Original Article

Daily Visibility and Hospital Admission in Shanghai, China*

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Abstract

Objective The study is to investigate the associations between visibility, major air pollutants and daily counts of hospital admission in Shanghai, China.

Methods Daily data on hospital admission, visibility, and air pollution during 2005-2008 were obtained from the Shanghai Insurance Bureau (SHIB), Shanghai Meteorological Bureau, and Shanghai Environmental Monitoring Center, respectively. The generalized additive model (GAM) with penalized splines was used to examine the associations between daily visibility and hospital admission.

Results Among various pollutants, $PM_{2.5}$ showed strongest correlation with visibility. Decreased visibility was significantly associated with increased risk of hospital admission in Shanghai. An inter-quartile range decrease in the 2-day (L01) moving average of visibility corresponded to 3.66% (95%CI: 1.02%, 6.31%), 4.06% (95%CI: 0.84%, 7.27%), and 4.32% (95%CI: 1.67%, 6.97%) increase of total, cardiovascular, and respiratory hospitalizations, respectively.

Conclusion Our analyses provide the first piece of evidence in China, demonstrating that decreased visibility has an effect on hospital admission, and this finding strengthens the rationale for further limiting air pollution levels in Shanghai.

Key words: Air pollution; Hospital admission; Visibility

Biomed Environ Sci, 2011; 24(2):117-121 doi:10.3967/0895-3988.2011.02.005 ISSN:0895-3988

www.besjournal.com(full text) CN: 11-2816/Q

INTRODUCTION

Visibility refers to the clarity or transparency of the atmosphere and the ability to see distant objects[1]. Environmental studies have found that particulate matter (PM) and gaseous pollutants in the air can scatter or absorb light, and therefore reduce the visibility. From 1973 to 2007, visibility had decreased substantially over land globally except in Europe[2]. In the Asian region, dozens of studies have reported a severe decline in visibility, to which particulate matter (PM), especially fine particles ($PM_{2.5}$, particulate matter with aerodynamic diameter less than 2.5 μm), was found to be the major contributor[3-5].

Visibility data are routinely collected at airports or meteorology stations throughout the world, and thus available for interpolation of missing pollutant measurements in developing countries. It is reasonable to make a hypothesis that visibility can be used as a surrogate of the air pollution level assessing the health effects in places where routine air monitoring is not available[6-7].

Although three studies have explored the association of visibility loss with mortality[6-8], no prior study examines its relationship with morbidity outcomes. We hypothesized that visibility loss, as an indicator of decreased air quality, might be associated with increased risk of hospital admission and we used daily visibility and hospital admission

*This study was funded by the National Basic Research Program (973 program) of China (2011CB503802), Gong-Yi Program of China Ministry of Environmental Protection (200809109), National Natural Science Foundation of China (30800892), Shanghai Pu Jiang Program (09PJ1401700), Program for New Century Excellent Talents in University (NCET-09-0314), and National High Technology Research and Development Program of China (863 Program) (2007AA06Z409).

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Received: July 6, 2010; Accepted: November 8, 2010

data in Shanghai, China, to test the hypothesis.

MATERIALS AND METHODS

Data

Daily hospital admission counts of residents living in the nine urban districts from January 1, 2005 to December 31, 2008 (1 461 days) were collected from the database of Shanghai Health Insurance Bureau (SHIB). SHIB is the government agency in charge of the Shanghai Health Insurance System. The Shanghai Health Insurance System, which provides compulsory universal health insurance, covers most of the fixed residents in Shanghai (and the coverage rate was 95% in 2008). In Shanghai, all hospitals are contracted with the SHIB. Computerized records of daily hospital admissions are available for each contracted hospital. All hospitals must submit standard claim documents for medical expenses on a computerized form that includes the date of admission and discharge, identification number, gender, birthday, and the diagnostic for each admission. Therefore, the information from the SHBI database appears to be sufficiently complete and accurate for use in epidemiological studies, and was successfully used to examine the short-term association between concentrations of air pollutants and morbidity outcomes in Shanghai[9]. The causes of hospital admission were coded according to International Classification of Diseases, Revision 10 (ICD 10): all non-accidental causes (A00-R99), cardiovascular diseases (I00-I99), and respiratory diseases (J00-J98).

Like previous visibility studies in Shanghai[6] and Hong Kong[7], daily visibility data in our analysis were measured at a fixed-site monitoring station in Baoshan District of Shanghai. The digital photo visibility system (DPVS) was installed about 3 m above ground, monitoring the real time atmospheric visibility.

Air pollution data, including $PM_{2.5}$, PM_{10} (particulate matter with aerodynamic diameter less than 10 μm), $PM_{10-2.5}$ (particulate matter with aerodynamic diameter between 10 and 2.5 μm), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and ozone (O_3), were obtained from the database of the Shanghai Environmental Monitoring Center, the government agency in charge of monitoring air pollution conditions in Shanghai. $PM_{10-2.5}$ concentrations were calculated by subtracting $PM_{2.5}$ from PM_{10}. We extracted the daily 24-h average concentrations for $PM_{2.5}$, $PM_{10-2.5}$, PM_{10}, SO_2, and NO_2, and an 8-h average concentration for O_3. To ensure the representativeness of the 24-h data on each day, estimates were based on at least 75% of the hourly values on that particular day; and for O_3, at least six hourly values from 10 A.M. to 6 P.M. should be valid.

Considering the potential effects of weather conditions on hospital admission, we also obtained the temperature and relative humidity data from the Shanghai Meteorological Bureau.

Statistical Methods

We calculated the Spearman correlation coefficients of visibility with air pollutants, including $PM_{2.5}$, $PM_{10-2.5}$, SO_2, NO_2, and O_3, to reveal the major contributors to visibility degradation in Shanghai.

The daily visibility and hospital admission data are linked by date and therefore can be analyzed with a time-series design. By design, time-series studies examine the same population repeatedly under varying exposure conditions, and thus, time-invariant characteristics, such as age and cigarette smoking, are no longer a potential confounder[10]. This is a key advantage of the time-series approach. We used a generalized additive model (GAM) with penalized splines to analyze the hospital admission, visibility, and covariate data. Because daily counts of hospital admission typically follow a Poisson distribution, a GAM with log link and Poisson error that accounted for smooth fluctuations in daily counts of hospital admission was used in the core analysis.

We first built basic models for daily hospital admission. We incorporated smoothed spline functions of time, which can accommodate nonlinear and non-monotonic patterns (e.g. long-term and seasonal trend) between hospital admission and time, offering a flexible modeling tool. Day of the week was included as dummy variable in the basic models. We used the partial autocorrelation function (PACF) to guide the selection of model parameters. We used 4-6 degrees of freedom (df) per year for time trend. If the absolute magnitude of the PACF plot was less than 0.1 for the first two lag days, the basic model was considered adequate[11]; otherwise, auto-regression (AR) terms for lag up to 7 days were introduced to improve the model. Residuals of the basic models were examined to check whether there were discernable patterns and autocorrelation by means of residual plots and PACF plots.

After basic models were established, we

introduced visibility in the regression models, and analyzed its association with hospital admission. We used 3 df for temperature and humidity, which were proved to be controlled well for their effects on health outcomes[12].

Both total non-accidental and cause-specific hospital admissions were assessed. We examined the effect of air pollutants with different lag (L) structures including both single-day lag (from L0 to L5) and multi-day lag (L01 and L05). For example, in single-day lag models, a lag of 0 day (L0) corresponds to the current-day pollutant concentration, and a lag of 1 day (L1) refers to the previous-day concentration; in multi-day lag models, L01 corresponds to a 2-day average of pollutant concentration of the current and previous day, and L05 corresponds to a 6-day average of pollutant concentration of the current and previous 5 days.

All analyses were conducted in R 2.10.1 software by using the MGCV package. The regression results are presented as the percent change in daily hospital admission per inter-quartile range decrease in air visibility (7 km).

RESULTS

From January 1, 2005 to December 31, 2008, a total of 2 377 846 hospital admissions were recorded. On average, there were approximately 1 628 hospital admissions per day in Shanghai, among which 359 were due to cardiovascular diseases and 126 were due to respiratory disease (Table 1). During our study period, the mean visibility in Shanghai was 16.6 km in distance.

Table 2 shows the Spearman correlation between visibility and air pollutants. Visibility was found strongly and negatively correlated with $PM_{2.5}$ (correlation coefficient, r=-0.62), moderately correlated with PM_{10} (r=-0.49), NO_2 (r=-0.52), and slightly correlated with $PM_{10-2.5}$ (r=-0.23), SO_2 (r=-0.27), and O_3 (r=0.17).

Table 3 shows results from the single-lag day (L0-L5) and cumulative exposure models (L01 and L05) for the percent increase in hospital admission per inter-quartile range decrease of visibility. The effect estimates varied with different lag structures of visibility. Statistically significant relationships were observed for total hospital admission with visibility at single-day lag 0 and 1, and multi-day lag 01. Cardiovascular hospital admission was significantly associated with visibility at multi-day lag 01. Respiratory hospital admission was significantly associated with visibility at single-day lag 0 and 1, and multi-day lag 01 and 05. An inter-quartile range decrease in the 2-day (L01) moving average of visibility corresponded to 3.66% (95%CI: 1.02%, 6.31%), 4.06% (95%CI: 0.84%, 7.27%), and 4.32% (95%CI: 1.67%, 6.97%) increase of total, cardiovascular, and respiratory hospital admission, respectively.

Table 1. Summary Statistics of Daily Hospital Admission, Visibility, Air Pollutant Concentrations, and Weather Conditions in Shanghai, 2005-2008

	$\bar{X} \pm S$	Min	P(25)	Median	P(75)	Max
Daily Hospital Admission						
Total	1627.5 ± 693.2	126.0	1258.0	1797.0	2080.0	4921.0
Cardiovascular	359.4 ± 168.8	13.0	271.0	387.0	471.0	1077.0
Respiratory	126.2 ± 56.7	8.0	97.0	138.0	161.0	336.0
Visibility (km)	16.6 ± 5.4	2.0	13.0	16.0	20.0	32.0
Air pollutants Concentrations (μg/m^3)						
$PM_{2.5}$	55.4 ± 35.8	5.0	30.0	48.0	72.0	389.0
$PM_{10-2.5}$	43.0 ± 33.0	5.0	23.0	34.5	53.0	490.0
PM_{10}	97.6 ± 59.2	15.0	56.0	86.0	123.0	632.0
SO_2	55.8 ± 29.7	8.0	33.0	51.0	72.0	223.0
NO_2	63.0 ± 23.6	13.0	47.0	60.0	76.0	167.0
O_3	66.3 ± 39.0	5.0	37.0	59.0	89.0	225.0
Weather Conditions						
Temperature (°C)	17.7 ± 9.1	-3.2	10.0	18.8	25.3	33.8
Humidity (%)	69.8 ± 11.9	31.0	63.0	70.0	78.0	95.0

Table 2. Correlation Coefficients between Visibility and Air Pollutant Concentrations in Shanghai, 2005-2008

	$PM_{2.5}$	$PM_{10-2.5}$	PM_{10}	SO_2	NO_2	O_3
Visibility	-0.62	-0.23	-0.49	-0.27	-0.52	0.17
$PM_{2.5}$	1	0.61	0.92	0.66	0.72	0.14
$PM_{10-2.5}$		1	0.86	0.70	0.67	0.12
PM_{10}			1	0.76	0.76	0.16
SO_2				1	0.74	0.09
NO_2					1	-0.03

Table 3. Percent Increase of Hospital Admission of Shanghai Residents per Inter-quartile Range Decrease of Visibility, 2005-2008

Lag (L)	Total Hospital Admission	Cardiovascular Hospital Admission	Respiratory Hospital Admission
L0	3.19 (0.27,6.11)*	3.11 (-0.50,6.71)	3.67 (0.74,6.64)*
L1	2.61 (0.04,5.19)*	3.07 (-0.04,6.19)	3.10 (0.51,5.70)*
L2	-0.44 (-3.10,2.22)	-0.16 (-3.41,3.09)	0.95 (-1.71,3.60)
L3	0.30 (-2.37,2.96)	0.13 (-3.15,3.41)	1.17 (-1.53,3.86)
L4	-1.03 (-3.71,1.64)	-0.96 (-4.24,2.32)	0.85 (-1.86,3.56)
L5	-0.66 (-3.33,2.02)	-1.09 (-4.40,2.22)	-0.27 (-3.00,2.45)
L01	3.66 (1.02,6.31)*	4.06 (0.84,7.27)*	4.32 (1.67,6.97)*
L05	1.45 (-1.65,4.55)	1.38 (-2.41,5.18)	3.64 (0.55,6.72)*

Note. *$P<0.05$.

DISCUSSION

Findings from our study showed that decreased visibility was associated with both total and cardiopulmonary hospital admission in Shanghai in 2005-2008. To our knowledge, this is the first study assessing the association between visibility and morbidity outcomes. Moreover, published data on the correlations between visibility and air quality are quite limited in China. Among various air pollutants, we found strongest correlation of visibility with $PM_{2.5}$, which is consistent with prior studies showing that visibility had higher correlation with smaller particles[13]. Therefore, our findings support the use of visibility as a surrogate of air quality in health research in developing countries, whereas visibility data are collected routinely.

Previously, there were only three studies examining associations between visibility loss and adverse health effects worldwide[6-8]. Huang et al. reported that variations in daily mortality were associated with fluctuations in visibility levels in Shanghai[6]. Similarly, Thatch et al. reported statistically significant association between visibility loss and daily mortality in Hong Kong[7]. Knobel et al. found that visibility loss was directly associated with sudden infant death syndrome in Taiwan[8]. However, there have been no prior studies reporting the association of visibility with morbidity outcomes. Hence, our study provides further evidence supporting coherence of the short-term association of visibility with adverse health effects.

The health effects of visibility implicated different lag structures for various morbidity outcomes in our study (Table 3), which is consistent with other air pollution morbidity studies in the Asian region[14]. It should be noted that we observed statistically significant associations for some, but not all, lag structures of visibility. Further research is needed to clarify the lag structure and magnitude of such effects. Different causes for cardiovascular and respiratory hospital admission may account for the various effect estimates and lag patterns of visibility on these two morbidity outcomes.

The limitations of our study should be noted. First of all, the chemical composition is hypothesized to affect the role of small particle in atmospheric visibility[15]. Our analyses did not involve chemical composition assessment of particles in Shanghai, which may be critical in interpreting the correlation between visibility and particles, and therefore in explaining the uncertainties of using visibility as a surrogate of air pollution in health research. Secondly, as in other time-series studies, we used routinely collected outdoor monitoring data to represent the population exposure to air pollution. The potential exposure misclassification may have implications for interpreting the effect of air pollutants[16]. Thirdly, our assessment of visibility and air pollution was derived entirely from one monitoring station. Compared with studies in Europe and North America, data collected in this study were limited by virtue of the single city and limited monitoring time period. This may have limited our power to detect significant associations with health outcomes.

In summary, visibility loss was associated with increased risk of hospital admission in Shanghai. Further research will be therefore needed to gain insights into the modification of individual socio-demographic characteristics and season on visibility loss-related health effects. Our analyses prove that the current visibility level has an adverse health effect and helps strengthen the rationale for further improvement of visibility in Shanghai.

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