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RESEARCH ARTICLE

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The effects of particulate matters on allergic rhinitis in Nanjing, China

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Abstract

Particulate matter pollution is a serious environmental problem. Individuals exposed to particulate matters have an increased prevalence to diseases. In the present study, we performed an epidemiological study to investigate the effects of particulate matter less than 10 μm in aerodynamic diameter (PM_{10}) and particulate matter less than 2.5 μm in aerodynamic diameter ($PM_{2.5}$) on allergic rhinitis in Nanjing, China. Daily numbers of allergic rhinitis patients (33,063 patients), PM_{10}, $PM_{2.5}$, and weather data were collected from January 2014 to December 2016 in Nanjing, China. Generalized additive models (GAM) were used to evaluate the effects of PM_{10} and $PM_{2.5}$ on allergic rhinitis. We found that the interquartile range (IQR) increases in PM_{10} (difference of estimates, 5.86%; 95% CI, 3.00–8.81%; $P = 4.72 \times 10^{-5}$) and $PM_{2.5}$ (difference of estimates, 5.39%; 95% CI, 2.73–8.12%; $P = 5.67 \times 10^{-5}$) concentrations were associated with the higher increased numbers of allergic rhinitis patients with 3-day cumulative effects in single-pollutant model. In addition, we found that the IQR increase in PM_{10} (age ≥ 18 years: 7.37%, 3.91–10.96%, 2.14×10^{-5}; 0–17 years: 0.83%, −4.00–5.91%, 0.740) and $PM_{2.5}$ (age ≥ 18 years: 7.00%, 3.78–10.32%, 1.40×10^{-5}; 0–17 years: 0.40%, −4.10–5.10%, 0.866) increased the number of allergic rhinitis patients in adults, but not in children. In summary, our findings suggested that exposure to PM_{10} and $PM_{2.5}$ was associated with the risk of allergic rhinitis.

Keywords PM_{10} · $PM_{2.5}$ · Allergic rhinitis · Cumulative effect

Introduction

Air pollution is the important environmental problem in the world. With the development of economy and urbanization in China, the air quality is getting worse with the increased emission of air pollution since 2000 (Wang et al. 2017). At present, we monitor the concentrations of six air pollutants, including particulate matter less than 10 μm in aerodynamic diameter (PM_{10}), particulate matter less than 2.5 μm in aerodynamic diameter ($PM_{2.5}$), nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), and ozone (O_3). Among the six air pollutants, PM_{10} and $PM_{2.5}$ are the important components, and the major sources are industry, traffic, burning, and so on.

Accumulated evidences also have proposed that exposure to PM_{10} and $PM_{2.5}$ can induce the disease morbidity and mortality, mainly involving the respiratory and cardiovascular system (Ji et al. 2018; Li et al. 2015). Studies demonstrate that PM_{10} can induce the physical damage to the alveolus and larynx (Atkinson et al. 2010). The aerodynamic diameter of $PM_{2.5}$ is less than PM_{10}, which may lead to chemical damage besides physical damage (Atkinson et al. 2010). Inhalation of particulate matter can induce the toxicity effect including inflammation and oxidative stress (Kim et al. 2017). Accumulative studies have revealed that air particulate matter can affect the respiratory system, leading to allergic rhinitis, asthma, pneumonia, and so on (Jansen et al. 2005; Molter et al. 2014; Wang et al. 2016).

Haiyan Chu and Junyi Xin contributed equally to this work.

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In the respiratory system, allergic rhinitis is a common cause of other health conditions including sinusitis, otitis media, asthma, and hypertension (Bousquet et al. 2001). However, we noticed that most studies focused on evaluating the association between particulate matters and asthma, pneumonia, chronic obstructive pulmonary disease, and there were relatively few studies involved in allergic rhinitis (Chen et al. 2016; Deng et al. 2016; He et al. 2017). Allergic rhinitis is an important public health problem, which can affect the life quality and increase the health care burden (Tripathi and Patterson 2001). Particulate matters can induce the inflammation of nasal airway by mediating the response to nasal allergen (Peden 2001). A latest research enrolled 30,759 children and demonstrated that $PM_{2.5}$ could increase the prevalence of allergic rhinitis, and the children that lived in non-urban had the higher risk of rhinitis than those that lived in urban (Chen et al. 2018). Teng et al. also found that particulate matters (PM_{10} and $PM_{2.5}$) were positively associated with allergic rhinitis risk (including children and adults) in Changchun, China (Teng et al. 2017). However, contradictory findings have been found for particulate matters in other studies (Hwang et al. 2006; Liu et al. 2013).

Particulate matter is complex and consisted of mineral dust, trace elements, organic carbon, ammonium, sulfates, nitrates, and water. The composition and concentration of particulate matter has a difference in different countries or cities. Although some epidemiological studies have investigated the effect of particulate matter in some areas, limited study focused on allergic rhinitis in Nanjing, China. Nanjing is the capital of Jiangsu province, and the average concentration of particulate matter is higher than the national levels. In the present study, we evaluated the effects of particulate matters (PM_{10} and $PM_{2.5}$) on allergic rhinitis in Nanjing.

Materials and methods

Air pollution and hospital data

Nanjing is the capital city of Jiangsu Province. In this study, through China Environmental Monitoring Centre, we collected the air pollutants data (PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, and O_3) of Nanjing City during the period of 28 January 2014 to 30 December 2016. Additionally, we also obtained the daily weather data (mean temperature and relative humidity) from the Meteorological Bureau. At the same time, we collected the information of daily allergic rhinitis patients' data from the First Affiliated Hospital of Nanjing Medical University. A person with symptoms of sneezing, or a running, itchy, or blocked nose without a cold or flu was defined as an allergic rhinitis patient. We diagnosed allergic rhinitis according to medical history, clinical symptoms, and the relevant test (skin prick test and serum allergen–specific IgE assay). This study was approved by the institutional review board of Nanjing Medical University.

Statistical analysis

The time-series regression model was applied to evaluate the association between air pollutants and allergic rhinitis, and generalized additive model (GAM) was used to analyze the data (Dominici et al. 2006; Wang et al. 2013). In order to remove unmeasured long-term and seasonal trends, a natural cubic smooth function of calendar time with 7 degrees of freedom (df) yearly was included in the model (Peng et al. 2005). Additionally, we chose the natural smooth functions of the current-day mean temperature (3 df) and relative humidity (3 df) to control the potential weather confounding effects (Yang et al. 2013). In the GAM, we also used the "day of week (DOW)" as the indicator variable.

Herein, single-pollutant model was used to investigate each air pollutants' effect on allergic rhinitis with single lag days (lag0, 1, 2, 3). In additional analyses, we also considered to analyze the cumulative effects with average exposure of multiple days (lag0–1, 0–2, 0–3) to control the possible misalignment of a single lag day exposure. It was worth to note that season, sex, and age might influence the effects of air pollutants on allergic rhinitis. Thus, we stratified the effects of air pollutants on allergic rhinitis according to season (warm: May to October; cool: last November to April), sex (male; female), and age (< 18; ≥ 18). Finally, two-pollutant model was conducted to detect the stability of results with the adjustment of co-pollutants.

In this study, R software (version 3.4.1) with mgcv package was applied in all models. The percentage change and 95% confidence intervals (CIs) showed that the effect estimates of interquartile range (IQR) increased air pollutant concentration and daily allergic rhinitis patients. All tests were two-sided, and we considered $P < 0.05$ as statistically significant.

Results

Data of air pollutants and allergic rhinitis patients

In this study, we summarized the information of air pollutants (PM_{10}, $PM_{2.5}$, NO_2, SO_2, CO, and O_3) and weather conditions (mean temperature and relative humidity) during 28 January 2014 to 30 December 2016 (Supplementary Table 1). Results showed the daily mean concentrations of air pollutants (PM_{10}, 98.9 $\mu g/m^3$; $PM_{2.5}$, 57.3 $\mu g/m^3$; NO_2, 47.1 $\mu g/m^3$; SO_2, 18,9 $\mu g/m^3$; CO, 1.0 mg/m^3; O_3, 79.0 $\mu g/m^3$). The daily mean temperature and relative humidity were 16.8 °C and 74.4%. We found that PM_{10} and $PM_{2.5}$ were both positively correlated with other air pollutants ($r > 0$), and negatively correlated with weather conditions ($r < 0$, Supplementary Table 2).

Table 1 Basic information of allergic rhinitis patients

Variables	Numbers[a] ($n = 33{,}063$)	Percent
Sex		
Male	17,984	54.39%
Female	15,073	45.59%
NA	6	0.02%
Age (mean ± SD)	31.76 ± 20.21	
Age		
< 18 years	10,072	30.46%
≥ 18 years	22,984	69.52%
NA	7	0.02%

[a] Some information was missing (i.e., NA)

We included 33,063 allergic rhinitis patients in this study (Table 1), among which there were 17,984 male and 15,073 female patients (sex unknown, 6 counts). In addition, of the total allergic rhinitis patients (age unknown, 7 counts), 30.5% (10,072 counts) were children (age < 18 years), and 69.5% (22,984 counts) were adults (age ≥ 18 years).

The effect estimates of air pollutants on daily allergic rhinitis patients

For lag0–2, we found that the estimated greatest cumulative effect of PM_{10} (difference of estimates, 5.86%; 95% CI, 3.00–8.81%; $P = 4.72 \times 10^{-5}$) and $PM_{2.5}$ (difference of estimates, 5.39%; 95% CI, 2.73–8.12%; $P = 5.67 \times 10^{-5}$) was associated with the increased numbers of allergic rhinitis patients (Fig. 1).

Season, sex, and age might influence the effects of PM_{10} and $PM_{2.5}$ on numbers of allergic rhinitis patients. In the further study, we investigated the estimated effect stratified by season, sex, and age. Table 2 suggests that the estimated effects of PM_{10} on the numbers of allergic rhinitis patients in adults (age ≥ 18 years; 7.37%, 3.91–10.96%, 2.14×10^{-5}) were stronger than those in children (0–17 years; 0.83%, −4.00–5.91%, 0.740). We found similar results in $PM_{2.5}$ (age ≥ 18 years: 7.00%, 3.78–10.32%, 1.40×10^{-5}; 0–17 years: 0.40%, −4.10–5.10%, 0.866). In the stratification of season, we noticed that PM_{10} (warm: 9.17%, 5.06–13.44%, 7.32×10^{-6}; cool: 3.24%, −0.74–7.39%, 0.112) and $PM_{2.5}$ (warm: 6.76%, 2.79–10.87%, 7.07×10^{-4}; cool: 3.19%, −0.25–6.75%, 0.070) were both significantly associated with increased risk of allergic rhinitis patients in warm season. When stratified by sex, we found significant associations between the effects of PM_{10}, $PM_{2.5}$, and the numbers of allergic rhinitis patients among male and female individuals.

Two-pollutant model also was used in this study (Table 3). For lag0–2, when adjusted for $PM_{2.5}$, NO_2, or SO_2, we did not find the significant cumulative effect of PM_{10} on the numbers of allergic rhinitis patients in two-pollutant model; however, the effect of PM_{10} remained significant after adjustment for CO or O_3. Similarly, when adjusted for PM_{10}, NO_2, or SO_2, we also did not observe the significant association between $PM_{2.5}$ and the numbers of allergic rhinitis patients in two-pollutant model, but the effect of $PM_{2.5}$ was still significant with the adjustment of CO or O_3.

Discussion

At present, air particulate matter has become the main air pollutants worldwide. Generally, air particulate matter can be divided into several kinds of particulate matter, according to its aerodynamics diameter. Among different particulate matters, PM_{10} and $PM_{2.5}$ have been reported to have a greater effect on human health. Studies demonstrated that PM_{10} can induce physical damage to the alveolus and larynx, and $PM_{2.5}$ may lead to more serious chemical damage besides physical damage (Atkinson et al. 2010). Moreover, accumulative

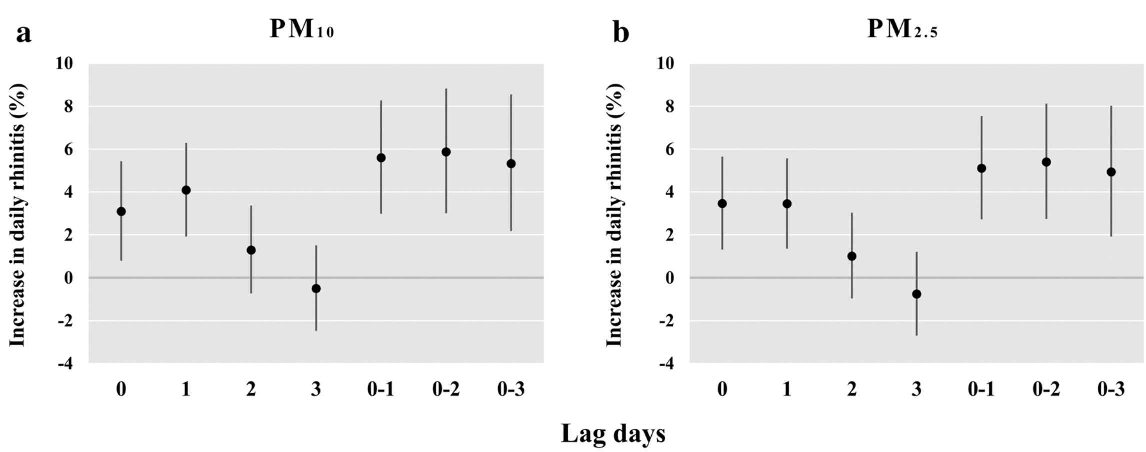

Fig. 1 Estimated changes with 95% confidence intervals in daily rhinitis percentage deviations (%) associated with an IQR increase in PM_{10} (**a**) and $PM_{2.5}$ (**b**) concentrations with different lag days in single-pollutant model

Table 2 Estimated changes with 95% confidence intervals in daily allergic rhinitis percentage change (%) associated with an interquartile range increase in PM_{10} and $PM_{2.5}$ concentrations (lag0–2 days) by stratifications using the single-pollutant model

Variables		PM_{10}		$PM_{2.5}$	
		Percent change, % (95% CI)	*P* value	Percent change, % (95% CI)	*P* value
Season	Warm	9.17 (5.06, 13.44)	7.32E−06	6.76 (2.79, 10.87)	7.07E−04
	Cool	3.24 (− 0.74, 7.39)	0.112	3.19 (− 0.25, 6.75)	0.070
Sex	Male	4.56 (0.8, 8.46)	0.017	4.10 (0.61, 7.71)	0.021
	Female	6.14 (1.91, 10.54)	0.004	5.55 (1.63, 9.61)	0.005
Age	0–17 years	0.83 (− 4.00, 5.91)	0.740	0.40 (− 4.10, 5.10)	0.866
	≥ 18 years	7.37 (3.91, 10.96)	2.14E−05	7.00 (3.78, 10.32)	1.40E−05

studies have revealed that air particulate matter can induce several respiratory system diseases, such as allergic rhinitis, asthma, and pneumonia (Jansen et al. 2005; Molter et al. 2014; Wang et al. 2016). Therefore, we performed this epidemiological study to further evaluate the effects of particulate matters (PM_{10} and $PM_{2.5}$) on allergic rhinitis risk.

In this study, we evaluated the association between air particulate matter (PM_{10} and $PM_{2.5}$) concentration levels and the numbers of daily allergic rhinitis patients. Results suggested that the estimated cumulative effect of PM_{10} and $PM_{2.5}$ was both associated with the increased daily numbers of allergic rhinitis patients with 3-day cumulative effects (lag0–2), especially among adult patients. Our finding was consistent with the published studies (Jo et al. 2017; Teng et al. 2017). For instance, Zhang et al. (2011) also found that higher concentration of PM_{10} could increase the risk of allergic rhinitis among adult patients. In fact, relative to adult individual, children are more susceptible to develop the respiratory symptoms, when exposed to air particulate matters (Miller et al. 2002; Ng'Ang'a et al. 1998). It was possible that we collect information about allergic rhinitis patients in a general hospital (the First Affiliated Hospital of Nanjing Medical University), and induce a lower number of children allergic rhinitis patients and the bias among children. Recent study reported that PM_{10} was associated with the hospital admissions of allergic rhinitis (Jo et al. 2017). A study from Changchun (China) also showed that PM_{10} was significantly associated with the prevalence of allergic rhinitis (Teng et al. 2017). In addition, we noticed that several studies focused on investigating the estimated effects of PM_{10} on rhinitis patients among children (Chen et al. 2016; Deng et al. 2016; He et al. 2017). For example, a sequential cross-sectional study proposed that exposure to traffic-related PM_{10} was associated with the increased risk of rhinitis among 8–9-year-old children (Wood et al. 2015). However, Liu et al. did not observe the effects of outdoor and indoor PM_{10} on allergic rhinitis among Chinese children (Liu et al. 2013), and the finding was similar to our results.

Several studies had demonstrated that season was the important factor involved in evaluating the estimated effects of air pollutants on population health (Chou et al. 2017; Gu et al. 2017). In the study, we found that PM_{10} and $PM_{2.5}$ were significantly associated with increased risk of allergic rhinitis patients in warm season. Similarly, when stratified by sex, we observed the significant association between PM_{10}, $PM_{2.5}$, and allergic rhinitis patients among male and female subjects; however, higher allergic rhinitis risk was shown in female. The result was consistent with previous study (Zhang et al. 2011), which indicated that female may be more sensitive to PM_{10} than male. We should consider some limitations in our study. Firstly, we merely collected the average data of daily air particulate matter data (PM_{10} and $PM_{2.5}$) in Nanjing. We could not evaluate the effect of individual air particulate matter exposure on allergic rhinitis. Secondly, individual lifestyle and other factors (such as seasonal pollen) can influence the occurrence of allergic rhinitis (Samitas et al. 2017). Thus, when detecting the association between air particulate matter and numbers of allergic rhinitis patients, we needed to adjust the effects of individual lifestyle and other factors. In the further study, we should collect the detailed information of

Table 3 Estimated changes with 95% confidence intervals in daily allergic rhinitis percentage change (%) associated with an interquartile range increase in PM_{10} and $PM_{2.5}$ concentrations (Lag0–2 days) in two-pollutant model

Air pollutants	Models	Percent change, % (95% CI)	*P* value
PM_{10}	Single	5.86 (3.00, 8.81)	4.72E−05
	+ $PM_{2.5}$	3.41 (− 2.75, 9.97)	0.285
	+ NO_2	− 0.26 (− 3.78, 3.38)	0.885
	+ SO_2	0.48 (− 3.03, 4.12)	0.792
	+ CO	5.00 (0.92, 9.25)	0.016
	+ O_3	6.01 (2.93, 9.18)	1.04E−04
$PM_{2.5}$	Single	5.39 (2.73, 8.12)	5.67E−05
	+ PM_{10}	2.48 (− 3.22, 8.52)	0.401
	+ NO_2	0.77 (− 2.28, 3.92)	0.625
	+ SO_2	1.70 (− 1.26, 4.75)	0.264
	+ CO	4.78 (0.67, 9.06)	0.022
	+ O_3	5.45 (2.62, 8.36)	1.30E−04

allergic rhinitis patients, including individual outdoor and indoor particulate matter, seasonal pollen exposure, and other air pollutants exposure.

In conclusion, this study indicated that short-term exposure to PM_{10} and $PM_{2.5}$ was associated with the increased numbers of allergic rhinitis patients among adults, in Nanjing. Consistent with the similar studies conducted in other areas, our results provided more evidences for confirming the adverse effects of particulate matters on human health. Further studies about the effects of air particulate matters on the respiratory system (e.g., allergic rhinitis) may be warranted.

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Compliance with ethical standards This study was approved by the institutional review board of Nanjing Medical University.

Conflict of interest The authors declare that they have no conflict of interest.

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