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Acute effects of air pollution on asthma hospitalization in Shanghai, China

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ABSTRACT

Air pollution has been accepted as an important contributor to asthma development and exacerbation. However, the evidence is limited in China. In this study, we investigated the acute effect of air pollution on asthma hospitalization in Shanghai, China. We applied over-dispersed generalized additive model adjusted for weather conditions, day of the week, long-term and seasonal trends. An interquartile range increase in the moving average concentrations of PM_{10}, SO_2, NO_2 and BC on the concurrent day and previous day corresponded to 1.82%, 6.41%, 8.26% and 6.62% increase of asthmatic hospitalization, respectively. The effects of SO_2 and NO_2 were robust after adjustment for PM_{10}. The associations appeared to be more evident in the cool season than in the warm season. Our results contribute to the limited data in the scientific literature on acute effects of air pollution on asthma in high exposure settings, which are typical in developing countries.

1. Introduction

According to a report by the Global Initiative for Asthma in 2004, asthma has been estimated to affect 300 million people worldwide and responsible for about 1 in 250 deaths during that year (Masoli et al., 2004). It has caused substantial economic and health care burden over the past decades. The prevalence of asthma tends to be higher in urbanized and well-developed areas compared to the developing areas (Ait-Khaled et al., 2001; To et al., 2012; Weiland and Pearce, 2004). Moreover, while there has been an overall trend of a decline in prevalence in developed countries (Moorman et al., 2012), there is an increasing trend in developing countries (Al-Hajjaj, 2008). In China, the asthmatic population has reached 30 million (Chen et al., 2013). The prevalence and risk factors of asthma in several metropolitan cities in China including Beijing, Shanghai and Guangzhou, have become comparable to those in other developed countries (Chen, 2003; Zhao et al., 2010).

Ambient air pollution has been linked to the development and exacerbation of asthma and its related diseases in Europe, North America, Korea, Japan and Taiwan (Abe et al., 2009; Jaffe et al., 2003; Park et al., 2013; Samet et al., 2000; Sunyer et al., 1997; Yang et al., 2007). Previous cross-sectional studies in China have shown that the prevalence of childhood asthma was related to the air pollution levels (Dong et al., 2011; Zhang et al., 2002), however, there have been no studies investigating the association of asthma exacerbation and air pollution. Understanding this association might be important for asthmatic patients to regulate their activities when the outdoor air pollution levels are high.

This study aims to investigate the acute effect of air pollution on asthma hospitalization in Shanghai, the largest city and economic center of China.

2. Method

2.1. Data

Our study area included nine urban districts in Shanghai. This region covers an area of 279 square kilometers and has approximately seven million permanent residents. We obtained daily number of asthmatic hospitalization for adult residents living in the nine urban districts between January 1, 2005 and December 31, 2011 (2922 days) from the Shanghai Health Insurance Bureau (SHIB). The SHIB is a government agency that administers the Shanghai Health Insurance System. The Shanghai Health Insurance System, which provides compulsory universal health insurance, covers most of the residents in Shanghai (the coverage rate was 95% in 2008). In Shanghai, all hospitals are under contract with the SHIB. Computerized records of hospital visits are maintained at each contracted hospital and sent to the

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SHIB through an internal computer network. The causes of hospital admission were coded according to International Classification of Diseases, Revision 10 (ICD-10): Asthma (J45). The data were also classified by season, sex and age. Warm season is defined from April to September, and cool season is defined as the rest of time period in a year. Hospital admissions were classified into two age groups: 18–64 years and ≥65 years.

Daily (24-h) air pollution concentration data including particulate matter less than 10 μm in aerodynamic diameter (PM_{10}), sulfur dioxide (SO_2) and nitrogen dioxide (NO_2), from January 1, 2005 to December 31, 2011 were obtained from Shanghai Environmental Monitoring Center (SEMC) database. The daily concentrations for each pollutant were averaged from the available data of six fixed-site monitoring stations (Hongkou, Jin'an, Luwan, Putou, Xuhui, and Yangpu). All the monitoring results reflect the general urban background level in the study area according to their strategic location design. Ambient PM_{10}, SO_2 and NO_2 measurements were made by Tapered Element Oscillating Microbalance (TEOM), ultraviolet fluorescence and chemiluminescence methods, respectively. Daily black carbon (BC) concentrations were obtained from the Shanghai Center for Urban Environmental Meteorology. Daily concentrations of BC were measured at a fixed-site station located in the center of our study area using an optical transmission method. The sample was collected on a filter and the optical transmission was measured (Quincey, 2007). Daily (24-h) BC average concentrations were available from April 25, 2007 to December 31, 2010 (1348 days) only. All ambient measurements of the abovementioned air pollutants were operated under the China National Quality Control ((HJ/T 193-2005) and (GB3095-2012)).

To allow adjustment for the effect of weather on hospital admission, meteorological data (daily mean temperature and relative humidity) were obtained from the Shanghai Meteorological Bureau. Weather data were measured at a fixed-site station located in Xuhui District of Shanghai.

2.2. Statistical analysis

Daily asthma hospitalization and air pollution levels were linked by date and therefore could be analyzed with a time-series design. Because daily hospital admission for asthma approximately follows a Poisson distribution, and the relationships between hospitalization and explanatory variables are mostly nonlinear (Dominicia et al., 2004), we utilized over-dispersed generalized additive Poisson models (quasi-likelihood) to estimate the association of asthma hospital admission with air pollution levels (Peng et al., 2008).

We applied natural smooth (ns) functions of calendar time with 7 degrees of freedom (df) per year to exclude unmeasured long-term and seasonal trends in the time-series dataset (Peng et al., 2009). We incorporated the ns functions of mean temperature (6 df for the period) and relative humidity (3 df for the period) to adjust for the potential nonlinear confounding effects of weather conditions (Chen et al., 2012). We also included the day of the week as an indicator variable in the basic models. After establishing the basic model, we introduced the air pollutant concentrations into the single-pollutant model one at a time to estimate their associations with asthmatic hospitalization.

We examined the robustness of the main results to: (1) adjustment in turn by co-pollutants using two-pollutant models and (2) lag selection. We did not adjust for BC in the two-pollutant models because the time period of BC measurement overlapping with other pollutants was less than 50%. Consequently, simultaneously entering BC into the models might introduce large uncertainty when the pollutants involved represent a different time period of data. We also examined the effect of air pollutants with different lag structures including both single-day lag from (Lag0 to Lag5) and two-day moving average lag (Lag 01). Lag 01 corresponds to 2-day moving average of pollutant concentration of the current and previous day. Lag 01 models were used for our main analysis, given that single-day lag models may underestimate the cumulative effect of pollutants on hospital admissions (Bell et al., 2004).

We conducted season-, sex- and age- specific analyzes. The statistical significance of differences on air pollution effect on asthmatic hospitalization between subgroups were tested by calculating the 95% confidence interval (95% CI) as$\widehat{Q}_2$, where $\widehat{Q}_1$ and $\widehat{Q}_2$ are the estimates for the two seasonal, sexual or age subgroups. And $\widehat{SE}_1$ and $\widehat{SE}_2$ are their respective standard errors (Zeka et al., 2006). The null hypothesis of this test, H_0, was that there were no differences of air pollution effects on asthmatic hospitalization between subgroups.

The results of all the statistical tests with $p < 0.05$ were considered statistically significant. All models were fitted using R software (version 2.15.1, R Foundation for Statistical Computing, http://cran.r-project.org/) with the mgcv package. Unless specified otherwise, the results are presented as the percent change in daily hospital admission for each inter-quartile range (IQR) increase in the pollutant concentration and 95% confidence intervals (CIs).

3. Results

Table 1 summarizes the basic statistics for our study. From 2005 to 2011, a total of 15,678 hospital admissions for asthma were recorded. On average, there were approximately 5 admission counts per day in our study area, females accounted for 44% and the elders (≥65 year-old) accounted for 30%. The percent of females and the elders (≥65 year-old) in the whole population of Shanghai was 48.50% and 10.12%, respectively (Shanghai Bureau of Statistics, 2011). Hospital admission for asthma was higher in cool season (7527 in total, i.e. 6 people per day), compared to warm season (5954 in total, i.e. 5 people per day). During the study period, the average of daily concentrations was 88 μg/m^3 for PM_{10}, 45 μg/m^3 for SO_2, 60 μg/m^3 for NO_2, and 3.9 μg/m^3 for BC, respectively. The means of daily average temperature and humidity were 17 °C and 70%.

Generally, PM_{10}, SO_2, NO_2 and BC had moderately high correlation coefficients with each other, and were negatively correlated with temperature and humidity (Table 2).

Table 3 shows results from the single-lag day (Lag0–Lag5) and cumulative exposure models (Lag 01) for the percent increase in hospital admission per IQR increase in pollution. Statistically significant relationships were observed for admission with both SO_2 and NO_2 at lag day 0, 1 and 01; and with BC at lag 1 and 01. For these three air pollutants, the largest effects were observed at Lag 01 models. Each IQR increase in concentration of SO_2 (36 μg/m^3), NO_2 (29 μg/m^3) and BC (2.8 μg/m^3) corresponds to 6.41% (95% CI: 2.32%, 10.49%), 8.26% (95%CI: 4.48%, 12.05%) and 6.62% (95%CI: 1.74%, 11.50%) increase on risk of asthmatic hospitalization, respectively. We did not find statistically significant relationships between

Table 1
Summary statistics of daily asthmatic hospital admission ($N = 15{,}678$), air pollutant concentrations and weather conditions in Shanghai from 2005 to 2011.

	Mean	SD	Min[a]	P (25)[a]	P (50)[a]	P (75)[a]	Max[a]
Daily Asthma hospitalization	5	3	0	3	5	8	29
Age[b]							
18–64	3	3	0	2	3	5	20
≥65	2	2	0	1	2	3	12
Sex[b]							
Female	3	2	0	1	2	4	13
Male	3	2	0	1	2	4	18
Season[c]							
Cool	6	4	0	3	6	8	29
Warm	5	3	0	3	4	7	18
Air pollution concentrations (24-h average)							
PM_{10} (μg/m^3)	88	56	7	50	74	110	643
SO_2 (μg/m^3)	45	28	5	24	38	60	223
NO_2 (μg/m^3)	60	23	11	43	56	72	167
BC[d] (μg/m^3)	3.9	2.6	0.6	2.1	3.3	4.9	24.3
Meteorological measures (24-h average)							
Temperature (°C)	17	9	−3	9	19	25	36
Elative Humidity (%)	70	12	23	62	70	79	95

Definition of abbreviations: PM_{10} = particulate matter less than 10 μm in aerodynamic diameter; SO_2 = sulfur dioxide; NO_2 = nitrogen dioxide; BC = black carbon.
[a] Min: minimum; P (25): 25th percentile; P (50): 50th percentile; P (75): 75th percentile; Max: maximum.
[b] The percent of females and elders (≥65 year-old) in the whole population of Shanghai was 48.5% and 10.1%, respectively (Shanghai Bureau of Statistics, 2011).
[c] Cool season: from October to March; Warm season: from April to September.
[d] BC data were from 2007 to 2010.

Table 2
Pearson correlation coefficients between daily air pollutant concentrations and weather conditions in Metropolitan Shanghai (2005–2011).

	BC[a]	SO_2	NO_2	Temperature	Relative humidity
PM_{10}	0.60	0.63	0.66	−0.19	−0.29
BC[a]		0.52	0.68	−0.13	−0.01
SO_2			0.70	−0.30	−0.35
NO_2				−0.35	−0.18
Temperature					0.16

Definition of abbreviations: PM_{10} = particulate matter less than 10 μm in aerodynamic diameter; SO_2 = sulfur dioxide; NO_2 = nitrogen dioxide; BC = black carbon.
[a] BC data were from 2007 to 2010.