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Ambient air pollution and daily hospital admissions: A nationwide study in 218 Chinese cities☆

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ABSTRACT

There have been few large multicity studies to evaluate the acute health effects of ambient air pollution on morbidity risk in developing counties. In this study, we examined the short-term associations of air pollution with daily hospital admissions in China. We conducted a nationwide time-series study in 218 Chinese cities between 2014 and 2016. Data on daily hospital admissions counts were obtained from the National Health Insurance Database for Urban Employees covering 0.28 billion enrollees. We used generalized additive model with Poisson regression to estimate the associations in each city, and we performed random-effects meta-analysis to pool the city-specific estimates. More than 60 million hospital admissions were analyzed in this study. At the national-average level, each 10 μg/m^3 increase in PM_{10}, SO_2, and NO_2, and 1 mg/m^3 increase in CO at lag 0 day was associated with a 0.29% (95% CI, 0.23%−0.36%), 1.16% (95% CI, 0.92%−1.40%), 1.68% (95% CI, 1.40%−1.95%), and 2.59% (95% CI, 1.69%−3.50%) higher daily hospital admissions, respectively. The associations of air pollution with hospital admissions remained statistically significant at levels below the current Chinese Ambient Air Quality Standards. The effect estimates were larger in cities with lower air pollutants levels or higher air temperatures and relative humidity, as well as in the elderly. In conclusion, our findings provide robust evidence of increased hospital admissions in association with short-term exposure to ambient air pollution in China.

1. Introduction

Numerous epidemiological studies have suggested a close, quantitative short-term association between ambient air pollution and mortality risk (Di et al., 2017a; WHO, 2013; Samet et al., 2000; Wong et al., 2008; Yin et al., 2017b), but there is relatively less scientific evidence regarding the effects of air pollution on morbidity risk, especially in developing countries such as China (Lu et al., 2015). Hospital admission, an important measure of morbidity, has been used in assessing the health effects associated with ambient air pollution. The quantity, disease composition, and demographics of hospital admissions are markedly different from those of mortality events. Hospital admissions greatly outnumber death events for a geographically defined population, thus representing a larger fraction of associated health impacts of air pollution. Moreover, hospitalization data can better explore the temporal pattern of clinical presentation of disease following short-term exposure to air pollution (Villeneuve et al., 2006).

Several large multicity studies have examined the associations between air pollution and daily hospital admissions in Europe, North America, and some developed Asian cities (Barnett et al., 2006; Bell et al., 2009; Katsouyanni et al., 2009; Larrieu et al., 2007; Peng et al., 2008; Son et al., 2013), with limited studies in developing countries, despite the much higher air pollutants levels in these countries. The paucity of scientific data generated in developing countries was mainly due to the scarcity in both air pollution and hospitalization data. China, the largest developing country, is one of the most polluted countries worldwide. Data on real-time measurements of air pollutants in major Chinese cities

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were publicly available for the first time in 2013. Only a handful of single-city studies to date have examined the associations between air pollution exposure and morbidity risk in China, and the findings were inconclusive (Chen et al., 2010; Tao et al., 2014; Zhang et al., 2014a). China has a vast territory with substantial regional differences in the components and levels of air pollution (Chan and Yao, 2008). Exploration of geographical heterogeneity in the acute effects of air pollution would contribute to policy making and air quality standards setting.

With the establishment of the national health insurance system (Hu et al., 2008), national morbidity data in China are first available in 2017. We therefore performed a national multi-site study to estimate the associations between shot-term exposure to air pollution and daily hospital admissions between 2014 and 2016 in China. We also explored effect modification by individual-level and city-level characteristics.

2. Methods

2.1. Study population

Daily hospital admissions counts for each city during 2014–2016 were collected from the National Health Insurance Database for Urban Employees, which is administrated by the China's Ministry of Human Resources and Social Security. The database records health insurance information for current and former employees. In 2016, the database covers 0.28 billion beneficiaries in 31 provincial administrative regions (except Tibet, Hong Kong, Macao and Taiwan), representing about a fifth of the total population in Mainland China (1.38 billion). According to reimbursement policy, an electronic standard claim form that includes the date of admission, sex, and age was recorded in the database. Hospital admissions under age 18 were too few and therefore were excluded from this study. In consideration of the striking variations in air pollution levels, weather conditions, and topography between southern and northern China (Almond et al., 2009; Ebenstein et al., 2017), the cities were classified into south and north regions based on the Huai River-Qinling Mountains line. To explore the potential individual-level modifiers, we divided daily hospitalizations into several strata by sex and age ranges (18–64 year, 65–74 year, and ≥75 year).

2.2. Air pollution and meteorological data

Data on daily levels of PM_{10} (particle diameter ≤ 10 μm), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and carbon monoxide (CO) were collected from the China's Ministry of Environmental Protection, the government agency in charge of the National Air Pollution Monitoring System. There are 1–17 monitoring stations in each city. The Chinese government has mandated extensive quality assurance and quality control programs at the monitoring stations to obtain reliable and comparable real-time hourly concentrations of criteria air pollutants (Zhao et al., 2016). The monitoring measurements have been demonstrated to be able to reflect urban background air pollution levels (Chen et al., 2012a; Chen et al., 2012b). Previous studies have widely used the monitoring data to evaluate the health effects associated with air pollution in China (Chen et al., 2012a; Chen et al., 2017; Yin et al., 2017a). The daily 24-h average concentrations for each air pollutant were averaged across the measurements from the available monitoring stations in each city. In China, the daily 24-h average value was generally used as the exposure metric for CO in studies assessing the health effects of CO (Cai et al., 2015; Chen et al., 2011; Liu et al., 2018). For easy comparisons with other Chinese studies, we chose the 24-h index for CO in this study. The missing rates for PM_{10}, SO_2, NO_2 and CO during the study period were all 0.21%. Due to the small proportion of days with missing data, we simply excluded these days from analysis.

We collected daily mean air temperature and mean relative humidity in each city from the China Meteorological Data Sharing Service System (http://data.cma.cn/).

2.3. Statistical analysis

In each city, daily hospital admissions counts, air pollutants levels, and meteorological conditions were linked by date. We applied a 2-stage approach to estimate regional and national-average associations between air pollution and daily hospital admissions.

In the first stage, we examined the city-specific associations using a generalized additive model with Poisson regression. We incorporated a natural spline smoother of calendar time with 7 degrees of freedom (*df*) per year to accommodate the seasonality in hospital admissions (Chen et al., 2017). We also applied natural spline smoothers of 3-day moving average air temperature (3 *df*) and relative humidity (3 *df*) to account for their non-linear and lagged confounding effects (Guo et al., 2011). Finally, two indicator variables of day of week and public holiday were included in the model to account for possible variations in the baseline admissions. After we established the basic model, we included the air pollutants variables in the model. Several large national studies have suggested immediate (lag 0) effects of air pollution and single lag of 0 day was used in their main analyses (Dominici et al., 2006a; Peng et al., 2008; Yin et al., 2017b), thus we used lag 0 day exposure as the primary exposure metric in this analysis. We still used single lags of 1, 2, 3 days to explore the lag pattern in the effects. We also estimated the associations with 4-day (lag 0–3 day) moving average air pollutants concentrations. To test whether air pollutants at levels below the current Chinese Ambient Air Quality Standards (CAAQS) also increase daily hospital admissions, we conducted a subset analysis that only includes days that met the air quality standards (150, 150, and 80 $\mu g/m^3$ for daily mean concentrations of PM_{10}, SO_2, and NO_2, and 4 mg/m^3 for CO).

In the second stage, random effects meta-analyses were performed to combine city-specific estimates on the associations between air pollution and hospital admissions at regional and national levels (Yin et al., 2017b). We estimated the heterogeneity between city-specific associations using the Cochran's *Q* test and I^2 statistic (Higgins and Thompson, 2002).

We further conducted subgroup analyses by region (south vs. north region), sex, and age. The statistical significance of differences among subgroups was tested using a Z-test (Altman and Bland, 2003). In addition, we investigated effect modification of the associations between air pollution and daily hospital admissions by cities' gross domestic product (GDP) per capita, mean temperatures, relative humidity, and air pollutants concentrations during the study periods using meta-regression models with city-specific relative risk as the outcome variable.

To assess the potential public health impacts of our risk estimates, the annual reduction in hospital admissions (H) attributable to a 10-$\mu g/m^3$ reduction in PM_{10}, SO_2, and NO_2, and a 1-mg/m^3 reduction in CO concentrations in China was calculated (Dominici et al., 2006a). H was estimated based on the following equation: $H=(\exp(\beta)-1) \times N$, where β is the national-average estimate for a 10 $\mu g/m^3$ increase in PM_{10}, SO_2, and NO_2 and for a 1 mg/m^3 increase in CO. Due to the lack of data on the number of hospital admissions aged larger than 18 years, the overall hospital admissions in China in 2016 was defined as N.

Finally, we conducted three sensitivity analyses to examine the robustness of the associations between air pollutants and daily