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Coarse particles and mortality in three Chinese cities: The China Air Pollution and Health Effects Study (CAPES)

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A B S T R A C T

Evidence concerning the health risks of coarse particles ($PM_{10-2.5}$) is limited. There have been no multi-city epidemiologic studies of $PM_{10-2.5}$ in developing Asian countries. We examine the short-term association between $PM_{10-2.5}$ and daily mortality in three Chinese cities: Beijing, Shanghai, and Shenyang. $PM_{10-2.5}$ concentrations were estimated by subtracting $PM_{2.5}$ from PM_{10} measurements. Data were analyzed using the over-dispersed generalized linear Poisson models. The average daily concentrations of $PM_{10-2.5}$ were 101 μg/m^3 for Beijing (2007–2008), 50 μg/m^3 for Shanghai (2004–2008), and 49 μg/m^3 for Shenyang (2006–2008). In the single-pollutant models, the three-city combined analysis showed significant associations between $PM_{10-2.5}$ and daily mortality from both total non-accidental causes and from cardiopulmonary diseases. A 10-μg/m^3 increase in 1-day lagged $PM_{10-2.5}$ was associated with a 0.25% (95% CI: 0.08 to 0.42) increase in total mortality, 0.25% (95% CI: 0.10 to 0.40) increase in cardiovascular mortality, and 0.48% (95% CI: 0.20 to 0.76) increase in respiratory mortality. However, these associations became statistically insignificant after adjustment for $PM_{2.5}$. $PM_{2.5}$ was significantly associated with mortality both before and after adjustment for $PM_{10-2.5}$. In conclusion, there were no statistically significant associations between $PM_{10-2.5}$ and daily mortality after adjustment for $PM_{2.5}$ in the three Chinese cities.

1. Introduction

Ambient air pollution is a complex mixture composed of both solid particles and gaseous pollutants. Among various air pollutants, particulate matter (PM) often shows the strongest evidence for adverse health effects (Brunekreef and Holgate, 2002). PM can be characterized as discrete particles spanning several orders of magnitude in size: PM_{10} (defined as particulate matter less than 10 μm in aerodynamic diameter); $PM_{2.5}$, also known as fine particles (defined as those particles less than 2.5 μm in aerodynamic diameter); and $PM_{10-2.5}$, also known as coarse particles (defined as those particles between 10 and 2.5 μm in aerodynamic diameter). Most prior studies have only used $PM_{2.5}$ or PM_{10} as PM measurements, leaving the effects of other particle sizes – particularly $PM_{10-2.5}$ – not well understood (Pope and Dockery, 2006).

Compared with $PM_{2.5}$, $PM_{10-2.5}$ have different sources, composition and deposition mode in the human airway (Lippmann and Schlesinger, 2000; Wilson and Suh, 1997). In addition, findings from existing epidemiological studies of $PM_{10-2.5}$ have been limited and inconclusive (Brunekreef and Forsberg, 2005; Chang et al., 2011; Mallone et al., 2011); some studies found significant health hazards of $PM_{10-2.5}$, while others did not. The inadequate evidence of health effects of $PM_{10-2.5}$ had led the US Environmental Protection Agency (EPA) to reject a proposal to replace the existing daily PM_{10} standard with daily $PM_{10-2.5}$. Furthermore, most studies of $PM_{10-2.5}$ were conducted in developed countries, with only a small number of studies conducted in Asia. As the results, there remains a need for studies in cities of developing countries, where characteristics of outdoor air pollution (e.g. air pollution level, chemical composition and size of particles, and fate and transport of pollutants), meteorological conditions, and socio-demographic status of local residents (e.g. disease pattern, age structure, and social economic status), may be different from developed countries.

As the largest developing country, China may have the worst PM pollution in the world (Kan et al., 2009). The current Chinese Air

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Quality Standard includes PM_{10} only, and $PM_{2.5}$ and $PM_{10-2.5}$ are still not criteria pollutants. In the literature, only one study in China has investigated the health impact of $PM_{10-2.5}$ and this is due to lack of monitoring data (Kan et al., 2007). The objective of this paper is to examine the short-term associations between $PM_{10-2.5}$ and daily mortality in three Chinese cities – Beijing, Shanghai, and Shenyang. This study is a component of the "**C**hina **A**ir **P**ollution and Health **E**ffects **S**tudy" (CAPES) initiated by the China Ministry of Environmental Protection (Chen et al., 2011).

2. Materials and methods

2.1. Data collection

We conducted our analysis of $PM_{10-2.5}$ in Beijing, Shanghai and Shenyang. To our knowledge, PM_{10} and $PM_{2.5}$ are simultaneously measured only in these three cities in China. Study areas were restricted to the urban areas of the three cities due to inadequate air pollution monitoring stations in the suburban areas. The study periods were from January 1, 2007 to September 30, 2008 for Beijing; March 4, 2004 to December 31, 2008 for Shanghai; and August 9, 2006 to December 31, 2008 for Shenyang.

$PM_{2.5}$ and $PM_{10-2.5}$ are not regularly monitored in China. Similar to previous studies (Brunekreef and Forsberg, 2005), $PM_{10-2.5}$ concentrations were estimated by subtracting $PM_{2.5}$ from PM_{10} measurements. The 24-hour average concentrations of PM_{10} and $PM_{2.5}$ were measured at each city using the tapered element oscillating microbalance (TEOM) method. According to the rules of Chinese government, the locations of these monitoring stations are mandated not to be in the direct vicinity of traffic or industrial sources; not to be influenced by local pollution sources; and to avoid buildings, housing, and large emitters such as coal-, waste-, or oil-burning boilers, furnaces, and incinerators.

Mortality data of urban residents were obtained from China Center for Disease Control and Prevention. The causes of death were coded according to International Classification of Diseases, 10 (ICD-10). The mortality data were classified into deaths due to total non-accidental causes (ICD-10: A00-R99), cardiovascular disease (ICD-10: I00-I99), and respiratory disease (ICD-10: J00-J98).

To allow adjustment for the effect of weather conditions on mortality, meteorological data (daily mean temperature and relative humidity) were obtained at each city.

2.2. Statistical methods

The CAPES project follows the same analytical approach as the Public Health and Air Pollution in Asia (PAPA) program (Wong et al., 2008). Daily counts of deaths and $PM_{10-2.5}$ levels were linked by date and were therefore analyzed with time-series methods (Bell et al., 2004).

To control for long-term and seasonal trends, generalized linear modeling, with natural spline smoothers, was used to model daily mortality. According to the PAPA Protocol, we used the partial autocorrelation function (PACF) to guide the selection of model parameters. Specifically, we used 4–6 degrees of freedom (*df*) per year for time trend for all mortality outcomes. When the absolute magnitude of the PACF plot was less than 0.1 for the first two lag days, the basic model was regarded as adequate; if this criteria was not met, autoregression (AR) terms for lag up to 7 days were introduced to improve the model (Kan et al., 2008). Day of the week (*DOW*) was included as a dummy variable in the basic models. Residuals of the basic model were examined to check whether there were discernable patterns and autocorrelation by means of residual plots and *PACF* plots.

After establishing the basic model, $PM_{10-2.5}$ and covariates (including temperature, relative humidity, and $PM_{2.5}$ concentrations) were introduced in the model. Based on the existing literature (Dominici et al., 2006), 3 *df* (whole period of study) for temperature and humidity could adequately control for their effects on mortality and was therefore used in the model. To examine the temporal relationship of $PM_{10-2.5}$ with mortality, models with different lag structures from lag 0 to lag 2 were fitted. A lag of day 0 (L0) corresponds to the current-day $PM_{2.5}$, and a lag of day 1 (L1) refers to the previous-day $PM_{2.5}$.

We fitted both single-pollutant and two-pollutant models to assess the stability of PM's health effect. In the single-pollutant models, $PM_{10-2.5}$ and $PM_{2.5}$ were included alone in the model. In the two-pollutant models, $PM_{10-2.5}$ and $PM_{2.5}$ were included jointly at the same lag. Given the difficulty of determining the optimal values of *df* for time trend, we conducted sensitivity analyses to test the impact of alternative *df* values on the estimated effects of $PM_{10-2.5}$.

After the health effects of $PM_{10-2.5}$ and $PM_{2.5}$ at each city were estimated, we calculated combined estimates of excess risk of mortality and their standard errors using a random-effects model. Estimates were weighted by the inverse of the sum of variance within and between-city.

All analyses were conducted in R 2.10.1 using the MGCV package. The results are presented as the percent change in daily mortality per 10 $\mu g/m^3$ increase of PM concentrations.

3. Results

Table 1 summarizes the mortality and PM data in the three cities. During the study periods, the mean daily death numbers for all non-accidental causes, cardiovascular causes and respiratory causes – in respective order – were 118, 54 and 14 in Beijing; 119, 46, and 13 in Shanghai; and 67, 31, and 7 in Shenyang (Table 1). Among all non-accidental deaths, cardiorespiratory diseases accounted for 58% in Beijing, 50% in Shanghai, and 57% in Shenyang.

Generally, the $PM_{10-2.5}$ levels in three Chinese cities were much higher than those reported in developed countries (Chang et al., 2011; Graff et al., 2009; Host et al., 2008; Lipsett et al., 2006; Malig and Ostro, 2009; Peng et al., 2008; Puett et al., 2009; Yeatts et al., 2007; Zanobetti and Schwartz, 2009) (Table 1). The average daily concentrations of $PM_{10-2.5}$ were 101 $\mu g/m^3$ for Beijing, 50 $\mu g/m^3$ for Shanghai, and 49 $\mu g/m^3$ for Shenyang. The ratios between $PM_{10-2.5}$ and PM_{10} were 0.59 in Beijing, 0.48 in Shanghai, and 0.35 in Shenyang. In general, $PM_{10-2.5}$ was strongly correlated with PM_{10} (correlation coefficients ranging from 0.74 to 0.86), and had a moderate correlation with $PM_{2.5}$ (correlation coefficients ranging from 0.28 to 0.53) (Table 2).

In the single-pollutant models, the city-specific associations of $PM_{10-2.5}$ with mortality varied by causes of death and lag structures (Table 3). The three-city combined analysis showed significant associations between $PM_{10-2.5}$ and daily mortality from both total non-accidental causes (L0, L1 and L2) and from cardiopulmonary diseases (L1 only). Specifically, a 10-$\mu g/m^3$ increase in $PM_{10-2.5}$ (L1) was associated with a 0.25% (95% CI: 0.08 to 0.42) increase in total mortality,

Table 1
Summary statistics (mean and SD) of daily death numbers, air pollution levels and weather conditions in Beijing, Shanghai and Shenyang.

	Beijing	Shanghai	Shenyang
Population size (millions)	7.1	6.5	3.5
Daily death numbers			
All-natural causes	118 (22)	119 (22)	67 (10)
Cardiovascular	54 (13)	46 (12)	31 (7)
Respiratory	14 (6)	13 (5)	7 (3)
Air pollutants (24-h average, $\mu g/m^3$)			
PM_{10}	172 (93)	105 (54)	141 (66)
$PM_{2.5}$	82 (52)	55 (30)	94 (52)
$PM_{2.5–10}$	101 (67)	50(31)	49 (30)
Weather conditions			
Temperature (°C)	15 (11)	19 (9)	9 (12)
Humidity (%)	54 (21)	69 (12)	66 (15)