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Mortality risks from a spectrum of causes associated with wide-ranging exposure to fine particulate matter: A case-crossover study in Beijing, China

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ABSTRACT

Background: Exposure to fine particulate matter (≤ 2.5 μm in aerodynamic diameter; $PM_{2.5}$) has been shown to be associated with an increased risk of mortality due to cardiovascular, respiratory, and other pulmonary diseases. However, fewer studies have investigated the relationship between ambient $PM_{2.5}$ and human mortality for a wider range of causes of death, or for more specific causes of death within these broader categories, especially at the high $PM_{2.5}$ concentrations currently experienced in Chinese megacities. Beijing, China, has a very large population and a wide range of $PM_{2.5}$ exposures, allowing a prime opportunity to estimate such risks across a broad spectrum of causes, including rarer causes of death.

Objective: To estimate the relative risk of cause-specific mortality associated with $PM_{2.5}$ for a spectrum of causes of death, as well as characterize the time course of cause-specific mortality following $PM_{2.5}$ exposure, in a location where $PM_{2.5}$ concentrations are representative of common exposures in Chinese megacities.

Methods: We collected daily data on mortality counts of Beijing residents and Beijing weather and air pollution measurements for January 1, 2009 to December 31, 2012. We used a time-stratified case-crossover study design to estimate the association between ambient $PM_{2.5}$ concentrations and risk of death from several broad causes of death and from more refined specific causes within these broader categories. Primary results were estimated for risks the day of and the day following exposure (lag 0–1), but the time pattern of associated risk was also explored up to seven days following exposure.

Results: Increased concentrations of $PM_{2.5}$ were associated with increased risks at lag days 0–1 of all-cause mortality (0.26% increase per 10 μg/m^3; 95% confidence interval [CI]: 0.12%–0.39%), non-accidental deaths (0.25%; 95% CI: 0.11%–0.38%), circulatory deaths (0.39%; 95% CI: 0.21%–0.59%), respiratory deaths (0.43%; 95% CI: 0.05%–0.81%), intentional self-harm deaths (1.94%; 95% CI: 0.19%–3.73%) and nervous system deaths (0.9%; 95% CI: − 0.2%–2%), although the observed increase was not statistical significant for the final one rarer cause of death. In addition to these five broad death outcomes, risk also increased following $PM_{2.5}$ exposure at lag days 0–1 for deaths from several specific causes, including most of the specific circulatory causes considered. The largest observed increased risk by far was for one of the rarest causes of death considered, extrapyramidal and movement disorders (2.35%; 95% CI: 0.03%–4.72%).

Conclusions: This study indicates that exposure to $PM_{2.5}$ in a study location more representative of exposures in developing cities is associated with an increased risk of mortality from broad range of causes of death, including some causes rarely studied previously in association with $PM_{2.5}$ exposure.

1. Introduction

Short-term exposure to fine particulate matter (≤ 2.5 μg/m^3 in aerodynamic diameter; $PM_{2.5}$) has been associated in past studies with increased risk of mortality, with much of the research focusing on risks for deaths from cardiorespiratory causes (Atkinson et al., 2014; Bell et al., 2013; Englert, 2004; Samet et al., 2000). Most of these acute health effect studies have been conducted in developed regions in the United States and Europe and have therefore predominantly assessed the risk of mortality following short-term exposure to levels of annual ambient mean $PM_{2.5}$ ranging from 5 to 30 μg/m^3 (Krzyzanowski and Cohen, 2008). However, there is significantly less information pertaining to cause-specific mortality relationships at the higher ambient $PM_{2.5}$ concentrations found in developing countries. There is an urgent need for up-to-date studies, conducted in cities within developing countries, which estimate the specific health risks associated with short-

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term air pollution exposure locally, where both exposure (pollution and meteorological conditions) and population susceptibility to $PM_{2.5}$ exposures might differ substantially from Western study populations.

Further, while some studies have provided evidence of increased cause-specific mortality associated with short-term $PM_{2.5}$ exposure (Atkinson et al., 2014; Chowdhury and Dey, 2016; Franklin et al., 2007), typically such studies only investigated deaths either collectively from all causes or all cardiorespiratory causes or, if they studied more refined categories of cause-specific deaths, were predominantly limited to cardiorespiratory causes, such as ischemic heart disease, stroke, and chronic obstructive pulmonary disease (Atkinson et al., 2014; Franklin et al., 2007). To date, no study has attempted to determine the complete spectrum of mortality risks associated with exposure to $PM_{2.5}$, an especially important research question in a setting like Beijing where $PM_{2.5}$ concentrations include the very high levels sometimes experienced in cities in developing countries.

Beijing is the center of politics, economics, science, technology, and education in China, with an area of about 16,400 km^2 (Beijing Statistical Bureau, 2015). It has a large population (21.5 million) (Beijing Statistical Bureau, 2015) and heavy air pollution (annual $PM_{2.5}$ mean of 80.6 $\mu g/m^3$ in 2015) (Beijing Environmental Protection Bureau, 2016) and so provides a unique opportunity to study the relationship between high exposure to $PM_{2.5}$ and cause-specific mortality, especially mortality associated with less common causes of death. In this study, we investigated the associations between $PM_{2.5}$ and cause-specific mortality in Beijing, China. Our objectives were to: (1) explore the relative risk of a broad spectrum of cause-specific mortality from high $PM_{2.5}$ exposure, (2) characterize the time course of cause-specific mortality risks in the week following $PM_{2.5}$ exposure, and (3) compare estimated mortality risks to risks observed in studies in western countries, where $PM_{2.5}$ levels are typically much lower, but which constitute much of the research informing the current scientific understanding of health risks of ambient $PM_{2.5}$ exposure.

2. Methods

2.1. Data

We collected daily mortality data for residents in Beijing from January 1, 2009, to December 31, 2012, from the Chinese Center for Disease Control and Prevention. Causes of death were categorized based on the International Classification of Disease, Revision 10 (ICD-10). In this study, we evaluated risks associated with $PM_{2.5}$ exposure first for deaths from all causes (ICD-10: A00-Z99) and total non-accidental deaths (A00-R99). We then estimated risks for cause-specific deaths from seven broad categories: circulatory system disease (I00-I99), respiratory system disease (J00-J99), digestive system disease (K00-K93), nervous system disease (G00-G99), genitourinary system disease (N00-N99), intentional self-harm (X60-X84), and mental and behavioral disorders (F00-F99). Finally, we estimated risks for deaths caused by specific causes within each broad of these seven broad categories (Table 1).

To obtain a daily estimate of $PM_{2.5}$ concentration in Beijing over the study period, data were collected from the two publicly-available $PM_{2.5}$ monitors in Beijing, located at Haidian district (Beijing Meteorological Bureau station) and the US Embassy (Fig. 1). These monitors are 18 km apart, and their measurement data for $PM_{2.5}$ concentrations were well-correlated, but not in perfect agreement, over the study period (R^2 = 0.77, Fig. S1). We averaged daily measurements from the two monitors to create a daily estimated exposure. On days for which a measurement was missing for one but not both monitors (Table 2), we interpolated a value for the missing monitor using a model based on the observed concentration at the non-missing monitor (Supplemental Material). After this interpolation, the time series of daily $PM_{2.5}$ concentration at the two monitors was available for 99.7% of study days (Table 2). To determine if results were sensitive to the monitor used to estimate $PM_{2.5}$ concentrations, we also performed a sensitivity analysis to re-assess the main study results using concentration measurements from each monitor separately.

Daily temperature, relative humidity and other meteorological data

Table 1
Summary statistics for cause-specific mortality (N = 1461 study days).

Code	Disease	Total over study period	Mean daily count (range)
A00-Z99	**All**	292,417	200 (131, 288)
By broad category			
A00-R99	Non-accidental	281,894	193 (122, 279)
I00-I99	Diseases of the circulatory system	141,259	97 (49, 164)
J00-J99	Diseases of the respiratory system	28,853	20 (6, 45)
K00-K93	Diseases of the digestive system	7559	5 (0, 14)
G00-G99	Diseases of the nervous system	3230	2 (0, 10)
N00-N99	Diseases of the genitourinary system	2542	2 (0, 7)
X60-X84	Intentional self-harm	1148	1 (0, 6)
F00-F99	Mental and behavioral disorders	1029	1 (0, 7)
Within broad categories			
I00-I99	**Diseases of the circulatory system**		
I60-I69	Cerebrovascular diseases	65,544	45 (19, 80)
I20-I25	Ischemic heart disease	65,077	45 (19, 85)
I60-I64	Stroke	39,156	27 (8, 56)
I20-I22,I24	Acute ischemic heart disease	33,121	23 (5, 44)
I21-I22	Acute Myocardial infarction	32,580	22 (5, 44)
I21-I23	Myocardial infarction	32,580	22 (5, 44)
I25	Chronic ischemic heart disease	31,956	22 (7, 47)
I63	Ischemic stroke	19,881	14 (3, 31)
I61	Intracerebral hemorrhagic stroke	17,622	12 (2, 28)
I30-I52	Other forms of heart disease	3808	3 (0, 10)
I10-I15	Hypertensive diseases	2985	2 (0, 10)
I26-I28	Pulmonary heart disease and diseases of pulmonary circulation	1382	1 (0, 7)
I05-I09	Chronic rheumatic heart diseases	1164	1 (0, 5)
I70-I79	Diseases of arteries, arterioles and capillaries	1035	1 (0, 5)
I26	Pulmonary embolism	583	0 (0, 4)
J00-J99	**Diseases of the respiratory system**		
J40-J47	Chronic lower respiratory diseases	14,274	10 (1, 29)
J09-J18	Influenza and pneumonia	8141	6 (0, 16)
J95-J99	Other diseases of the respiratory system	3528	2 (0, 9)
J80-J84	Other respiratory diseases principally affecting the interstitium	1583	1 (0, 6)
J60-J70	Lung diseases due to external agents	1012	1 (0, 4)
K00-K93	**Diseases of the digestive system**		
K70-K77	Diseases of liver	3146	2 (0, 8)
K20-K31	Diseases of oesophagus, stomach and duodenum	1165	1 (0, 7)
K80-K87	Disorders of gallbladder, biliary tract and pancreas	1164	1 (0, 5)
K55-K63	Other diseases of intestines	855	1 (0, 6)
K90-K93	Other diseases of the digestive system	842	1 (0, 4)
G00-G99	**Diseases of the nervous system**		
G30-G32	Other degenerative diseases of the nervous system	1235	1 (0, 5)
G20-G26	Extrapyramidal and movement disorders	502	0 (0, 4)
N00-N99	**Diseases of the genitourinary system**		
N00-N39	Urinary	2478	2 (0, 7)
N00-N08	Glomerular diseases	1112	1 (0, 5)
N17-N19	Renal failure	863	1 (0, 5)
F00-F99	**Mental and behavioral disorders**		
F00-F09	Organic, including symptomatic, mental disorders	804	1 (0, 4)