Environmental Pollution 230 (2017) 621–631

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Association of individual-level concentrations and human respiratory tract deposited doses of fine particulate matter with alternation in blood pressure☆

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ARTICLE INFO

Article history:
Received 22 December 2016
Received in revised form
13 June 2017
Accepted 3 July 2017
Available online 12 July 2017

Keywords:
Fine particulate matter
Blood pressure
Deposited dose
Human respiratory tract
Inflammatory indicator

ABSTRACT

Fine particulate matter ($PM_{2.5}$) contributes to the risk of cardiovascular events, partially owing to its deposition in the human respiratory tract. To investigate short-term effects of ambient $PM_{2.5}$ exposure on alternation of blood pressure (BP), this study was conducted during the winter-summer period between 2014 and 2015. The study included 106 community residents in Wuhan city, China. We repeatedly monitored the household and outdoor $PM_{2.5}$ concentrations as well as individual-level $PM_{2.5}$ in each season, and then assessed personal $PM_{2.5}$ exposure (including deposited doses of $PM_{2.5}$ in the human respiratory tract) by using different methodology (such as using a dosimetry model). All participants took part in the physical examination, including the inflammatory indicators, BP and lung function parameters measurements. Subsequently, we assessed the health damage of exposure to $PM_{2.5}$ using generalized additive models. We observed increased BP at 2-day lag for an interquartile range increase in ambient fixed-site, households, individual-level $PM_{2.5}$ exposure and the corresponding lung deposited doses of each exposure concentration ($p < 0.05$), decreased BP at 3-day lag for an interquartile range increase in ambient fixed-site, households $PM_{2.5}$ and the corresponding lung deposited doses of each exposure concentration ($p < 0.05$). The estimated deposited doses of $PM_{2.5}$ by the deposition fractions in this study and the referenced deposition fractions by previous reported method were equivalent associated with alternation in BP. In conclusion, lung deposited dose of $PM_{2.5}$ as a quantitative indicator may be used to assess adverse cardiovascular effects following the systemic inflammation. However, we require careful assessment of acute adverse cardiovascular effects using ambient fixed-site $PM_{2.5}$ after short-term $PM_{2.5}$ exposure.

1. Introduction

Exposure to fine particulate matter (≤2.5 μm in aerodynamic diameter, $PM_{2.5}$) was associated with increased risk of hypertension (Cai et al., 2016; Wu et al., 2016). Chinese women with high individual-level $PM_{2.5}$ (≥58 μg/m^3) had an increase of 4.6 mmHg in systolic blood pressure (SBP) and 4.1 mmHg in pulse pressure, compared with those with low individual-level $PM_{2.5}$ (<58 μg/m^3) (Shan et al., 2014). A cohort study indicated that American women aged 35–76 years (n = 43,629) had an increase of 1.4 mmHg in SBP for each 10-μg/m^3 increase in $PM_{2.5}$ (Chan et al., 2015). Noteworthyly, the results remain controversial. A recent study reported

Abbreviation: BMI, body mass index; BF, breathing frequency; BP, blood pressure; CRP, C-reactive protein; CI, confidence interval; DF, deposition fraction; ET, extrathoracic/head region; FRC, functional residual capacity; FeNO, fractional exhaled nitric oxide; HRT, human respiratory tract; IQR, interquartile range; MPV, mean platelet volume; MPPD, multiple path particle dosimetry model; PM, particulate matter; $PM_{2.5}$, particulates with an aerodynamic diameter ≤2.5 mm; PUL, pulmonary/alveolar region; PLT, platelets; PDW, platelet distribution width; SD, standard deviation; TV, tidal volume; TB, pulmonary/tracheobronchial region; URT, upper respiratory tract; WBC, white blood count.

☆ This paper has been recommended for acceptance by David Carpenter.

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http://dx.doi.org/10.1016/j.envpol.2017.07.006
0269-7491/

that a 1-μg/m^3 increment in $PM_{2.5}$ elemental carbon was associated with 1.7% (95% confidence interval (CI): −2.81, −0.58) decreases in SBP (Mirowsky et al., 2015).

The discrepancy between studies may partially be explained by differences in exposure assessment methods. At present, there are two main kinds of methods to assess personal exposure level of PM. The direct measurement method was based on the measurement of personal exposure to $PM_{2.5}$ using a PM personal sampler, while the indirect measurement method was to simulate personal exposure by a modeling approach based on outdoor $PM_{2.5}$ concentrations, human time-activity patterns (Ni et al., 2016; Nieuwenhuijsen et al., 2006). However, the characteristics of $PM_{2.5}$ (such as lung deposition, surface area and solubility) were omitted in most studies. Thus the multiple path particle dosimetry model (MPPD, Chemical Industry Institute of Toxicology, Research Triangle Park, NC) has been used in quantitative estimation of deposited $PM_{2.5}$ doses in the human respiratory tract (HRT) (Hussein et al., 2013).

Mechanisms underlying the association between exposure to $PM_{2.5}$ and alternation in BP remain unknown. Several experimental studies indicated that biological mechanisms (e.g.), inflammatory response, oxidative stress and platelet activation) were involved in $PM_{2.5}$-induced cardiovascular events (Huang et al., 2012b; Ying et al., 2014). Inhalable $PM_{2.5}$ induced releases of pro-inflammatory mediators (such as cytokines, nitric oxide and platelets (PLT) from the lung cells, and then mediators spilled over into circulation system and stimulated generations of acute phase proteins from liver hepatocytes (such as C-reactive protein (CRP)), finally led to cardiovascular toxicity (Brook et al., 2010). A panel study showed that oxidative stress and inflammatory mediators (including leukocytes, PLT and CRP) modified effect of exposure to $PM_{2.5}$ on the nighttime standard deviation of normal-to-normal intervals reductions in American adults (Lee et al., 2014). Additionally, the associations of mean platelet volume (MPV) and platelet distribution width (PDW) with inflammation and thrombosis were found (Yuri Gasparyan et al., 2011).

The study assessed individual-level PM exposure using different technological methods, including measurements of $PM_{2.5}$ concentrations in the ambient fixed-site, residential outdoor environment, households, personal exposure level and estimation of deposited $PM_{2.5}$ dose in the HRT, and investigated health effects of personal short-term exposure level of $PM_{2.5}$ based on the environmental $PM_{2.5}$ concentrations and deposited doses of $PM_{2.5}$ in the HRT on alterations in fractional exhaled nitric oxide (FeNO), PLT, CRP and BP.

2. Material and methods

2.1. Study population and design

A total of 1240 participants (including three age groups: under 18 years, 18–60 years, over 60 years) were recruited from the Jinqiao community of Jiangan district and Qingchuan community of Hanyang district in Wuhan city, China using stratified random cluster sampling method. They had continuously lived in the communities for at least two years and did not have to think about moving in the next year. They took part in a basic physical examination and questionnaire survey covered the winter (from December 12, 2014 to February 5, 2015) and summer (from May 27, 2015 to July 30, 2015).

To assess the individual-level $PM_{2.5}$ exposure and its association with acute adverse health effect of $PM_{2.5}$ exposure, a panel study with repeated measurements of 106 participants was conducted after controlling major factors (such as gender, age, education, monthly per capita income, smoking status, drinking alcohol, physical activity, self-cooking and body mass index (BMI)) in relation to the clinic outcomes. They were free for pulmonary diseases (including tuberculosis, emphysema and asthma), cardiovascular disease (including myocardial infarction, peripheral vascular diseases, angina and heart failure) and cancer. The participants in this study were asked to take part in measurements on three consecutive days in each season (including 24 h $PM_{2.5}$ concentrations in their households and personal $PM_{2.5}$ level) and provide the blood samples on the day of the physical examination and urine samples for three consecutive days within the winter and summer seasons. We only found a significant difference in the distribution of participants with self-cooking meals between the panel study individuals and the baseline ones, but no significant differences in the other variables (including gender, age, education, monthly per capita income, active smoking, passive smoking, drinking alcohol, physical activity, FeNO, BMI, SBP, and diastolic BP (DBP)) (see Supplementary Materials, Table S1).

A written informed consent was obtained from all participants prior to this study. The study was approved by the Medical Research Ethics Committee of Tongji Medical College, Huazhong University of Science and Technology.

2.2. Measurements of $PM_{2.5}$ concentrations

We collected data on the $PM_{2.5}$ concentrations reported by the China National Environmental Monitoring Center (marked as ambient fixed-site) nearby the communities (one ambient fixed-site is located approximately 2.0 km away from the Jinqiao community of Jiangan district, the other is located approximately 1.2 km away from the Qingchuan community of Hanyang district) (see Supplementary Materials, Fig. S1). Simultaneously, in each season we monitored outdoor $PM_{2.5}$ concentration in these two communities for 15 consecutive days, household concentrations of $PM_{2.5}$ and individual-level $PM_{2.5}$ using personal environmental monitor for three consecutive days with daily simultaneous measurements among 106 participants. To monitor the residential outdoor $PM_{2.5}$ concentrations, the air samplers were set up on the roof of the school building at an altitude of about 18 m in the Jinqiao community of Jiangan district and on the roof of the hospital building at an altitude of about 15 m in the Qingchuan community of Hanyang district, respectively. The straight-line distance between the school building or community hospital building and the main traffic road was corresponding about 330 m or 260 m. No obvious air pollution sources were found in 300 m surrounding area of the school building and in 200 m surrounding one of the community hospital building. The 24 h $PM_{2.5}$ samples were collected on quartz microfiber filters with 90-mm diameter (Whatman Inc., Maidstone, UK) by air samplers at a flow rate of 100 L/min (TH-150C type, Wuhan Tianhong Instruments Co., Ltd., Wuhan, China). The filter was replaced at 10:00 a.m. Beijing time daily during the sampling periods.

Meanwhile, we detected $PM_{2.5}$ concentrations in the households and individual-level $PM_{2.5}$ using personal environmental monitor (model 200, MSP Corporation, Minnesota, USA) for three consecutive days with daily simultaneous measurements. The household $PM_{2.5}$ sampling site was located at the living room and away from the opening windows. Air sampling pump (Gilian 5000, Gilian Instruments Corp., Sensidyne Inc., Clearwater, Florida, USA) was placed at about 1.5 m above the floor. Meanwhile, each participant was required to wear a backpack with a Gilian 5000 pump. The personal environmental monitor was kept in the breathing zone of each participant during the daytime, but was done near the participant's bed during the night sleeping period. $PM_{2.5}$ sample was collected on quartz microfiber filters with 37-mm diameter (Munktell Inc., SE-79110 Falun, Sweden) at a flow rate of 2.0 L/min during 24-h continuous sampling. The sampler