leq 10\,\mu m$ (PM_{10}) were also obtained from the nearest governmental air monitoring stations, and levels of coarse PM ($PM_{2.5-10}$, PM with aerodynamic diameter between 2.5 and 10 μm) were calculated as the differences between PM_{10} and $PM_{2.5}$ levels.

Daily mass concentrations of $PM_{2.5}$ samples were determined by standard weighing procedures before and after the sample collection [20] and $PM_{2.5}$ mass samples were analyzed in the laboratory for the following 29 specific chemical constituents using professional techniques [19]: carbonaceous fractions of organic carbon (OC) and EC; anions of sulfate ($SO_4{}^{2-}$), nitrate ($NO_3{}^{-}$), chloride (Cl^-) and fluoride (F^-); crustal metals of aluminum (Al), calcium (Ca), sodium (Na), potassium (K), magnesium (Mg), strontium (Sr) and barium (Ba); transition metals of iron (Fe), zinc (Zn), copper (Cu), titanium (Ti), cobalt (Co), nickel (Ni), molybdenum (Mo), cadmium (Cd), vanadium (V), chromium (Cr) and manganese (Mn); and other metals/metalloid elements of arsenic (As), selenium (Se), stannum (Sn), antimony (Sb) and lead (Pb). Concentrations of three additional carbonaceous fractions, including primary OC (POC), secondary OC (SOC) and particulate organic matter (POM), were estimated based on the method documented in Supplementary material.

2.4. Statistical analysis

Linear mixed-effects models with a random intercept for each subject and a first order autoregressive covariance structure in SAS 9.2 (SAS Institute, Cary, NC, USA) were used to investigate the associations between pulmonary function and air pollutants and $PM_{2.5}$ constituents. In order to control the heterogeneity in pulmonary