Ischemic Heart Disease and Ambient Air Pollution of Particulate Matter 2.5 in 51 Counties in the U.S.

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SYNOPSIS

Objective. Ischemic heart disease (IHD) is one of the most common health threats to the adult population of the U.S. and other countries. The objective of this study was to examine the association between exposure to elevated annual average levels of Particulate matter 2.5 ($PM_{2.5}$) air quality index (AQI) and IHD in the general population.

Methods. We combined data from the Behavioral Risk Factor Surveillance System and the U.S Environmental Protection Agency air quality database. We analyzed the data using SUDAAN software to adjust the effects of sampling bias, weights, and design effects.

Results. The prevalence of IHD was 9.6% among respondents who were exposed to an annual average level of $PM_{2.5}$ AQI >60 compared with 5.9% among respondents exposed to an annual average $PM_{2.5}$ AQI ≤ 60. The respondents with higher levels of $PM_{2.5}$ AQI exposure were more likely to have IHD (adjusted odds ratio = 1.72, 95% confidence interval 1.11, 2.66) than respondents with lower levels of exposure after adjusting for age, gender, race/ethnicity, education, smoking, body mass index, diabetes, hypertension, and hypercholesterolemia.

Conclusions. Our study suggested that exposure to relatively higher levels of average annual $PM_{2.5}$ AQI may increase the likelihood of IHD. In addition to encouraging health-related behavioral changes to reduce IHD, efforts should also focus on implementing appropriate measures to reduce exposure to unhealthy AQI levels.

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Ischemic heart disease (IHD) is one of the most common health threats to the adult population of the U.S. and many other countries. It is a condition in which heart muscle is damaged or works inefficiently because of an absence or relative deficiency of its blood supply; most often caused by atherosclerosis, it includes angina pectoris, acute myocardial infarction, chronic IHD, and sudden death. Age, gender, race, education, diabetes, smoking, diet, hypertension, and serum cholesterol level are important IHD risk factors.[1–8]

Particulate matter 2.5 ($PM_{2.5}$) are well-known criteria pollutants that pose a risk to public health.[9–11] Studies have shown that ambient air pollution is associated with increased risk of respiratory disease and cardiovascular disease (CVD) mortality.[12–14] However, research literature does not show a consistency in the association between $PM_{2.5}$ and IHD.[15–17] Most of the previous studies focused on short-term exposure; that is, exposure that lasted only hours or days.[15,17,18] In addition, some of the studies did not adjust the confounding effects of other risk factors. Moreover, most of the studies were hospital-based and did not represent the general U.S. population.

The purpose of this study was to examine the association between $PM_{2.5}$ and IHD in the general U.S. population while adjusting for potential covariates. We used data from a state-based survey, the Behavioral Risk Factor Surveillance System (BRFSS), and from the U.S. Environmental Protection Agency (EPA) 2001 air quality data.

METHODS

Survey data collection

The BRFSS[19] is a standardized, state-based telephone survey system designed to collect data on the health behaviors and health conditions of noninstitutionalized adults aged 18 years and older. Data are collected by state health departments with assistance from the U.S. Centers for Disease Control and Prevention (CDC). All BRFSS questions and methods are available at www.cdc.gov/brfss.

In 2001, 20 states participated in the CVD module used in the survey. The question asked was, "Has a doctor, nurse, or other health professional ever told you that you had any of the following? (*1*) A heart attack, also called myocardial infarction; (*2*) angina or coronary heart disease." We defined IHD as a "yes" response to either of the questions.

Environmental data

The $PM_{2.5}$ air quality index (AQI) data are based on the EPA's Air Quality System (AQS) database. The database contains measurements of six criteria pollutants at sites in all 50 states. Ambient air measurements collected from a network of national, state, and local air monitoring stations were used to calculate the AQI. According to the EPA, the highest individual pollutant AQI for each area was reported as the daily AQI, and the pollutant corresponding to the highest daily AQI was identified. Because our study focused on $PM_{2.5}$, we used the daily AQI, which reported daily air quality based on the concentration levels of $PM_{2.5}$. The daily $PM_{2.5}$ AQI represented the highest concentrations of $PM_{2.5}$ for that day.

As part of increasing the utility of BRFSS data, we merged data from the AQS with BRFSS data by county. For a county to be included in the analysis, it had to have (*1*) at least 125 respondents who participated in the CVD module of the survey to ensure a representative sample with a minimum weighting class, and (*2*) at least 90 days of $PM_{2.5}$ AQI monitoring to ensure that the annual average $PM_{2.5}$ AQI was adequately representative. Data from 51 counties in the U.S. were included in our analyses.

Based on EPA air quality standards, the daily AQI scale runs from 0 to 500 and is categorized into six groups based on the pollutant health effects: (*1*) 0 to 50 = good, (*2*) 51 to 100 = moderate, (*3*) 101 to 150 = unhealthy for sensitive groups, (*4*) 151 to 200 = unhealthy, (*5*) 201 to 300 = very unhealthy, and (*6*) 301 to 500 = hazardous. We calculated the mean annual level of $PM_{2.5}$ AQI by converting the daily concentrations of $PM_{2.5}$ into AQI scores and then to an annual average AQI level. The formula used for the conversion from daily concentration to AQI is discussed in detail on the EPA's website.[20]

We categorized the annual mean $PM_{2.5}$ AQI where we used an annual mean of $PM_{2.5}$ AQI >50 to examine the association between the prevalence of IHD and the annual mean $PM_{2.5}$ AQI. In addition, to examine whether the prevalence of IHD increased with the increased level of the annual mean $PM_{2.5}$ AQI, we repeated the analysis using annual mean levels of >55 and >60. We did not consider using higher annual mean levels because at an annual mean $PM_{2.5}$ AQI level >60, we had one county with 412 respondents.

We classified respondents into two groups: (*1*) respondents who lived in counties with an annual mean level of $PM_{2.5}$ AQI >50 and (*2*) all respondents who lived in counties with an annual mean level of $PM_{2.5}$ AQI ≤ 50. Because at an annual mean $PM_{2.5}$ AQI >60 the sample size was small and the conversion we did may have introduced bias, we repeated the analysis by calculating the prevalence of IHD and annual mean $PM_{2.5}$ at county level. We categorized the annual mean

$PM_{2.5}$ AQI into 10th percentile to assess the association between the prevalence of IHD and annual mean $PM_{2.5}$ by county. In our analysis, we used an annual mean $PM_{2.5}$ as a categorical variable because EPA air quality data were collected daily, while BRFSS data reflect events that happened in the last 30 days or more. Therefore, using the annual mean can be more reasonable and may possibly reduce bias.

In addition, we examined the seasonal variations of the quarterly $PM_{2.5}$ AQI and the association between quarterly variation and IHD prevalence. The quarterly data included quarter 1 (January to March), quarter 2 (April to June), quarter 3 (July to September), and quarter 4 (October to December). We used logistic regression analyses to assess the association between the annual mean $PM_{2.5}$ AQI and IHD while adjusting for covariates including age, gender, race/ethnicity, education, diabetes, body mass index, hypertension, hypercholesterolemia, and smoking. We used statistical analysis package SAS[21] and SUDAAN[22] for data analysis to account for the complex sampling design.

RESULTS

A total of 15,968 respondents participated in the survey in 51 selected U.S. counties during 2001. The age of the respondents ranged from 18–99 (Table 1). The respondents included 48.3% male and 51.7% female; 74.0% white/non-Hispanic; 11.9% black/non-Hispanic; and 14.1% other races/ethnicities, including Asian, Hispanic, other race, and multirace. Of the 15,968 respondents, 922—a prevalence of 6.0%—reported being told by health professionals that they had IHD. The prevalence of IHD was higher among respondents who were aged 50 years or older, male, smokers, and with no high school education. In addition, IHD was higher among respondents with diabetes, hypertension, obesity, and hypercholesterolemia (Table 1).

The prevalence of IHD among respondents exposed to an annual mean $PM_{2.5}$ AQI >50 was 6.9%. As we increased the cutoff value to >55 and >60, the prevalence of IHD increased to 7.2% and 9.6%, respectively. The prevalence of IHD among respondents exposed to an annual average $PM_{2.5}$ AQI ≤ 50, ≤ 55, and ≤ 60 remained almost the same at 5.6% to 5.9% (Table 1).

No statistical association was found between the prevalence of IHD and an annual mean level of $PM_{2.5}$ AQI >50 (odds ratio [OR]=1.24; 95% confidence interval [CI] 0.97, 1.57) or >55 (OR=1.24; 95% CI 0.95, 1.64) before adjusting for covariates (Table 2). However, a statistical association was found between the prevalence of IHD and an annual mean level of $PM_{2.5}$ AQI >60 both before (OR=1.69; 95% CI 1.15, 2.49) (Table 2) and after adjusting for covariates (adjusted odds ratio [AOR]=1.72, 95% CI 1.11, 2.66) (Table 3). This association persisted when we repeated the analysis using annual mean $PM_{2.5}$ AQI and prevalence of IHD to build a regression model at county level ($p=0.0019$). As the annual mean of $PM_{2.5}$ AQI by county increased, the prevalence of IHD increased (Figure).

The mean quarterly level of $PM_{2.5}$ AQI was 48.04, 39.33, 42.27, and 39.47 for quarters 1, 2, 3, and 4, respectively. The difference of the quarterly mean was statistically significant ($p<0.001$); however, no association was found between quarterly variations of the mean levels of $PM_{2.5}$ AQI and quarterly variations of the prevalence of IHD (data not shown).

An elevated annual mean of $PM_{2.5}$ AQI >60 was still a significant predictor for IHD even after adjusting for potential covariates. Our findings also demonstrated that the prevalence of IHD was independently associated with known risk factors such as age, gender, level of education, diabetes, hypertension, hypercholesterolemia, and smoking (Table 3).

DISCUSSION

To our knowledge, this study was the first to combine data from BRFSS and the EPA AQI database to examine the association of IHD with $PM_{2.5}$ among the general U.S. population. Our findings showed that respondents exposed to a higher level of annual mean $PM_{2.5}$ AQI at individual levels and at county levels were more likely to report IHD than respondents exposed to a lower level of annual mean $PM_{2.5}$ AQI.

IHD is one of the main manifestations of atherosclerotic coronary artery disease. Numerous clinical and epidemiological studies have shown that age, gender, race, diabetes, smoking, diet, hypertension, and serum cholesterol level are important risk factors.[1–7] Studies have also shown that air pollution increases the risk of death from CVD.[12–14] The association of IHD with long-term exposure to $PM_{2.5}$ was robust by an annual mean in our models. This finding was consistent with other studies. Studies by Pope et al.[23] demonstrated that long-term $PM_{2.5}$ exposure was most strongly associated with mortality attributable to IHD, dysrhythmias, heart failure, and cardiac arrest. A study by Schwartz et al.[24] found an association of $PM_{2.5}$ with increased mortality caused by IHD and chronic obstructive pulmonary disease. Pekkanen et al.[25] suggested that $PM_{2.5}$ pollution was associated with cardiovascular morbidity, at least through increased susceptibility to IHD.

The mechanism of induced IHD, including myocardial infarctions, from $PM_{2.5}$ pollution is not yet clear. However, one short-term study[15] suggested that elevated

Table 1. Distribution of ischemic heart disease by risk factors in 51 counties in the U.S., 2001

Characteristic	*Sample size (n=15,968)*	*Total percentage (percent, SE)*[a]	*Angina/myocardial infarction (percent, SE)*[a] *Yes (n=922)*	*No (n=15,046)*
$PM_{2.5}$ level by county of residence				
Annual average AQI >50	3,105	29.7 (0.5)	6.9 (0.7)	93.1 (0.7)
Annual average AQI ≤50	12,863	70.3 (0.5)	5.6 (0.3)	94.4 (0.3)
Annual average AQI >55	1,287	10.1 (0.2)	7.2 (0.8)	92.8 (0.8)
Annual average AQI ≤55	14,681	89.9 (0.2)	5.9 (0.3)	94.1 (0.3)
Annual average AQI >60	412	2.8 (0.1)	9.6 (1.6)	90.4 (1.6)
Annual average AQI ≤60	15,556	97.2 (0.1)	5.9 (0.3)	94.1 (0.3)
Age				
18–34	4,809	32.3 (0.5)	0.5 (0.1)	99.5 (0.1)
35–49	5,187	31.3 (0.5)	2.4 (0.3)	97.6 (0.3)
50+	5,972	36.4 (0.5)	14.0 (0.7)	86.0 (0.7)
Gender				
Male	6,595	48.3 (0.6)	7.2 (0.5)	92.8 (0.5)
Female	9,373	51.7 (0.6)	4.9 (0.3)	95.1 (0.3)
Race/ethnicity				
White/non-Hispanic	12,814	74.0 (0.6)	6.1 (0.3)	93.9 (0.3)
Black/non-Hispanic	1,458	11.9 (0.4)	4.9 (0.9)	95.1 (0.9)
Other	1,552	14.1 (0.5)	6.2 (1.2)	93.4 (1.2)
Education				
Not graduated from high school	1,346	10.7 (0.4)	12.7 (1.6)	87.3 (1.6)
High school graduate	4,235	26.3 (0.5)	6.4 (0.5)	93.6 (0.5)
Attended college	4,729	28.8 (0.5)	5.1 (0.4)	94.9 (0.4)
College graduate/higher degree	5,633	34.3 (0.5)	4.3 (0.4)	95.7 (0.4)
Smoking				
Current or former smoker	7,433	46.7 (0.6)	8.2 (0.5)	91.8 (0.5)
Never smoked	8,495	53.2 (0.6)	4.1 (0.4)	95.9 (0.4)
Diabetes				
Yes	939	5.9 (0.3)	21.2 (1.9)	78.8 (1.9)
No	15,023	95.0 (0.3)	5.0 (0.3)	95.0 (0.3)
Body mass index				
Not overweight/obese	6,767	43.8 (0.6)	4.4 (0.4)	95.6 (0.4)
Overweight	5,404	35.5 (0.5)	6.3 (0.4)	93.7 (0.4)
Obese	3,119	20.7 (0.5)	9.4 (0.8)	90.6 (0.8)
Hypertension				
Yes	3,882	23.7 (0.5)	15.0 (0.9)	85.0 (0.9)
No	12,064	76.3 (0.5)	3.2 (0.3)	96.8 (0.3)
Hypercholesterolemia				
Yes	3,643	29.5 (0.49)	14.9 (0.9)	85.1 (0.9)
No	8,735	70.5 (0.49)	3.8 (0.3)	96.2 (0.3)

[a]Percentage and SE are calculated based on weighted sample using SUDAAN software. [Research Triangle Institute. SUDAAN User's Manual: Release 9.0. Research Triangle Park (NC): Research Triangle Institute; 2005.]

$PM_{2.5}$ = Particulate matter 2.5

AQI = air quality index

SE = standard error

$PM_{2.5}$ may trigger myocardial infarction possibly because of the association between hemodynamic and hemostatic alterations with particulate matter air pollution. According to Peters et al.[26–28] this theory appears to be supported by observations from at least several other studies[14,29–32] that found associations of ambient particle pollutions with: (*1*) increased plasma viscosity,[26] (*2*) acceleration of heart rates and diminished heart rate variability,[14,26,31,32] and (*3*) ventricular fibrillation and increased number of therapeutic interventions in patients with implanted cardioverter-defibrillators.[28]

Similar to other studies, our findings demonstrate

Table 2. Non-adjusted odds ratio of ischemic heart disease by risk factor in 2001

Independent variable	*OR (95% CI)*	*95% CI Lower limit*	*95% CI Upper limit*
$PM_{2.5}$ level by county of residence			
Annual average AQI >50	1.24	0.97	1.57
Annual average AQI ≤50	1.00	1.00	1.00
Annual average AQI >55	1.24	0.95	1.62
Annual average AQI ≤55	1.00	1.00	1.00
Annual average AQI >60	1.69	1.15	2.49
Annual average AQI ≤60	1.00	1.00	1.00
Age			
18–34	1.00	1.00	1.00
35–49	4.80	2.78	8.27
50+	31.75	19.18	52.55
Gender			
Female	1.00	1.00	1.00
Male	1.52	1.25	1.85
Race/ethnicity			
White/non-Hispanic	0.98	0.64	1.50
Black/non-Hispanic	0.78	0.45	1.37
Other	1.00	1.00	1.00
Education			
Not graduated from high school	3.20	2.28	4.50
High school graduate	1.51	1.18	1.94
Attended college	1.19	0.92	1.53
College graduate/higher degree	1.00	1.00	1.00
Diabetes			
Yes	5.06	3.94	6.50
No	1.00	1.00	1.00
Smoking			
Current or former smoker	2.07	1.66	2.57
Never smoked	1.00	1.00	1.00
Body mass index			
Not overweight/obese	1.00	1.00	1.00
Overweight	1.49	1.16	1.90
Obese	2.28	1.72	3.01
Hypertension			
Yes	5.37	4.35	6.62
No	1.00	1.00	1.00
Hypercholesterolemia			
Yes	4.41	3.56	5.46
No	1.00	1.00	1.00

OR = odds ratio

CI = confidence interval

$PM_{2.5}$ = Particulate matter 2.5

AQI = air quality index

that in addition to an elevated annual mean of $PM_{2.5}$ AQI being a significant predictor of IHD, age, gender, diabetes, smoking, hypertension, and hypercholesterolemia are important predictors as well.[1–6] In addition, a low level of education was a risk factor of IHD, a finding also reported in other studies,[4,8] and was strongly associated with overweight/obesity, smoking, diabetes, hypercholesterolemia, and hypertension (data not shown). A plausible explanation for this association could be a lack of access to information on modifying health behaviors or lack of knowledge on how to prevent CVD.

Table 3. Adjusted odds ratio of ischemic heart disease (IHD) by risk factor, 2001

		95% CI	
Independent variable	*AOR*[a]	*Lower limit*	*Upper limit*
$PM_{2.5}$ level by county of residence			
Annual average AQI >60	1.72	1.11	2.66
Annual average AQI ≤60	1.00	1.00	1.00
Age			
18–34	1.00	1.00	1.00
35–49	3.62	1.75	7.50
50+	17.83	8.80	36.12
Gender			
Female	1.00	1.00	1.00
Male	1.95	1.53	2.48
Race/ethnicity			
White/non-Hispanic	0.89	0.55	1.43
Black/non-Hispanic	0.59	0.33	1.08
Other	1.00	1.00	1.00
Education			
Not graduated from high school	2.35	1.60	3.46
High school graduate	1.37	1.01	1.85
Attended college	1.30	0.97	1.74
College graduate/higher degree	1.00	1.00	1.00
Diabetes			
Yes	1.71	1.25	2.33
No	1.00	1.00	1.00
Smoking			
Current or former smoker	1.39	1.08	1.77
Never smoked	1.00	1.00	1.00
Body mass index			
Not overweight/obese	1.00	1.00	1.00
Overweight	0.93	0.71	1.22
Obese	1.09	0.79	1.51
Hypertension			
Yes	1.90	1.48	2.44
No	1.00	1.00	1.00
Hypercholesterolemia			
Yes	2.33	1.85	2.92
No	1.00	1.00	1.00

[a]AOR of IHD by annual average $PM_{2.5}$ AQI level, adjusted by age, gender, race, education, diabetes, smoking, body mass index, hypertension, and hypercholesterolemia

AOR = adjusted odds ratio

CI = confidence interval

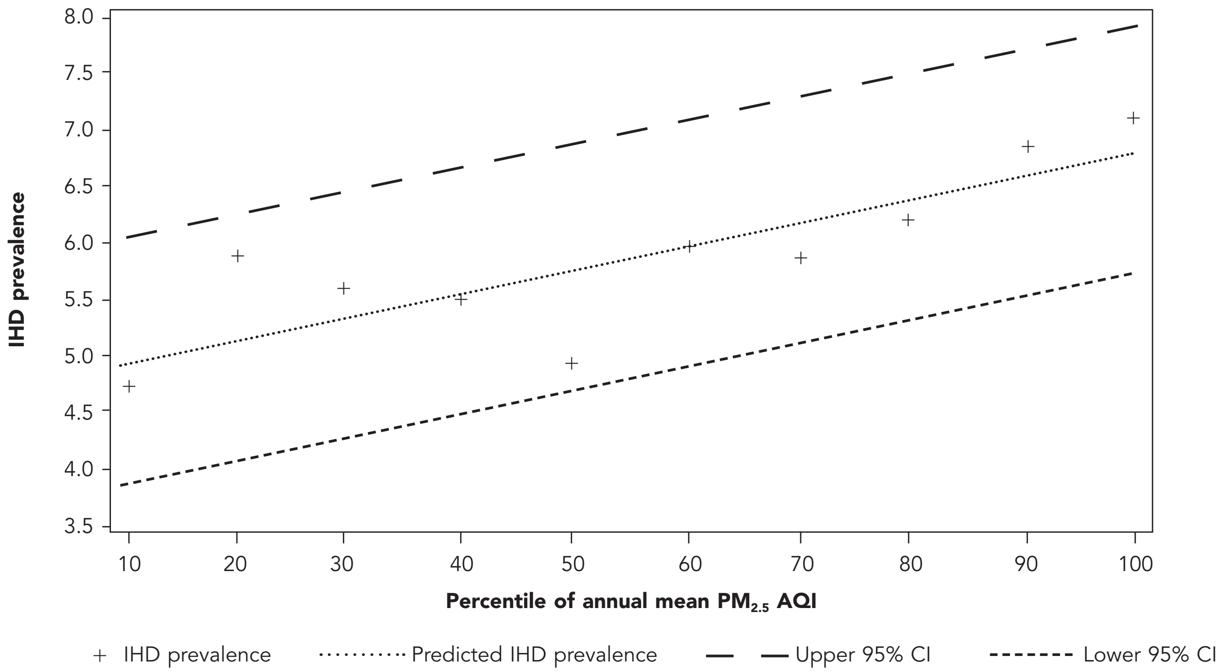
$PM_{2.5}$ = Particulate matter 2.5

AQI = air quality index

Limitations

Our study had some limitations. Because BRFSS is a telephone survey, people who do not have telephones are excluded, which may result in sampling bias. All data on IHD and risk factors were self-reported and may have been subject to recall bias. We did not have meteorological data or county level measurements of the social ecological data, which could be very important confounders of IHD. Our study was cross-sectional; therefore, we were unable to determine a cause-and-effect relationship. In addition, we could not measure true exposure because data related to factors that could influence true exposure were lacking. Data on number of $PM_{2.5}$ monitors, location in each county, distance of individual residence and workplace, and indoor exposure were unavailable. Therefore, individuals may have

Figure. Association of IHD with $PM_{2.5}$ air pollution at county level



IHD = ischemic heart disease
$PM_{2.5}$ = Particulate matter 2.5
AQI = air quality index
CI = confidence interval

higher or lower exposure. Because our study included only 51 counties, the findings of this study cannot be generalized to all U.S counties. The prevalence of IHD could be underestimated in our study because our survey focused on noninstitutionalized adults.

CONCLUSION

Our findings suggest that exposure to a relatively higher level of annual mean $PM_{2.5}$ AQI may increase the likelihood of IHD. Although age, gender, hypercholesterolemia, hypertension, diabetes, and education were major covariates, $PM_{2.5}$ was still a significant predictor. The likelihood of IHD was 1.72 times higher for populations with elevated levels of exposure to $PM_{2.5}$.

The health effect of $PM_{2.5}$ air pollution cannot be ignored in the prevention of CVD. Efforts to prevent or reduce IHD should not only focus on encouraging behavioral modification but should also target the implementation of appropriate measures to reduce $PM_{2.5}$ exposure, especially for susceptible individuals living in areas with a frequent unhealthy level of $PM_{2.5}$ AQI. Government agencies should continue to implement measures to reduce the $PM_{2.5}$ air pollution effectively and enforce air quality standards. In addition communities should develop innovative and affordable approaches to improve air quality.

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