Original Article

Correlation between air temperature, air pollutants, and the incidence of coronary heart disease in Liaoning Province, China: a retrospective, observational analysis

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Background: The concentration of air pollutants is affected by changes in climatic conditions. Air temperature is a main factor affecting the concentration of air pollutants. This study sought to examine the relationship between air temperature, air pollutants, and their interactions in elderly patients with coronary heart disease (CHD) in Liaoning Province, China.

Methods: The population data primarily comprised data on daily hospitalizations due to CHD between January 1, 2015 and December 31, 2019 at the Shengjing Hospital of China Medical University. A total of 25,461 patients, who were permanent residents of Liaoning Province, were included in the study. The meteorological data included data on the average daily temperature and air pollutant data of the average daily concentrations of sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and ozone (O_3) over the hospitalization period. A multiple linear regression model was constructed to analyze the relationship between meteorological factors and CHD.

Results: The interaction between air temperature and SO_2, NO_2, and O_3 concentrations was related to the number of daily CHD-related hospitalizations in elderly patients aged ≥65 years (P=0.0023); however, this correlation was lower than that of the interaction between SO_2 and NO_2 concentrations (P=0.0026). Additionally, age exerted a greater effect than air temperature and air pollutants.

Conclusions: The incidence of CHD in elderly patients aged ≥65 years was found to be related to the interaction of SO_2 and NO_2 concentrations, and the interaction of air temperature and the concentrations of SO_2, NO_2, and O_3.

Keywords: Air temperature; air pollutants; coronary heart disease

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Introduction

According to a report published by the World Health Organization in 2016, an estimated 17.9 million people died of cardiovascular disease, and cardiovascular deaths account for approximately 31% of the total deaths worldwide. Eighty-five percent of cardiovascular deaths are caused by either heart disease or stroke (1). In China, the incidence of cardiovascular disease remains high. According to the 2018 "Report on Cardiovascular Diseases in China", of the 290 million patients with cardiovascular disease in

China, 11 million have been diagnosed with coronary heart disease (CHD) (2). Arterial hypertension, dyslipidemia, and smoking have been shown to affect the morbidity and mortality of individuals with cardiovascular disease, particularly CHD (3). The 5th China National Health Services Survey of 2013 showed that the prevalence of CHD among people aged >60 years was 27.8% (1). Due to its aging population, geriatric health is currently an important public health challenge in China. In addition to lifestyle and eating habits, meteorological factors, such as temperature, relative humidity, wind speed, and air pressure, have been found to be associated with the concentrations of atmospheric pollutants, such as sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and the incidence of CHD (4-8).

Recent studies have shown that the concentration of air pollutants varies with climatic factors, especially temperature (9). Liaoning is a coastal province in northeast China, bounded between 38°43' to 43°26' north latitude and 118°53' to 125°46' east longitude. It has a temperate sub-humid continental monsoon climate and 4 distinct seasons (a long cold winter, a short rainy summer, a windy spring, and a sunny autumn) characterized by large temperature differences, including rapid temperature changes in the spring and autumn. During the cold seasons, the concentration of air pollutants is higher due to the use of coal-fired central heating (10). The interaction between temperature and atmospheric pollutants may increase the susceptibility of elderly individuals to cardiovascular disease. Additionally, elderly individuals are more vulnerable to cardiovascular disease due to a decline in their immune function.

This study used a general linear model to investigate the relationship between temperature and concentrations of SO_2, NO_2, and ozone (O_3) and the daily number of CHD-related hospitalizations in Liaoning Province, China. The purpose of this study is to explore the correlation between air temperature, air pollutants, and the incidence of coronary heart disease in temperate semi-humid continental climate regions with four distinctive seasons and severe cold winter. Therefore, air pollution is more serious in winter for heating. The results provide a basis for future studies on the relationship between the atmospheric environment and cardiovascular disease in other similar areas. It will also provide effective evidence to support the development of disease prevention strategies in the relevant health sectors. We present the following article in accordance with the STROBE reporting checklist (available at https://dx.doi.org/10.21037/apm-21-3212).

Methods

Health data

The Shengjing Hospital of China Medical University provided data on hospitalizations due to CHD between January 1, 2015 and December 31, 2019 (see https://cdn.amegroups.cn/static/public/10.21037apm-21-3212-1.xlsx). All patients (n=25,461) in the study were diagnosed with CHD as defined in the 10th Revision of the International Classification of Diseases (ICD-10), including acute myocardial infarction (AMI) (I21–I22), unstable angina (I20.0), stable ischemic heart disease (I20 except I20.0, I25), and other types of CHD (complications following AMI and other acute ischemic heart diseases, I23–I24). All procedures performed in this study involving human participants were in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Institutional Review Board of Shengjing Hospital of China Medical University (ethics approval No.: 2021PS493K). Individual consent for this retrospective analysis was waived.

Meteorological and air pollution data

Meteorological data, including data on air temperature (℃), between January 1, 2015 and December 31, 2019 were retrospectively retrieved from the Shenyang Meteorological Bureau. Similarly, retrospective data on atmospheric pollutants, including particulate matter of 2.5 μm in diameter (PM2.5), PM10, SO_2, CO, O_3, and NO_2, were retrieved from the Shenyang Meteorological Bureau (see https://cdn.amegroups.cn/static/public/10.21037apm-21-3212-1.xlsx).

Statistical analysis

The measured values of air pollutants and meteorological factors are expressed as mean ± standard deviation. The independent-samples *t*-test was used to analyze differences in the monthly number of CHD-related hospitalizations among different age groups and sexes. The concentrations of each air pollutant were divided into 2 groups based on median values as follows: SO_2 (≤22.90 and ≥23.23), O_3 (≤57.37 and ≥58.00), and NO_2 (≤38.87 and ≥39.00). A general linear model was constructed to investigate the effects of temperature and air pollutants on CHD. SPSS 20.0 software (IBM, Armonk, NY, USA) was used for all the statistical analyses. A P value <0.05 was considered statistically significant.

Table 1 Sex- and age-specific CHD-related hospitalizations per month

Hospital admissions	Sex			Age		
	Male (n=14,376)	Female (n=11,085)	P	≤64 years (n=12,768)	≥65 years (n=12,693)	P
January	1,239	1,011	0.146	1,140	1,110	0.188
February	1,139	830		1,025	944	
March	1,428	1,098		1,280	1,246	
April	1,231	1,004		1,068	1,167	
May	1,312	983		1,169	1,126	
June	1,107	904		990	1,021	
July	1,143	773		1,002	914	
August	1,102	878		979	1,001	
September	970	742		858	854	
October	1,238	958		1,084	1,112	
November	1,400	1,068		1,238	1,230	
December	1,067	836		935	968	

P>0.05, no significant differences. CHD, coronary heart disease.

Table 2 Air temperature and concentrations of air pollutants between January 2015 and December 2019

Data	Air temperature (℃)	SO_2	NO_2	O_3
January	–10.33±4.71	89.60±65.19	51.28±17.59	28.14±10.41
February	–6.01±4.74	71.72±56.50	42.79±17.60	43.92±12.98
March	3.18±5.21	45.39±25.72	43.07±16.01	62.51±20.36
April	11.74±4.62	20.71±9.75	34.34±10.46	77.72±24.25
May	18.39±3.94	17.55±8.03	30.55±9.68	97.14±33.53
June	22.27±2.73	16.58± 7.38	32.01±8.77	94.13±33.28
July	25.82±2.47	12.65±7.55	27.30±9.30	83.57±27.01
August	23.82±3.30	15.84±9.52	29.43±8.01	67.00±23.42
September	18.22±3.33	19.59±8.05	38.63±12.93	54.43±21.31
October	9.40±4.64	22.95±11.61	42.40±16.50	41.88±22.56
November	0.10±5.82	45.84±34.05	44.89±14.66	29.29±13.22
December	–6.82±5.34	61.90±45.87	48.88±15.23	24.75±11.39

All data in the table are expressed as mean ± standard deviation. SO_2, sulfur dioxide; NO_2, nitrogen dioxide; O_3, Ozone.

Results

General characteristics

As *Table 1* shows, no significant differences were found in the monthly number of CHD-related hospitalizations between sexes and among different age groups. stated above, Liaoning is located in a region with a temperate semi-humid continental climate and four distinct seasons (a long cold winter, a short rainy summer, a windy spring, and a sunny autumn) characterized by large temperature differences, and rapid temperature changes in spring and autumn (see *Table 2*). Due to the use of heating during the cold season (each year, coal-fired central heating is used from early November to the end of March in the following year), the concentration of SO_2 is significantly higher in the cold season than the warm season (data not shown).

The relationship between air temperature, air pollutants, and their interactions and the daily number of CHD-related hospitalizations

A general linear model was used to investigate the relationship between air temperature, air pollutants, and their interactions, and CHD. The results of our analysis are displayed in *Table 3*. Among patients aged <65 years, age was the only major factor that was found to be significantly associated with the incidence of CHD. Conversely, air temperature, air pollutants, and their interactions were not associated with the incidence of CHD. However, in patients aged >65 years, the incidence of CHD was significantly associated with age, temperature, the interaction between SO_2 and NO_2 concentrations, and the interaction between temperature and SO_2, NO_2, and O_3 concentrations. Among these factors, the interaction of SO_2 and NO_2 concentrations was more related to CHD.

Discussion

The effect of air pollution due to climate change on human health has been the subject of increasing attention. The present study used a general linear model to investigate the relationship between air temperature, air pollutants, and their interactions, and CHD. The results showed that there was a correlation between CHD patients >65 years old and the interaction between air temperature and air pollutants, and the interaction between SO_2 and NO_2 concentration and the incidence of CHD were slightly more related.

It has shown that cardiovascular disease is the leading cause of death in women and coronary heart disease is the main cause of cardiovascular disease, and the prevalence rate of coronary heart disease in women is 6.2%, lower than that of men at 7.4% in adults ≥20 years of age in the 2019 U.S. Cardiovascular and Stroke Report (11). Hyperlipidemia is the common risk factor for premature coronary heart disease in men and women (12). In addition, because of the prominent problem of male smoking, the smoking rate of Chinese men over 15 years of age is as high as 52.1%. Long-term smoking has a direct toxic effect on vascular endothelial cells, and it makes changes of vascular endothelial cells structure, starts atherosclerosis prematurely, and accelerates the development of coronary heart disease (13). Male cases were more than female ones in each month of the study, but the difference was not statistically significant. It is possibly due to the small sample size of this study, and patient data from different regions should be collected in future studies to ensure data stability.

In recent years, severe environmental pollution has resulted in major climatic changes, such as a drastic change in the environmental temperature. The effect of temperature on cardiovascular diseases has been extensively studied (14,15), and a negative correlation has been found between temperature and cardiovascular disease. A study by Khanjani and Bahrampour conducted in Kerman, Iran, showed that the rate of cardiovascular death increased by 0.6% for every 1 ℃ decrease in temperature. In the present study, the relationship between cardiovascular death and air temperature was nearly linear, and the number of cardiovascular deaths decreased as the temperature increased (16). However, few studies have demonstrated a positive correlation between temperature and mortality from cardiovascular disease (17,18). Low temperature stimulation causes sympathetic excitation, vasoconstriction, an increase in catecholamine secretion, blood pressure, heart rate, and myocardial oxygen demand index, and aggravates myocardial hypoxia. Low temperatures also lead to increased levels of cholesterol and fibrinogen A, the promotion of inflammatory responses, platelet activation, and increased blood viscosity, which promote thrombosis (6). In addition, low temperature stimulation can also result in decreased myocardial ischemic tolerance and myocardial electrophysiological stability, ultrastructural changes in cardiomyocytes that cause injury and apoptosis, and disturbances to the opening function of cardiomyocyte membrane ion channels, which lead to calcium overload, changes in expression levels of various cytokines, and consequently aggravate clinical symptoms related to cardiovascular diseases (19). The present study only found a correlation between CHD and temperature in patients aged >65 years in Liaoning Province. This may be attributed to the longer winter season in the region. To adapt to the ever-changing climate, the bodies of people living in such environments unconsciously undergo continuous functional accommodations. Any change in the external temperature triggers an automatic adjustment of the diameter and number of open arterioles and venules to maintain a constant body temperature. In this process,

Table 3 Effects of temperature, air pollutants, and their interactions on coronary heart disease incidence

Data	Type III sum of squares	Mean square	F	P	Interaction
≤64 years of age					
Age	140.46	140.46	5.65	0.018[b]	0.0032
Temperature	14.01	14.01	0.56	0.453	–
SO_2	0.95	0.95	0.04[a]	0.845	–
NO_2	7.03	7.03	0.28	0.595	–
O_3	46.69	46.69	1.88	0.171	–
Temperature × SO_2	1.09	1.09	0.04[a]	0.834	–
Temperature × NO_2	4.94	4.94	0.20	0.656	–
Temperature × O_3	10.76	10.76	0.43	0.511	–
SO_2 × NO_2	5.26	5.26	0.21	0.646	–
SO_2 × O_3	7.80	7.80	0.31	0.576	–
NO_2 × O_3	11.38	11.38	0.46	0.499	–
Temperature × SO_2 × NO_2	1.32	1.32	0.05	0.818	–
Temperature × SO_2 × O_3	1.18	1.18	0.05	0.827	–
Temperature × NO_2 × O_3	0.16	0.16	0.01[a]	0.936	–
SO_2 × NO_2 × O_3	10.95	10.95	0.44	0.507	–
Temperature × SO_2 × NO_2 × O_3	0.28	0.28	0.01	0.916	–
≥65 years of age					
Age	340.41	340.41	16.56	<0.001[b]	0.0094
Temperature	92.59	92.59	4.51	0.034[b]	0.0026
SO_2	10.69	10.69	0.52	0.471	–
NO_2	0.26	0.26	0.01[a]	0.911	–
O_3	27.62	27.62	1.34	0.246	–
Temperature × SO_2	6.12	6.12	0.30	0.585	–
Temperature × NO_2	3.48	3.48	0.17	0.681	–
Temperature × O_3	54.86	54.86	2.67	0.102	–
SO_2 × NO_2	93.62	93.62	4.56	0.033[b]	0.0026
SO_2 × O_3	21.61	21.61	1.05	0.305	–
NO_2 × O_3	24.68	24.68	1.20	0.273	–
Temperature × SO_2 × NO_2	11.98	11.98	0.58	0.445	–
Temperature × SO_2 × O_3	23.39	23.39	1.14	0.286	–
Temperature × NO_2 × O_3	0.11	0.11	0.01[a]	0.942	–
SO_2 × NO_2 × O_3	2.38	2.38	0.12	0.734	–
Temperature × SO_2 × NO_2 × O_3	81.16	81.16	3.95	0.047[b]	0.0023

[a], F<0.05, there is a statistical significance; [b], P<0.05, there is a statistical significance. SO_2, sulfur dioxide; NO_2, nitrogen dioxide; O_3, Ozone.

changes are made to blood viscosity and the regulation of vascular function by the sympathetic nervous system. However, as age increases, a relative decline is observed in bodily functions; for example, a decrease in the elasticity of vascular walls may lead to deficits in cardiovascular functions (20).

In addition to temperature, atmospheric pollutants also have a significant effect on cardiovascular vessels. The precisely mechanism by which air pollutants affect the cardiovascular system remains unknown. Air contaminants may have effects on the cardiovascular system directly or influence the cardiovascular system indirectly through epigenetic changes, inflammatory responses, and other mechanisms. The combined effects of air pollution stimulate pathological processes, including endothelial damage, vascular dysfunction, autonomic and neuroendocrine dysfunction, thrombosis and atherosclerosis (21,22). The present study also found that elderly patients with CHD were relatively susceptible to the effects of air pollutants. The interactions between SO_2 and NO_2 concentrations and between temperature and air pollutant concentrations were revealed to have an effect on elderly patients with CHD. As Liaoning Province is a major heavy industry hub in China, its concentration of air pollutants is higher than those in the coastal regions of southern China. During the long winter season, the correspondingly long heating period aggravates the formation of air pollutants, decreases peoples' exercise levels and outdoor activities, which leads to reduced coronary perfusion, and poor indoor ventilation, which exacerbates cardiac ischemia and hypoxia. Even if adequate outdoor activity levels can be maintained during the winter season, the additional damage caused to the human body by air pollutants must also be taken into consideration. Increased concentrations of SO_2 and NO_2 have been causatively associated with an increase in mortality from cardiovascular diseases (23). Additionally, elderly patients have been found to be more susceptible to these effects (24). Studies have shown that atmospheric pollutants exposure may contribute to worsening heart failure and decreasing heart rate variability in older populations due to circulatory function and immunity reducing (25). However, we found the interaction between temperature and air pollutant concentrations was relatively weak, which could be due to the effect exerted by changes in temperature on air pollutant concentrations. Changes in temperature have been shown to affect the diffusion of air pollutants, thereby affecting their concentrations and ultimately their effects on human health (18,26). In this study, air temperature changes were found to neutralize the risks of high concentrations of air pollutants with respect to CHD.

Studies have also shown that meteorological factors and atmospheric pollutants affect the incidence of cardiovascular disease (19,27). Among meteorological factors, temperature is still the main influence factors, however, the types of pollutants that induce cardiovascular disease are slightly different. SO_2 is the major effect factors in some regions, and particulate matter is the key influencing factor in other parts (28,29). The cause of the inconsistency may be that the main atmospheric pollutants are different in different regions, and the discrepancy of climatic environment can also cause the diffusion movement of different atmospheric pollutants, resulting in differences in the concentration of atmospheric pollutants, which may lead to discrepancies in their health benefits. The region this study carried out belongs to temperate semi-humid continental climate. The average annual temperature is from 6.2 to 9.7 ℃, and atmospheric pollutants concentration changes show a trend of decreasing year by year. The concentration of NO_2 in recent years appeared an upward trend, but SO_2 concentration showed a downward trend year by year. Because of the heating period, air pollution may be aggravated during cold winter, resulting in adverse health effects. In addition to meteorological factors and air pollution, unhealthy lifestyle, dietary habits and indoor living environment may affect the incidence of cardiovascular disease, and the most principal factors include smoking and drinking. Studies have shown that inflammatory responses promote atherosclerosis, while inflammatory markers of cardiovascular disease such as white blood cell counts decreased significantly after 1 year of smoking. When quitting smoking, the inflammatory response of blood vessels significantly reduced and process of atherosclerosis slowed down (30). In the future studies, the confounding effects of non-meteorological environmental factors such as lifestyle should be further eliminated, so as to explore the effects of meteorological factors and atmospheric pollutants on cardiovascular disease in depth.

Our study had a number of limitations. First, as this was an ecological study, ecological fallacy was unavoidable. Second, as the study was conducted solely on a regional population in Liaoning Province, other regions with the same climate require further study. Third, the admission rate was biased due to the use of hospitalization records. Finally, the delayed effects of temperature and air pollutants were not considered, as the study included only patients with an acute onset of CHD. To address these limitations, further studies with greater rigor and a larger sample size should be designed to give adequate consideration to the effects of admission rate bias and the subsequent effects.

Conclusions

The present study provided evidence of the relationship between air temperature, air pollutants, and the incidence of CHD in Liaoning Province, China. Our results showed that the onset of CHD in the elderly population in Liaoning Province was significantly associated with the interactions of air temperature and air pollutants. Under stable meteorological conditions, our results will be of great significance to the planning of public health intervention measures for elderly populations in areas with latitude, longitude, and climatic conditions similar to those of Liaoning Province. These findings can be used to address the effects of air temperature and pollutants on health.

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Footnote

Reporting Checklist: The authors have completed the STROBE reporting checklist. Available at https://dx.doi.org/10.21037/apm-21-3212

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Ethical Statement: The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All procedures performed in this study involving human participants were in accordance with the Declaration of Helsinki (as revised in 2013). The study was approved by the Institutional Review Board of Shengjing Hospital of China Medical University (ethics approval No.: 2021PS493K). Individual consent for this retrospective analysis was waived.

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