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Particle size and chemical constituents of ambient particulate pollution associated with cardiovascular mortality in Guangzhou, China

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A B S T R A C T

Though significant associations between particulate matter (PM) air pollution and cardiovascular diseases have been widely reported, it remains unclear what characteristics, such as particle size and chemical constituents, may be responsible for the effects. A time-series model was applied to examine the cardiovascular effects of particle size (for the period of 2009–2011) and chemical constituents (2007–2010) in Guangzhou, we controlled for potential confounders in the model, such as time trends, day of the week, public holidays, meteorological factors and influenza epidemic. We found significant associations of cardiovascular mortality with PM_{10}, $PM_{2.5}$ and PM_1; the excess risk (ER) was 6.10% (95% CI: 1.76%, 10.64%), 6.11% (95% CI: 1.76%, 10.64%) and 6.48% (95% CI: 2.10%, 11.06%) for per IQR increase in PM_{10}, $PM_{2.5}$ and PM_1 at moving averages for the current day and the previous 3 days (lag_{03}), respectively. We did not find significant effects of $PM_{2.5\text{-}10}$ and $PM_{1\text{-}2.5}$. For $PM_{2.5}$ constituents, we found that organic carbon, elemental carbon, sulfate, nitrate and ammonium were significantly associated with cardiovascular mortality, the corresponding ER for an IQR concentration increase at lag_{03} was 1.13% (95% CI: 0.10%, 2.17%), 2.77% (95% CI: 0.72%, 4.86%), 2.21% (95% CI: 1.05%, 3.38%), 1.98% (95% CI: 0.54%, 3.44%), and 3.38% (95% CI: 1.56%, 5.23%), respectively. These results were robust to adjustment of other air pollutants and they remained consistent in various sensitivity analyses by changing model parameters. Our study suggests that PM_1 and constituents from combustion and secondary aerosols might be important characteristics of PM pollution associated with cardiovascular mortality in Guangzhou.

1. Introduction

Epidemiological studies have consistently demonstrated significant associations between particulate matter (PM) air pollution and cardiovascular health (Brook et al., 2004; Atkinson et al., 2014; Stafoggia et al., 2014). These studies mainly investigated the association of cardiovascular health with total mass concentration of the particles, the question remained what physical characteristics of the particles were more directly responsible for the cardiovascular effects, such as particle size and chemical constituents (Brook et al., 2010; Dai et al., 2014; Wang et al., 2014).

Previous studies examined health effects of different particle size fractions, such as PM_{10} (particles less than 10 μm in aerodynamic diameter), $PM_{2.5}$, PM_1 and $PM_{0.1}$; and increasing evidence suggested that smaller particles might be more harmful to human health (Liu et al., 2013; Meng et al., 2013). Only a few

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epidemiological studies, however, have examined the associations between cardiovascular health and particles of different size fractions with inconsistent findings (Wichmann et al., 2000; Perez et al., 2009). For example, a study from Barcelona, Spain examined the relationship between cardiovascular mortality and three size fractions ($PM_{2.5-10}$, $PM_{1-2.5}$ and PM_1), and found that PM_1 and $PM_{2.5-10}$, rather than $PM_{1-2.5}$, were associated with cardiovascular mortality (Perez et al., 2009). A recent study in Beijing demonstrated significant cardiovascular impacts of $PM_{0.1}$ and $PM_{1-2.5}$ (Liu et al., 2013). In contrast, a study from Taiwan investigated the association between $PM_{2.5-10}$, $PM_{1-2.5}$, PM_1 and heart rate variability in the elderly, and found a stronger association for $PM_{2.5-10}$ (Chang et al., 2007).

The health impact of PM pollution varies regionally, which might be ascribed to heterogeneity in chemical composition and emission sources of the particles (Lu et al., 2015). And the current air pollution control regulations or guidelines generally use total mass concentration of particulate pollution as the exposure indicator (World Health Organization, 2006; Ministry of Environmental Protection of China, 2012). More targeted air quality standards are warranted to incorporate PM chemical constituents or emission sources that are more directly related to the health impacts (Tian et al., 2013). Understanding of the local health effects of $PM_{2.5}$ constituents is a fundamental component from the viewpoint of both science and public health regulations (Cao et al., 2012; Dai et al., 2014).

PM pollution has been a major public health concern in Guangzhou, China. Based on the literature, we hypothesize that particles with smaller size fraction are more harmful to human health, and some specific chemical constituents, such as organic carbon (OC) and elemental carbon (EC) might be more harmful than others. The unique air pollution monitoring stations in Guangzhou, which collected three particle size fractions (PM_{10}, $PM_{2.5}$ and PM_1) and $PM_{2.5}$ constituents, provided some rich data to catch up this research gap.

2. Materials and methods

2.1. Study setting

Guangzhou is an important city of Pearl River Delta and economic center of south China. Alongside its rapid economic development, Guangzhou has experienced some of the worst air pollution among China's cities. The residents of urban districts in Guangzhou were selected as the sample for the present study. The urban areas were chosen for two reasons. First, they are close to the air monitoring stations. Second, the mortality data are of high quality (Liu et al., 2014).

2.2. Data collection

Daily mortality data from 1 January 2007 to 31 December 2011 were obtained from Guangdong Provincial Center for Disease Control and Prevention. In Guangzhou, all deaths were obliged to be reported to the death registry system. The Chinese government has mandated detailed quality assurance (QA) and quality control (QC) for the death registry (Xu et al., 2013). The cause of death was coded using the International Classification of Diseases, Tenth Revision (ICD-10). Mortality from cardiovascular diseases (ICD-10: I00–I99) were extracted to construct the time series.

The concentrations of different particle size fractions and $PM_{2.5}$ chemical constituents were measured at two air monitoring stations. An automatic air monitoring system was installed on the rooftop of Panyu Meteorological Center (Station 1) to measure daily air pollution from 1 January 2009 through 31 December 2011, including PM_{10}, $PM_{2.5}$ and PM_1, as well as gaseous pollutants (SO_2 and NO_2). The measurements were performed using a GRIMM Aerosol Spectrometer (Model 1.108, Grimm Aerosol Technik GmbH, Ainring, Germany). Details about the air pollution collection and quality control have been described elsewhere (Li et al., 2012). In brief, the GRIMM model 1.108 monitor is designed to measure particle size distribution and particulate mass based on a light scattering measurement of individual particles in the collected air samples. Thus, the particle density, determined by chemical composition, should affect the measured concentration of PM mass. The PM mass concentrations are converted to a mass distribution using a density factor corresponding to the GRIMM established "urban environment" factor. Although the optical scattering method is not a standard approach recommended by the Chinese EPA, the measured $PM_{2.5}$ mass concentrations by TEOM and GRIMM were in good agreement (Grimm and Eatough, 2009). We estimated $PM_{2.5-10}$ concentrations by subtracting $PM_{2.5}$ from PM_{10}, and $PM_{1-2.5}$ by subtracting PM_1 from $PM_{2.5}$. When no concentration was measured on some days, they were treated as missing data; during the period 2009–2011, the proportion of missing data was very low (ranging from 1% to 2%).

Daily $PM_{2.5}$ chemical composition (as well as SO_2 and NO_2) was measured at another automatic monitoring system located on the rooftop of the South China Institute of Environmental Sciences (Station 2) (Tao et al., 2015). $PM_{2.5}$ samples were collected on 47 mm quartz microfiber filters (Whatman International Ltd, Maidstone, England, QMA) using a sampler (BGI Incorporated, Waltham, MA, US, Model PQ200) operating at a flow rate of 16.7 L/min. For this study, we measured $PM_{2.5}$ chemical constituents for four months (January, April, July and November) of each year from 2007 through 2010, the original purpose was to examine the seasonal variations of these chemical constituents and their effects on aerosol light scattering (Tao et al., 2014). There were about 20 days without records and were treated as missing observations. The measures included organic carbon (OC), elemental carbon (EC), and five water-soluble ions (nitrate (NO_3^-), sulfate (SO_4^{2-}), ammonium (NH_4^+), sodium ions (Na^+), and chloride (Cl^-)). Details of the measurement and QA/QC procedure can be found elsewhere (Tao et al., 2012, 2014).

The two stations were surrounded by residential areas without major industrial sources or local fugitive dust sources (Fig. 1). The median correlation of daily air pollutants of these two monitoring stations with other stations in this city was 0.78 for PM_{10}, 0.64 for SO_2, 0.76 for NO_2, suggesting that the air pollution concentrations at these two stations could represent the temporal variation of air pollution in the study area (See Supplementary Figures s1-s3).

We also collected daily meteorological data, including mean temperature (°C) and relative humidity (%) from Guangzhou Weather Station. Additionally, we collected daily influenza epidemic information which was routinely collected as part of the national infectious disease surveillance system. Approval to conduct this study was granted by the Medical Ethics Committee of Guangdong Provincial Centre for Disease Control and Prevention.

2.3. Statistical analysis

Due to different time periods to measure the concentrations of particle size fractions and chemical constituents, we constructed two datasets for the analyses. The first one involved daily mass concentrations of PM_{10}, $PM_{2.5-10}$, $PM_{2.5}$, $PM_{1-2.5}$, and PM_1 for 1 January 2009 through 31 December 2011 and the second included daily concentrations of $PM_{2.5}$ chemical constituents for January, April, July and November of 2007–2010.

We examined the short-term association between daily PM pollution and cardiovascular mortality using generalized additive