Environmental Pollution 230 (2017) 227–233

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Fine particulate air pollution and hospital visits for asthma in Beijing, China☆

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ARTICLE INFO

Article history:
Received 6 April 2017
Received in revised form
12 June 2017
Accepted 12 June 2017
Available online 24 June 2017

Keywords:
Asthma
$PM_{2.5}$
Air pollution
Hospitalization

ABSTRACT

Data on fine particulate matter ($PM_{2.5}$) in China were first announced in 2013. The primary objective of this study was to evaluate the acute effects of $PM_{2.5}$ on asthma morbidity in Beijing, China. A total of 978,658 asthma hospital visits consisting of 928,607 outpatient visits, 40,063 emergency room visits and 9988 hospital admissions from January 1, 2010, to June 30, 2012, were identified from the Beijing Medical Claim Data for Employees. A generalized additive Poisson model was applied to explore the association between $PM_{2.5}$ and health service use. The mean daily $PM_{2.5}$ concentration was 99.5 $\mu g/m^3$ with a range from 7.2 $\mu g/m^3$ to 492.8 $\mu g/m^3$. Ambient $PM_{2.5}$ concentration was significantly associated with increased use of asthma-related health services. Every 10 $\mu g/m^3$ increase in $PM_{2.5}$ concentration on the same day was significantly associated with a 0.67% (95% CI, 0.53%–0.81%), 0.65% (95% CI, 0.51%–0.80%), and 0.49% (95% CI, 0.35%–0.64%) increase in total hospital visits, outpatient visits and emergency room visits, respectively. The exposure–response association between $PM_{2.5}$ concentration and hospital visits for asthma exacerbations was approximately linear. In conclusion, this study found that short-term elevations in $PM_{2.5}$ concentration may increase the risk of asthma exacerbations. Our findings contribute to the limited scientific literature concerning the acute effects of $PM_{2.5}$ on asthma morbidity outcomes in developing countries.

1. Introduction

Asthma is a widespread non-communicable respiratory disease affecting an estimated 300 million people worldwide (Masoli et al., 2004). As no available therapeutic regimen can cure asthma, identification of modifiable risk factors and then taking effective countermeasures has significant public health implications for prevention of asthma exacerbations. A growing number of studies have examined an association of short-term exposure to ambient air pollution with risk of asthma exacerbations, yielding inconsistent findings. Some studies have found that air pollution showed a positive association with asthma exacerbations, while others have found no relationship between air pollution and increased risk of asthma morbidity (Atkinson et al., 2001; Silverman and Ito, 2010; Sunyer et al., 1997; Zheng et al., 2015). Unlike lifestyle-associated risk factors for asthma, such as demographics, cigarette smoking, and dietary habits (Beasley et al., 2015), air pollution represents a modifiable risk factor that is independent of individual behavioral change. Improving ambient air quality may offer a unique advantage in enhancing prevention efforts aimed at reducing the burden of asthma from a public health perspective.

Among various air pollutants, fine particulate matter ($PM_{2.5}$, particles with an aerodynamic diameter $\leq$ 2.5 μm) has been most strongly linked to adverse effects on respiratory health because it can be deposited more deeply into lungs and carry larger concentrations of adsorbed or condensed toxic air pollutants per unit mass with its greater surface area (Pope and Dockery, 2006; Sarnat et al., 2016). Elevated ambient level of $PM_{2.5}$ has been associated with excess daily asthma-attributed hospital admissions (Cai et al., 2014; Kim et al., 2012; Silverman and Ito, 2010) and emergency room visits (Halonen et al., 2008; Malig et al., 2013; Strickland et al., 2010). However, little is known about the association of ambient $PM_{2.5}$ with daily office visits to physician because outpatient visits in many countries including the United States are generally scheduled by appointment (Cayirli and Veral, 2003). In the United States, 13.9 million visits for asthma were made to private physician offices in 2007 (Akinbami et al., 2011), while there were only an

☆ This paper has been recommended for acceptance by David Carpenter.

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http://dx.doi.org/10.1016/j.envpol.2017.06.029
0269-7491/

estimated 1.8 million annual emergency room visits and 440,000 hospitalizations for asthma (Sullivan et al., 2014). Therefore, hospital admissions and emergency room visits can detect only a small proportion of asthma patients potentially affected by ambient air pollution. In contrast, outpatient visits provide greater coverage by including less severe asthma cases and thus confer a greater statistical power to detect adverse health effects of air pollution. To help advance understanding of the association between ambient $PM_{2.5}$ concentrations and risk of asthma exacerbations, further investigation regarding the effect of $PM_{2.5}$ on outpatient visits for asthma exacerbations is needed.

In China, there is no general practitioner-based referral system (Li and Xie, 2013). Regular outpatient visits are usually unscheduled, and are first-come first-served (Xu et al., 1995). According to the China Health and Family Planning Yearbook, hospital outpatient and emergency room visits accounted for more than 95% of the total hospital visits, while hospital admissions accounted for less than 3% in 2014 (Liu et al., 2017; Xu et al., 1995). Therefore, the hospital records could provide reliable morbidity information for a geographically defined population (Xu et al., 1995). In China, the use of outpatient data has become an important tool in studies examining the association between air pollution and public health (Ding et al., 2017; Liu et al., 2017; Zhao et al., 2017). The recently established city-wide morbidity reporting system in Beijing, the capital of China, provides an opportunity to examine the association between $PM_{2.5}$ and hospital visits for asthma exacerbations.

2. Material and methods

2.1. Data collection

Data on hospital utilization (including outpatient visits, emergency room visits and hospital admissions) for asthma were obtained from Beijing Medical Claim Data for Employees, which contains medical claim data for all working or retired employees who have basic medical insurance in Beijing. The database is documented with basic demographics, dates of hospital visits, medication use, discharge diagnoses in Chinese and corresponding International Classification of Diseases, 10th Revision (ICD-10) codes, and reimbursement information. We identified daily hospital visits with a primary discharge diagnosis of asthma between January 1, 2010, and June 30, 2012 (a total of 912 days) from the database using ICD-10 codes J45 and J46. Patients aged <18 years were excluded from this study.

Data on hourly $PM_{2.5}$ concentration during the study period was collected from the reports published by the US embassy, which established an ambient air quality monitoring station on the rooftop of embassy building located in Chaoyang district, Beijing. The levels of $PM_{2.5}$ obtained from the monitoring station have been suggested to exhibit approximately the same trend as city-wide $PM_{2.5}$ concentrations (Wang et al., 2013a). To reduce exposure misclassification, the maximum distance here considered was approximately 40 km (km). 79.2% of Beijing's total population resided within a 40-km radius of the U.S. embassy ambient monitoring station. All areas of high population density (>5000 people/km^2), 97.8% (44/45) of the tertiary hospitals and 79.3% (69/87) of the secondary hospitals in Beijing located within a 40-km radius of the monitoring station (Xie et al., 2015). It has been suggested that the monitoring data could be used as a proxy for personal exposure among individuals residing <40 km from the monitoring station (Dockery et al., 2005; Wellenius et al., 2012; Xie et al., 2015). Daily (24-h) mean concentrations of $PM_{2.5}$ were used as a proxy for population exposure levels in this study. Meteorological data on temperature (°C) and relative humidity (%) were obtained from the Chinese Meteorological Bureau.

2.2. Statistical analysis

Daily hospital visits for asthma, $PM_{2.5}$ concentrations and meteorological variables were linked by date and thus can be analyzed with a time-series design. A generalized additive Poisson model was applied to examine the association between $PM_{2.5}$ and asthma:

$$\mathrm{Log}[E(Y_t)] = \alpha + \beta PM_{2.5} + \text{day of week} + \text{public holiday} + ps(\text{calendar time}, 10) + ps(\text{Temperature}, 3) + ps(\text{Relative humidity}, 3)$$

where, $E(Y_t)$ is the expected number of hospital visits for asthma at day t; β represents the log-relative risk of asthma morbidity associated with a unit increase of $PM_{2.5}$; *ps*() indicates penalized spline function and public holiday was controlled for as a binary variable. Degrees of freedom (*df*) for calendar time, relative humidity and temperature were selected based on previous studies (Dominici et al., 2006; Kan et al., 2007; Xie et al., 2015). Sensitivity analyses were conducted to examine the robustness of the results in terms of the *df* in the smooth function of time trend (8–12), temperature (2–6) and relative humidity (2–6) using total asthma hospital visits.

Smoothing function was applied to graphically analyze the exposure-response association between the log-relative risk of asthma morbidity and $PM_{2.5}$ concentration. To examine the temporal association between asthma morbidity and $PM_{2.5}$ concentration, we fitted the models with single-day lags (from lag0 to lag4) and multiple-day lags (lag0–2 and lag0–4) (Bell et al., 2004). We also explored potential effect modification of asthma risk by age (18–64 years and ≥65 years), sex, and season (warm and cool season) using 3-day (lag0–2) moving averages of $PM_{2.5}$ concentration. Warm season is defined from April to September, and cool season is defined as the rest of time period in a year. The Z-test was used to test the statistical significance of subgroup differences (Altman and Bland, 2003).

All analyses were performed using R Programming Language (V.3.2.2, R Development Core Team) with the "*mgcv*" and "*nlme*" packages. The results were expressed as the percent change and 95% confidence intervals (CIs) in daily asthma hospital visits associated with per-10 μg/m^3 increase in $PM_{2.5}$ concentration.

3. Results

Table 1 summarizes the basic characteristics for our study. A total of 978,658 qualified hospital visits for asthma, including 928,607 outpatient visits, 40,063 emergency room visits and 9988 hospital admissions, between January 1, 2010, and June 30, 2012 (912 days), formed the basis for this study. There were 57.3% male patients, and 37.0% patients were ≥65 years old. The mean (standard deviation, SD) age of the asthma patients was 59.8 (14.2) years.

Table 2 shows the summary statistics for daily hospital visits, air pollution and weather conditions during the study period. The mean (SD) daily count for asthma-attributed total hospital visits, outpatient visits, emergency room visits and hospitalizations were 1076 (776), 1021 (754), 44 (31), and 11 (8), respectively. The overall mean daily $PM_{2.5}$ concentration during the study period was 99.5 μg/m^3 with a range from 7.2 μg/m^3 to 492.8 μg/m^3. In terms of the Chinese Ambient Air Quality Standards Grade II standards for daily mean concentrations of $PM_{2.5}$ (≤75 μg/m^3), 498 (54.6%) days of the daily $PM_{2.5}$ concentrations were below this standard. However, in terms of the WHO Air Quality Standards for daily mean concentrations of $PM_{2.5}$ (≤25 μg/m^3), only 124 (13.6%) days met the standard. The means (SD) daily temperature and relative humidity