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Differentiating the associations of black carbon and fine particle with daily mortality in a Chinese city

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ABSTRACT

There is only limited monitoring data of black carbon for epidemiologic analyses. In the current study, we used the distributed lag models to evaluate the association between mortality outcomes (both total and cause-specific) and exposure to black carbon and fine particle ($PM_{2.5}$) in Shanghai, China. During our research period, the mean daily concentrations of black carbon and $PM_{2.5}$ were 3.9 μg/m^3 and 53.9 μg/m^3, respectively. The regression results showed that black carbon was significantly associated with total and cardiovascular mortality, but not with respiratory mortality. An inter-quartile range increase (2.7 μg/m^3) of black carbon corresponded to a 2.3% (95% confidence interval [CI]: 0.6–4.1), 3.2% (95% CI: 0.6–5.7), and 0.6% (95% CI: −4.5 to 5.7) increase in total, cardiovascular and respiratory mortality, respectively. When adjusted for $PM_{2.5}$, the effects of black carbon increased and remained statistically significant; in contrast, the associations of $PM_{2.5}$ with daily mortality decreased and became statistically insignificant after adjustment for black carbon. To our knowledge, this is the first study in China, or even in Asian developing countries, to report the acute effect of black carbon and $PM_{2.5}$ on daily mortality simultaneously. Our findings suggest that black carbon is a valuable additional air quality indicator to evaluate the health risks of ambient particles.

1. Introduction

Short term exposure to ambient air pollution has been linked to adverse health effects, including increased mortality, increased rates of hospital admissions and emergency department visits, exacerbation of chronic respiratory conditions, and decreased lung function (Brunekreef and Holgate, 2002). Among various pollutants in the ambient mixture, fine particle ($PM_{2.5}$, defined as particle less than 2.5 μm in aerodynamic diameter) shows the most consistent association with adverse health effects (Pope and Dockery, 2006). Levels of $PM_{2.5}$ in China are among the highest in the world (van Donkelaar et al., 2010). Although $PM_{2.5}$ is still not a criteria pollutant in China, the relationship between $PM_{2.5}$ and daily mortality/morbidity has been examined in several large Chinese cities, including Shanghai (Kan et al., 2007), Chongqing (Venners et al., 2003), Shenyang (Ma et al., 2011) and Guangzhou (Yang et al., 2012). These single-city analyses basically followed the commonly used time-series (Kan et al., 2007; Ma et al., 2011; Venners et al., 2003) and case-crossover (Yang et al., 2012) approaches, and their results were in accordance with those reported from developed countries. A recent multi-city study conducted in China provides further evidence supporting the coherence and plausibility of the acute effect of $PM_{2.5}$ on cardiorespiratory system (Chen et al., 2011).

Black carbon, a short-lived greenhouse pollutant coming from the incomplete combustion of biomass or fossil fuels, is not only a warming agent (Menon et al., 2002), but also damaging to health (Smith et al., 2009). In a meta analysis of existing time-series studies of black carbon and daily mortality, most of which were conducted in North America and Europe, Smith et al. (2009) reported positive significant associations of black carbon with cardiopulmonary mortality. Several previous studies support the biological plausibility of a link between exposure to black carbon and exacerbations of cardiopulmonary disorders (Gold et al., 2005; Henneberger et al., 2005; Mar et al., 2005). For instance, one study in Germany examined weekly electrocardiograms of 56 men with a history of heart disease, and found significant associations of black carbon with changes in myocardial repolarization, which could increase the risk of sudden cardiac death (Henneberger et al., 2005). Gold et al. (2005) found associations of black carbon with ST-segment depression among a panel of 24

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elderly Boston residents. Exposure to black carbon was also associated with increased nitric oxide in exhaled breath, a marker of airway inflammation (Mar et al., 2005). Thus, exposure to black carbon is associated with a number of indicators that could contribute to cardiopulmonary deaths. However, due to lack of monitoring data, few studies have examined the adverse health effect of black carbon in China. To our knowledge, only one study in Beijing has examined the association of recent exposure to black carbon with acute respiratory inflammation in schoolchildren (Lin et al., 2011).

In the current study, we conducted a time-series analysis to evaluate the associations of black carbon and $PM_{2.5}$ with daily mortality in Shanghai, the largest city in China.

2. Materials and methods

2.1. Data

Our study area included nine urban districts in Shanghai. Within an area of 279 km^2, there are around seven millions permanent residents. We obtained daily mortality data (excluding accidents or injuries) between 19 April 2007 and 31 December 2008 from the Shanghai Municipal Center of Disease Control and Prevention database. The causes of death were coded according to the International Classification of Diseases, Revision 10 (ICD 10). The mortality data were classified into deaths due to all causes (ICD-10: A00-R99), cardiovascular diseases (ICD-10: I00-I99) (including subcategories such as stroke and heart diseases), and respiratory diseases (ICD-10: J00-J98) (including subcategories such as chronic obstructive pulmonary disease and acute respiratory infection). The data were also classified by sex and age (0–4, 5–44, 45–64, 65+) for all-cause deaths.

We obtained daily black carbon and $PM_{2.5}$ data from the Shanghai Center for Urban Environmental Meteorology. The daily concentrations for both pollutants were collected from a fixed-site station located in the center of our study area, which is under China National Quality Control. Measurement of black carbon was performed by an optical transmission method; the sample was collected on a filter and the optical transmission was measured (Quincey, 2007). The method based on Tapered Element Oscillating Microbalance (TEOM) was used for the $PM_{2.5}$ measurement. For the calculation of 24-h average concentrations, we required at least 75% of the 1-hour values on that particular day. We only used the actual collected data and did not fill in the missing data for black carbon and $PM_{2.5}$. According to relevant rules of Chinese government, the location of this station should not be in the direct vicinity of traffic or of industrial sources. Moreover, the location should not be influenced by local pollution sources and should also avoid buildings, or housing large emitters such as coal-, waste-, or oil-burning boilers, furnaces, and incinerators. Thus our monitoring results reflect the general background urban air pollution level in Shanghai rather than local sources such as traffic or industrial combustion.

To allow adjustment for the effect of weather on mortality, we collected daily average temperature and humidity data from the Shanghai Meteorological Bureau.

2.2. Statistical methods

Daily counts of deaths and air pollution levels were linked by date and were therefore analyzed with a time-series design (Bell et al., 2004). We used the distributed lag models (DLM) to examine the associations of black carbon and $PM_{2.5}$ with daily mortality (Gasparrini et al., 2010; Schwartz, 2000). Briefly, the DLM allows the effect of a single exposure event to be distributed over a specific period of time, using several parameters to explain the contributions at different lags, thus providing a comprehensive picture of the time-course of the exposure–response relationship (Gasparrini et al., 2010).

Because the relationships between particulate air pollution and mortality are mostly linear (Bell et al., 2004), we used the polynomial DLM, with an empirical maximum lag of 3 day, to quantitatively estimate the cumulative effects of air pollutants over the current day and the 2 previous days (Gasparrini, 2011). To plot the relationships between air pollutants and mortality, we used the distributed lag nonlinear model with three degrees of freedom in the natural cubic splines. We applied three degrees of freedom for the lag space in the distributed lag model of air pollutants (Gasparrini et al., 2010).

We incorporated natural smooth functions of time, with seven degrees of freedom per year, to control the long-term and seasonal trend of daily mortality. We also included the day of the week as an indicator variable. To control the delayed and non-linear confounding effects of temperature and humidity, we applied the distributed lag non-linear models with three degrees of freedom in the natural cubic splines and a maximum lag of 3 day (Goldberg et al., 2011). We used four degrees of freedom for the lag space in the distributed lag nonlinear model of temperature and humidity (Gasparrini et al., 2010). We did not adjust for sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) in our regression models because PM was highly correlated with SO_2 and NO_2 in Shanghai (Chen et al., 2008) and simultaneously entering SO_2 (or NO_2) into the models can yield unstable parameter estimates when the pollutants involved had high inter-correlation.

To differentiate the associations of black carbon and $PM_{2.5}$ with daily mortality, we fitted both single-pollutant and two-pollutant models to assess the stability of black carbon's health effects. In the single-pollutant models, black carbon and $PM_{2.5}$ were included alone in the model. In the two-pollutant models, black carbon and $PM_{2.5}$ were included jointly at the same lag.

Given the difficulty of determining optimal values of degrees of freedom for time trend, we conducted sensitivity analyses to test the effect of alternative values of degrees of freedom on the estimated effects of black carbon. We also analyzed the effects of black carbon separately for the cool (November–April) and warm (May–October) seasons.

All analyses were conducted in R 2.15.1 using the MGCV and DLNM packages. The results are presented as the percent change in daily mortality per interquartile range (IQR) increase of pollutant concentrations unless specified otherwise. Statistical significance was defined as $p<0.05$.

3. Results

From 19 April 2007 to 31 December 2008 (623 day), a total of 77,964 deaths (41,094 males and 36,870 females) were recorded in the study population. The percentages of total deaths by age group were 0.2% for 0–4 years old, 2.5% for 5–44, 13.7% for 45–64 and 83.6% for 65+, respectively. On average, there were 125.1 non-accidental deaths per day, including 50.0 from cardiovascular diseases, and 12.6 from respiratory diseases (Table 1). Cardiopulmonary disease accounted for 50.0% of the total non-accidental deaths for the urban residents in Shanghai.

During our research period, the mean daily concentrations of black carbon and $PM_{2.5}$ were 3.9 $\mu g/m^3$ and 53.9 $\mu g/m^3$, respectively, which were much higher than reported levels of black carbon and $PM_{2.5}$ in developed countries. Compared with the Global Air Quality Guidelines set by World Health Organization (10 $\mu g/m^3$ for annual mean and 25 $\mu g/m^3$ for 24-h mean) (World Health Organization, 2006) and US National Ambient Air Quality

Table 1
Summary statistics of daily deaths, BC and $PM_{2.5}$ concentrations, and weather conditions in Shanghai, China.

Variables	Mean ± SD	Minimum	First quartile	Median	Third quartile	Maximum	Inter-quartile range
Daily death counts							
Total (non-accident)	125.1 ± 22.4	71.0	110.0	121.0	137.0	201.0	27.0
Cardiovascular	50.0 ± 12.4	25.0	41.0	48.0	56.0	100.0	15.0
Respiratory	12.6 ± 5.2	2.0	9.0	12.0	16.0	33.0	7.0
Air pollutants concentrations							
BC ($\mu g/m^3$)	3.9 ± 2.4	0.8	2.2	3.4	4.9	15.6	2.7
$PM_{2.5}$ ($\mu g/m^3$)	53.9 ± 31.4	9.0	30.0	47.0	71.8	174.0	41.8
Meterologic measures							
Mean temperature (°C)	19.1 ± 8.7	−1.5	12.6	21.0	26.2	33.8	13.6
Relative humidity (%)	70.0 ± 12.0	31.0	63.0	71.0	78.0	95.0	15.0

BC, black carbon; $PM_{2.5}$, fine particle, particle less than 2.5 μm in aerodynamic diameter; SD, standard deviation.