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Original Article

Influence of air pollution and wind chill on hospital admissions for COPD exacerbation in Fengxian District, Shanghai

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Abstract: Chronic obstructive pulmonary disease (COPD) is one of the leading causes of morbidity and mortality worldwide. Among the possible triggers for acute exacerbation of COPD (AECOPD), air pollution and meteorological factors are under consideration. The study aimed to investigate the influence of outdoor air pollution and wind chill on COPD exacerbation. For this purpose, weekly hospital admissions were collected for AECOPD modified by disease severity in Fengxian District, Shanghai, China for the years 2004-2009. Data of air pollutants including sulfur dioxide (SO_2), nitrogen dioxide (NO_2), inhalable particulate matter (PM_{10}), and meteorological factors including temperature, wind speed, and wind chill index (WCI) were obtained from central weather monitoring and local meteorology station. In stepwise regression models, daily average SO_2 and WCI showed influences on weekly hospital admissions for moderate, severe, very severe, or multi-severity AECOPD. The effect of SO_2 was stronger for very severe COPD admissions while WCI was for moderate COPD admissions. However, the effects of PM_{10} and NO_2 were not observed in the above correlation. In conclusion, air pollutants and wind chill have significant impacts on AECOPD.

Keywords: Air pollution, wind chill, chronic obstructive pulmonary disease, exacerbation, hospital admission

Introduction

Chronic obstructive pulmonary disease (COPD) is characterized by persistent respiratory symptoms and airflow limitation, which are often associated with enhanced chronic inflammatory responses in the airway and lung [1, 2]. The disease is a leading cause of morbidity and mortality worldwide, which severely weakens personal and public health [3, 4]. According to the report released by the Forum of International Respiratory Societies, an estimated 200 million people suffer from COPD and 65 million from moderate-to-severe COPD worldwide [5]. In China, COPD cases increased dramatically from 32.4 million in 1990 to 54.8 million in 2013, provided by a subnational analysis from the Global Burden of Disease Study 2013 [6]. The overall prevalence of the disease among the population aged 40 years or older was 7.3% [6]. Another stratified meta-analysis of studies published in 1990 and 2014 showed that the prevalence of COPD in Chinese rural area was 9.6% [7]. Disability-adjusted life years (DALYs) is an indicator to measure the overall disease burden. It is predicted that COPD would rise from the 13th-highest cause of DALYs in 2002 to the 7th-highest in 2030 around the world [3]. Although the age-standardized death rate for COPD decreased by 50.3% over the past two decades, it still ranked the fourth cause of DALYs in 2013 in China, higher than the corresponding worldwide ranking [6].

Environmental pollutants not only are the risk factors of COPD [8-10] but also may trigger its exacerbation associated with faster decline in lung function, worse quality of life, increased risk of hospitalization, and greater mortality [11, 12]. A series of studies have been conducted to assess the effects of air pollution on COPD, which reveal that pollutants increase its morbidity, exacerbation, emergency room visits, hospital admissions and mortality [13-17].

With rapid development of the mainland Chinese economy, environmental pollution is becoming a more and more prominent issue. However, there are rare studies focusing on the influence of air pollution on hospital admissions for COPD exacerbation in mainland China [18-20].

Previous studies have demonstrated that a drop in temperature is often associated with decreased lung function, increased exacerbation rate, as well as increased hospital or emergency room admissions for patients with COPD, especially for elderly patients [21-25]. Another study showed that diurnal temperature range is a risk factor for acute COPD death [26]. However, the effect of weather on the thermal balance of the human body is determined not only by ambient conditions but also by other meteorological factors such as wind speed. It is well known that the faster the wind blows, the faster the human body loses heat and feels cold. Wind chill index (WCI) is used to evaluate the combined effect of temperature and wind speed on heat loss of the human body [27]. A prior study showed that WCI is a better marker than temperature alone for assessing cold-related health problems [28]. To our knowledge, there have been no studies to date using WCI to estimate the effect of weather on COPD.

The aim of this study was to investigate the influence of outdoor air pollution and wind chill on hospital admissions for COPD exacerbation in Fengxian District, which is located in the south of Shanghai, China. Agriculture was the main industry of Fengxian District in the past. However, along with the rapid industrialization and urbanization, environmental pollution is becoming more and more troublesome in the district. Even in rural areas of Fengxian District, farmers seldom rely on solid fuels for domestic energy. Therefore, we only paid attention to outdoor air pollution. Moreover, Fengxian District is situated in the East China Seaside, which is always affected by the strong wind, so we used WCI as a marker to assess the effect of weather on COPD.

Materials and methods

Participants

The study population was a cohort of 1191 COPD patients who requested medical services and were hospitalized in Fengxian District Central Hospital, Shanghai. This cohort was retrospectively collected from March 29th, 2004 to August 2nd, 2009 for investigation of COPD exacerbation. All patients enrolled here met the following inclusion criteria: (a) The first diagnosis for hospitalization was acute exacerbation of COPD (AECOPD); (b) Hospitalization due to AECOPD conformed to the principal diagnosis of COPD and the definition of AECOPD from Global Initiative for Chronic Obstructive Pulmonary Disease (GOLD) [29]; (c) Resided and worked in the study area of Fengxian District; (d) Underwent the lung function tests after symptoms were alleviated.

Lung function test

The lung function tests were performed after symptom alleviation and were measured by MedGraphics Spirometer (America) or Jager Spirometer (Germany) according to the spirometry standards from American Thoracic Society [30, 31]. COPD is defined as a post-bronchodilator Forced Expiratory Volume in 1 s (FEV_1) of Forced Vital Capacity (FVC) < 0.7. The spirometric classification of severity of COPD included four stages based on GOLD [29]:

Stage I, mild COPD: $FEV_1 \geq 80\%$ predicted; Stage II, moderate COPD: $50\% \leq FEV_1 < 80\%$ predicted; Stage III, severe COPD: $30\% \leq FEV_1 < 50\%$ predicted; Stage IV, very severe COPD: $FEV_1 < 30\%$ predicted or $FEV_1 < 50\%$ predicted plus chronic respiratory failure*.

*Respiratory failure: arterial partial pressure of oxygen (PaO_2) < 8.0 kPa (60 mm Hg) with or without arterial partial pressure of CO_2 ($PaCO_2$) > 6.7 kPa (50 mm Hg) while breathing air at sea level.

Outdoor air pollution data

We acquired a set of daily outdoor air pollution data from March 29th, 2004 to August 2nd, 2009 (sample size of 5026 days, 718 weeks) in Fengxian District, such as daily concentrations of sulfur dioxide (SO_2), nitrogen dioxide (NO_2) and inhalable particulate matter (PM_{10}, particulates less than 10 μm in diameter). The data were available for public use from the central weather monitoring station in Shanghai.

Wind chill index

Wind chill is the feeling of temperature by human body. It can be quantified based on the

Table 1. Characteristics of weekly hospital admissions for AECOPD modified by disease severity

Group	Total (Percent, %)	Male (n = 961)	Female (n = 230)	Average age (Year)
Moderate	199 (16.7%)	133	66	72.96 ± 8.81
Severe	412 (34.6%)	302	110	73.45 ± 7.72
Very severe	580 (48.7%)	526	54	70.92 ± 5.92

Table 2. Summary statistics of outdoor air pollutants and meteorological factors in Fengxian District

Variables	Mean ± SD	Min	Max
SO_2 (μg/m^3)	46.33 ± 19.09	8.00	113.00
NO_2 (μg/m^3)	37.50 ± 17.81	8.00	132.00
PM_{10} (μg/m^3)	67.34 ± 29.56	12.00	500.00
Temperature (°C)	17.03 ± 8.91	-4.00	33.70
Wind speed (m/s)	31.62 ± 11.33	4.00	105.00
WCI	62.86 ± 22.49	14.16	583.06

Note: all the variables were 24-hour averages. Abbreviation: Min, minimum value; Max, maximum value.

simultaneous effect of temperature and wind on the body, namely WCI. The newly modified formula of WCI provided by the National Oceanic and Atmospheric Administration (NOAA) Meteorology Service Center has been widely used in all the meteorology centers (http://www.nws.noaa.gov) [27].

$WCI = 35.74 + 0.6215T - 35.75(V^{0.16}) + 0.427-5T(V^{0.16})$

T = air temperature (°F), V = wind speed (mile/h)

WCI was calculated from the above formula based on the average daily temperature and wind speed from March 29th, 2004 to August 2nd, 2009, provided by the meteorology station in Fengxian District.

Statistical analysis

All data were verified for normal distribution and are presented as mean ± standard deviation (SD) including the average ages, concentrations of SO_2, NO_2, and PM_{10}. All participants were classified into the following groups: (1) weekly hospital admissions for moderate AECOPD (A group); (2) weekly hospital admissions for severe AECOPD (B group); (3) weekly hospital admissions for very severe AECOPD (C group). Associations between outdoor air pollutants, WCI and hospital admissions for COPD exacerbation were analyzed with a stepwise regression method in SPSS, Version 20.0 (USA). The regression model was established with SO_2, NO_2, PM_{10}, and WCI serving as independent variables, and either A, B, C group, or multiple groups serving as dependent variables (sle = 0.05, sls = 0.10).

Results

A total of 1191 COPD patients were collected in this study, including 961 males and 230 females (average age: 71.76 ± 7.17 years old). According to the lung function tests performed after symptom alleviation, participants were all over 49 years old and had moderate to very severe COPD (**Table 1**). A majority of COPD patients experienced severe and very severe exacerbations (34.6% and 48.7%, respectively), whereas the left 16.7% experienced moderate exacerbation.

The descriptive statistics of air pollutants and meteorological factors in Fengxian District were shown in **Table 2**. The daily average concentrations of SO_2, NO_2 and PM_{10} were 46.33 ± 19.09 μg/m^3, 37.5 ± 17.81 μg/m^3, and 67.34 ± 29.56 μg/m^3, respectively. The values of daily average temperature ranged from -4°C to 33.7°C, and daily average wind speed was between 4 m/s and 105 m/s. The corresponding calculation of WCI was 62.86 ± 22.49 with a minimum of 14.16 and a maximum of 583.06.

There was a statistically significant correlation between daily average SO_2, WCI and total hospital admissions for COPD exacerbation, after exclusion of NO_2 and PM_{10} effects. COPD admissions correlated positively with daily average SO_2 ($P < 0.001$) but negatively with WCI ($P < 0.01$) (**Table 3**). The higher the daily average SO_2 reached, the greater the total COPD admissions were. The lower the WCI reached, the greater the total COPD admissions were. In terms of standardized regression coefficients, daily average SO_2 exerted stronger effects on total COPD admissions than WCI.

To obtain the results for COPD exacerbation stratified by differently declined lung functions, we also separately correlated these air pollutants and WCI for the population of single group (A, B or C group) or double-severity group (namely B + C group) (**Table 3**). The association between WCI and moderate COPD admissions

Table 3. Association between outdoor air pollutants, WCI and hospital admissions for AECOPD

	Included variables	B (Regression coefficient)	*t*-value	*p*-value
A + B + C[#]	Constant	3.576	3.875	< 0.001
	SO_2	0.053	4.373	< 0.001
	WCI	-0.028	-3.371	0.001
	PM_{10}	0.007	0.086	0.931
	NO_2	-0.171	-1.919	0.056
A[$]	Constant	1.210	7.141	< 0.001
	WCI	-0.008	-3.084	0.002
	PM_{10}	0.082	1.353	0.177
	SO_2	0.125	1.919	0.056
	NO_2	-0.003	-0.042	0.967
B[*]	Constant	1.173	2.483	0.014
	SO_2	0.023	3.680	< 0.001
	WCI	-0.012	-2.810	0.005
	PM_{10}	0.084	1.042	0.299
	NO_2	-0.147	-1.606	0.110
C[§]	Constant	0.750	2.160	0.032
	SO_2	0.029	3.963	< 0.001
	PM_{10}	-0.072	-0.870	0.385
	NO_2	0.003	0.032	0.974
	WCI	-0.123	-1.899	0.059
B + C[&]	Constant	2.883	3.551	< 0.001
	SO_2	0.045	4.218	< 0.001
	WCI	-0.022	-3.067	0.002
	PM_{10}	0.006	0.081	0.935
	NO_2	-0.130	-1.445	0.150

[#] $y_{A+B+C} = 3.56 + 0.053x_{SO2} - 0.028x_{WCI}$. [$] $y_A = 1.210 - 0.008x_{WCI}$. [*] $y_B = 1.173 + 0.023x_{SO2} - 0.012x_{WCI}$. [§] $y_C = 0.750 + 0.029x_{SO2}$. [&] $y_{B+C} = 2.883 + 0.045x_{SO2} - 0.022x_{WCI}$.

presented negative after adjusting for PM_{10}, SO_2, and NO_2. On average, the number of moderate COPD admissions decreased when WCI increased ($P < 0.01$). Both WCI and SO_2 were observed in the association with the hospital admissions for severe to very severe COPD exacerbation. For the B + C group, increased COPD admissions followed with elevated SO_2 ($P < 0.001$) and reduced WCI ($P < 0.01$), in which SO_2 contributed much more.

SO_2 played an important role in severe and very severe COPD exacerbations. Increased daily average SO_2 resulted in increased hospital admissions of B and C groups, respectively (both $P < 0.001$). Moreover, SO_2 emerged as a major factor accounting more for very severe than severe COPD exacerbation according to their corresponding standardized regression coefficients. The negative effect of WCI was present in the hospital admissions for severe rather than very severe COPD exacerbation ($P < 0.01$). Above all, effects of NO_2 and PM_{10} were not observed in any correlation with COPD admissions modified by disease severity.

Discussion

The current study assessed the relationship of hospital admissions for COPD exacerbation with the ambient air pollutants and meteorological factor WCI in Fengxian District, Shanghai, China. The weekly average hospital admissions for COPD exacerbation, modified by disease severity, increased as the daily average SO_2 increased or WCI decreased. To our knowledge, this study is one of the few that have investigated both the air pollutants and wind chill on AECOPD with moderately to very severely declined lung functions.

AECOPD can be triggered by infectious and environmental (air pollution and meteorological) factors. Together with increased industrialization and motor vehicle traffic congestion, there is a growing issue with outdoor air pollution. Air pollution is known to be responsible for respiratory symptoms, cardiovascular events, hospitalizations and mortality [32]. The respiratory system is vulnerable to air pollutants including SO_2, NO_2, and particulate matter. Exposure to SO_2, NO_2, and PM_{10} resulted in increased acute excerbations or respiratory infections in COPD patients [33-35]. Specifically, SO_2, NO_2, and PM_{10} concentrations were positively associated with emergency room admissions or outpatient visits for AECOPD [36, 37]. DeVries et al. [38] demonstrated that short-term exposure to SO_2 had a robust association with increased COPD exacerbation risk [odds ratio (OR) = 2.45], whereas NO_2 had a weaker association (OR = 1.17) after adjustment for $PM_{2.5}$. However, most of the available evidence has not explored the effect of air pollutants on COPD exacerbation stratified by disease severity. In this study, exposure to SO_2 resulted in increases of the total, severe and very severe COPD admissions, respectively. SO_2 was an independent risk factor for very severe COPD admissions. No significant associations between NO_2, PM_{10} and COPD admissions were found here, which is inconsistent with literature concerning air pollution and COPD-related emergency room visits. It is possible that NO_2 and

PM_{10} emerge as confounders or competing pollutants whose effects might be masked and were not maintained in the presence of SO_2 or WCI in the multi-factor regression models. Generally, mild COPD exacerbation would not result in emergency visits or hospital admissions; therefore they were not included in the analysis.

Wind chill is the degree of cold perceived by human body and worsened by high wind speed. Previous studies have proven cold temperature was a significant predictor of respiratory mortality [39, 40]. A population-based study in metropolitan area reported that mean temperature was closely and independently associated with a mean increase of 4.7% in weekly hospitalizations for COPD [41], consistent with the existing literature [38]. McCormack et al. [42] confirmed that decreases in minimum daily outdoor temperature were associated with increased respiratory symptoms and decreased lung function. Moreover, stratified models showed that the effect of temperature on daily lung function was stronger among those with less severe COPD. It has been suggested that the effect of cold temperature is most severe when accompanied by strong winds [43]. The wind speed and other meteorological factors were associated with number of ambulatory care visits for COPD patients in North Bavaria [44]. Therefore, WCI, the composite index of wind chill, may be a better marker to estimate the effect of weather on COPD exacerbation than temperature alone. However, there have been few studies exploring the direct relationship of WCI with COPD morbidity or exacerbation. Herein, increases in moderate, severe, or multi-severity COPD exacerbation were found to be negatively associated with WCI. WCI was the robust independent factor in moderate COPD exacerbation while it did not have any influences on very severe COPD exacerbation. The exact interpretation of these results is not clear. Athletes and tourists tend to learn from WCI to protect themselves in cold weather by putting on warmer clothes or covers [27]. So it is possible that increased WCI may prevent stable COPD patients from brief excursions or limit their time spent outdoors in cold days, thus decreasing the morbidity of AECOPD, especially for these less severe COPD patients. Also, indoor air pollutants are not considered factors because people usually rely on electric home appliances such as air-conditioning instead of biomass fuel for heating in Fengxian District.

There are several limitations of this study. First, data of outdoor air pollutants, meteorological factors, and COPD patients were separately collected from only one meteorology station and one central hospital. The data may not well represent the comprehensive changes in Fengxian District or compare with other areas in Shanghai. Second, the correlation among these air pollutants has not been discussed, so the intrinsic cross-over effects of SO_2 and NO_2, PM_{10} could not be estimated. Finally, the study lacks information of $PM_{2.5}$, which was not regularly monitored during the study period. Further investigation should be done to improve the shortcomings to better illustrate the causal relationship between air pollution, weather and COPD exacerbation.

In summary, our study shows for the first time that SO_2 and WCI have influences on COPD exacerbation modified by disease severity. In stepwise regression analysis, the effect of SO_2 was stronger for very severe COPD exacerbation and WCI was for moderate COPD exacerbation. Further study is needed to minimize the limitations and incorporate the related findings into public health advisories for the vulnerable COPD population.

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Disclosure of conflict of interest

None.

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