Ambient Air Pollution and Hospitalization for Congestive Heart Failure among Elderly People in Seven Large US Cities

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ABSTRACT

Objectives. Preexisting data sets were used to investigate the association between hospital admissions for congestive heart failure and air pollutants.

Methods. Medicare hospital admissions data, ambient air pollution monitoring data, and meteorological data were used to create daily values of hospital admissions for congestive heart failure, maximum hourly temperature, and maximum hourly levels of carbon monoxide, nitrogen dioxide, sulfur dioxide, and ozone. Data were compiled for each of seven cities (Chicago, Detroit, Houston, Los Angeles, Milwaukee, New York, and Philadelphia) for 1986 through 1989. Single-pollutant and multipollutant models with adjustments for temperature, seasonal effects, and weekly cycles were used in conducting negative binomial regression analyses.

Results. Ambient carbon monoxide levels were positively associated with hospital admissions for congestive heart failure in the single-pollutant and multipollutant models for each of the seven cities. The relative risk of hospital admission for congestive heart failure associated with an increase of 10 ppm in carbon monoxide ranged from 1.10 in New York to 1.37 in Los Angeles.

Conclusions. Hospital admissions for congestive heart failure exhibited a consistent association with daily variations in ambient carbon monoxide. This association was independent of season, temperature, and other major gaseous pollutants. (*Am J Public Health.* 1995;85:1361–1365)

Introduction

The study of morbidity and mortality associated with air pollution has historically focused on respiratory disease. Because airborne toxicants interact most directly with the epithelial cells of the respiratory tract, the respiratory system seems the most likely site for injury and disease. Several studies, however, suggest that the effect of air pollution on persons with underlying cardiovascular disease may be equal to or greater than the effect on persons with respiratory disease. Analyses of a dramatic air pollution episode in London in 1952 showed concomitant elevations in both emergency requests for hospital beds and mortality related to cardiovascular disease.[1] More recently, Kinney and Ozkaynak[2] found an association between ambient air pollution and daily mortality in Los Angeles for the period 1970 through 1979 that was stronger for cardiovascular disease than for respiratory disease deaths. During a 1985 episode of acute air pollution in Germany, mortality, hospital admissions, outpatient visits, and ambulance transports all increased.[3] Again, the association between these measures of adverse health effects and air pollution was stronger for cardiovascular diseases than for respiratory diseases.

To further explore the relationship between air pollution and cardiovascular morbidity, we examined the temporal association between ambient, gaseous air pollutants and hospital admissions for congestive heart failure among elderly people residing in seven large American cities.

Methods

Ambient levels of gaseous air pollutants were combined with Medicare hospital admissions data for Chicago, Detroit, Houston, Los Angeles, Milwaukee, New York, and Philadelphia. These cities were chosen because their populations were large enough to generate sufficient numbers of daily admissions for the analysis. They were also selected to provide a variety of climates and pollution patterns. As a means of minimizing the effect of exposure misclassification due to spatial variation in pollutant levels, analyses were limited to a single central, urban county in each city except New York. Unlike the other cities, New York does not have a single county that contains the majority of the urban population. Therefore, three counties representing the boroughs of Manhattan, Queens, and Brooklyn were combined for this investigation.

Outcome Measures

Hospital admissions for congestive heart failure among the Medicare population were the outcome of interest in this study. The Health Care Financing Administration maintains databases on the use of inpatient hospital services covered by the Part A Medicare (insurance) program referred to as the Medicare Provider Analysis and Review file. The file covers the entire United States, includes all hospital admissions for Medicare patients (96% of admissions for persons more than

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Editor's Note. See related editorial by Schwartz (p 1343) in this issue.

TABLE 1—Maximum Daily Pollutant Levels by City, 1986 through 1989

City	Pollutant Level, ppm, Mean ± SD			
	Carbon Monoxide	Nitrogen Dioxide	Sulfur Dioxide	Ozone
Los Angeles	4.206 ± 2.64	0.077 ± 0.028	0.010 ± 0.005	0.075 ± 0.031
Chicago	2.510 ± 1.002	0.045 ± 0.013	0.025 ± 0.011	0.039 ± 0.015
Philadelphia	2.936 ± 1.164	0.054 ± 0.017	0.029 ± 0.015	0.045 ± 0.020
New York	5.578 ± 1.958	0.064 ± 0.022	0.032 ± 0.015	0.041 ± 0.017
Detroit	2.387 ± 1.217	0.041 ± 0.015	0.025 ± 0.013	0.039 ± 0.015
Houston	2.291 ± 1.327	0.041 ± 0.017	0.018 ± 0.009	0.052 ± 0.025
Milwaukee	1.794 ± 0.984	0.040 ± 0.014	0.017 ± 0.013	0.046 ± 0.018

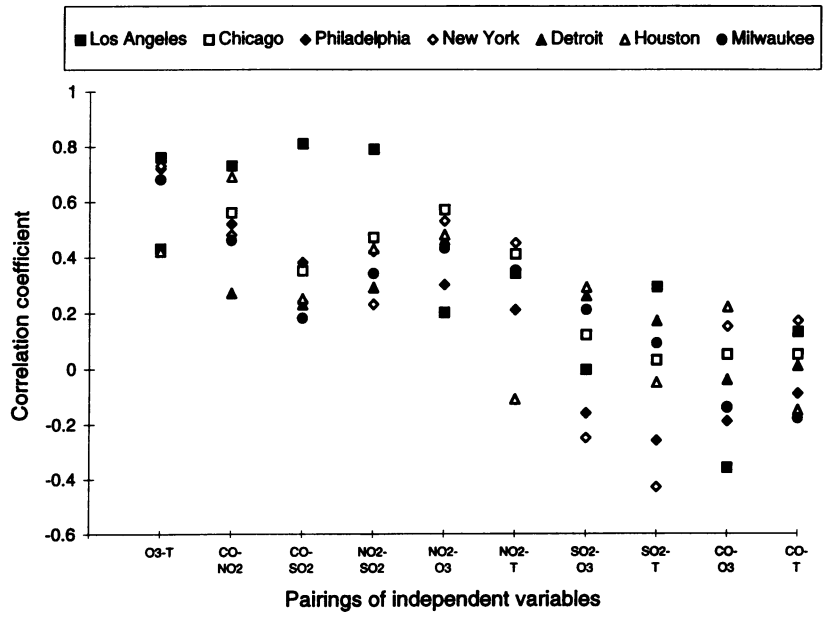

FIGURE 1—Correlations between pairings of predictor variables (ozone [O3], carbon monoxide [CO], nitrogen dioxide [NO2], sulfur dioxide [SO2], and temperature [T]) in each of the seven cities: 1986 through 1989.

64 years of age),[4] and contains approximately 10 million records per year. Each record in the file includes the principal discharge diagnosis and up to four additional diagnoses (coded by means of the *International Classification of Diseases,* 9th edition, *Clinical Modification* [ICD-9 CM]), together with information on the age, sex, race, zip code of residence, and date of admission of the patient.

All admissions involving a primary discharge diagnosis of congestive heart failure (ICD-9 CM code 428) were selected for the seven cities from the Medicare Provider Analysis and Review files for the period 1986 through 1989. The number of congestive heart failure admissions was determined for each day in the entire 4-year period, and time series were compiled for each city. A study that evaluated the validity of these data through comparisons with hospital records found that a primary discharge diagnosis of congestive heart failure was 85% sensitive and had a predictive value of 87%.[5]

Persons with ventricular dysfunction may have substantial comorbidity. The secondary diagnoses for all patients with a discharge diagnosis of congestive heart failure were compiled and tabulated to assess the range and general distribution of other illnesses in this population.

Exposure Measures

Ambient air quality data for the seven cities were extracted from the Aerometric Information and Retrieval System, which is maintained by the National Air Data Branch of the Environmental Protection Agency. Hourly measures of sulfur dioxide, carbon monoxide, nitrogen dioxide, and ozone were obtained for all measurement sites in each of the counties studied. The maximum hourly values for these sites were determined, and an average of these maxima was calculated for each day and each city. Daily maximum temperature data for each of the cities were obtained from the National Weather Service to allow adjustment for the effects of weather on hospital admissions.

Four years of time series data were compiled for each of the seven cities. Complete data were available for at least 94% of the days in each of the cities.

Analysis

Descriptive statistics were determined for each of the variables in each of the seven cities. Pearson correlation coefficients among the temperature and pollutant levels were calculated for each of the cities.

Generalized linear models were used to analyze the time series. The admission counts for the seven cities followed a variety of distributions, with variance to mean ratios ranging from 1.41 for Milwaukee to 3.64 for Los Angeles. In order to accomodate the extra Poisson variation in these data sets with a single method, the model was fit on the basis of a negative binomial distribution. This distribution allows the desirable properties of asymmetry and dependence of the variance on the mean provided by the Poisson distribution but uses a more flexible expression for the mean–variance relationship.[6–8] For each city, congestive heart failure admissions were predicted as a function of daily values for air pollution. All of the models included temperature as well as indicator variables for the month to adjust for weather effects and seasonal trends. Indicator variables were also included for the day of the week and the year to adjust for weekly cycles and secular trends in the data. The regression analyses were repeated with lagged exposure variables ranging from 0 to 7 days. Model residuals were checked for autocorrelation. In cases in which the autocorrelation was significant, models were recalculated with an autoregressive component.[9] All analyses were conducted with S-plus.

For any pollutant showing consistent associations with congestive heart failure admissions (more than half of the cities with significant elevations in risk), the relationship between pollutants and admission rates for congestive heart failure

was plotted by means of the "lowess" smoothing algorithm in S-plus.[10] These plots were adjusted for all of the predictor variables with the exception of the covarying pollutants.

The number and percentage of admissions during the 4-year period that could be attributed to the association with the pollutant were calculated for each city. These values were determined by calculating the predicted number of admissions for each day of the 4-year period as derived from the lowess smoothing algorithm, with adjustment for the prevailing conditions. The attributable risk was based on the sum of the increase in cases that could be attributed to ambient carbon monoxide levels each day over the 4-year period after normalization.

Results

The descriptive statistics for each of the pollutants are listed in Table 1.These results show that New York had the highest average values for carbon monoxide and sulfur dioxide. Los Angeles had the highest values for nitrogen dioxide and ozone.

Admission rates for congestive heart failure were lowest in New York and highest in Philadelphia. Among secondary diagnoses, the most frequent noncardiac diagnosis, chronic airway obstruction (ICD-9 CM code 496), was listed for 15% of all cases.

Correlations between the predictor variables are shown in Figure 1. Ozone and temperature exhibited the strongest positive correlations, while carbon monoxide and temperature had the lowest correlations.

The results of the single-pollutant and multipollutant regression analyses are listed in Table 2. Carbon monoxide had by far the most consistent pattern of association with congestive heart failure admissions. In terms of the relative risk (RR) associated with an increase of 10 ppm in carbon monoxide levels, Los Angeles had the strongest association (RR = 1.36, $P < .001$). New York (RR = 1.10, $P = .007$) and Houston (RR = 1.11, $P = .12$) had the weakest associations, and relative risks for the other four cities fell in a range from 1.17 (Philadelphia) to 1.29 (Chicago and Milwaukee) ($P < .01$ in all four cases). These associations did not change substantially in the multipollutant model except for Houston (RR = 1.25, $P = .01$) and New York (RR = 1.05, $P = .25$). Nitrogen dioxide was associated with congestive heart failure admissions in Los Angeles, Chicago, and New York, but these associations did not persist in the multipollutant model except in New York.

TABLE 2—Relative Risks of Congestive Heart Failure Admission among Medicare Patients as a Function of Ambient Pollutant Levels

	Single-Pollutant Model		Multipollutant Model	
Pollutant and City	Relative Risk	95% Confidence Interval	Relative Risk	95% Confidence Interval
Carbon monoxide				
Los Angeles	1.36	1.28, 1.46	1.39	1.23, 1.56
Chicago	1.29	1.16, 1.44	1.23	1.07, 1.43
Philadelphia	1.17	1.05, 1.31	1.22	1.05, 1.41
New York	1.10	1.03, 1.18	1.05	0.97, 1.14
Detroit	1.24	1.11, 1.39	1.38	1.17, 1.63
Houston	1.11	0.97, 1.26	1.25	1.05, 1.49
Milwaukee	1.29	1.07, 1.57	1.26	0.89, 1.77
Nitrogen dioxide				
Los Angeles	1.15	1.10, 1.19	0.98	0.91, 1.05
Chicago	1.17	1.07, 1.27	1.06	0.92, 1.22
Philadelphia	1.03	0.95, 1.12	0.95	0.84, 1.08
New York	1.07	1.02, 1.13	1.08	1.01, 1.16
Detroit	1.04	0.92, 1.18	1.01	0.88, 1.15
Houston	0.99	0.88, 1.10	0.83	0.70, 1.00
Milwaukee	1.05	0.89, 1.23	0.87	0.68, 1.12
Sulfur dioxide				
Los Angeles	1.60	1.41, 1.82	1.00	0.81, 1.24
Chicago	1.05	1.00, 1.10	1.00	0.95, 1.06
Philadelphia	1.01	0.96, 1.06	0.99	0.94, 1.05
New York	1.04	1.01, 1.08	1.01	0.97, 1.06
Detroit	1.00	0.95, 1.06	0.98	0.91, 1.06
Houston	1.07	0.97, 1.17	1.11	0.99, 1.24
Milwaukee	1.07	0.99, 1.15	1.07	0.97, 1.19
Ozone				
Los Angeles	1.06	1.01, 1.11	1.03	0.97, 1.09
Chicago	1.03	0.93, 1.14	0.98	0.87, 1.10
Philadelphia	0.95	0.87, 1.05	0.98	0.89, 1.09
New York	0.89	0.81, 0.97	0.84	0.76, 0.92
Detroit	0.90	0.78, 1.05	0.92	0.76, 1.12
Houston	0.99	0.90, 1.08	0.98	0.87, 1.11
Milwaukee	1.00	1.90, 0.53	0.84	0.69, 1.02

Note. The multipollutant model included all four pollutants. All models included temperature, month, day of week, and year. Values refer to the relative risk associated with an increase of 10 ppm of carbon monoxide, 0.1 ppm of nitrogen dioxide, 0.05 ppm of sulfur dioxide, or 0.12 ppm of ozone.

These associations diminished rapidly with time. The model without lags provided the strongest associations in almost all cases. At a lag of 1 day, the associations were statistically significant only in Los Angeles (RR = 1.10, $P = .004$). In Houston, carbon monoxide levels were significantly associated with heart failure admissions at a lag of 3 days (RR = 4.1, $P < .001$). No other lagged associations were significant. Even without adjustment for the autoregressive component, all autocorrelations in the residuals were less than 0.07. Adjustment reduced these values to less than 0.03 and had essentially no influence on estimates of relative risk. All possible two-way interactions were evaluated for carbon monoxide, but none were significant, and the inclusion of these interactions did not substantially alter the results of the regressions.

Figure 2 shows hospital admissions as a function of carbon monoxide concentration for each of the seven cities after lowess smoothing. All seven cities showed similar patterns of increasing admissions with increasing ambient carbon monoxide concentrations. The curves for Chicago, Milwaukee, and Houston appeared to have a break point in this association, with a decrease in slope with carbon monoxide concentrations above 3 ppm. In all seven cities, admissions increased monotonically with carbon monoxide. (Note that, because of the assumptions of linearity used in calculating the relative risks in Table 2, those risks differ somewhat from the relative risks derived directly from Figure 2.)

Los Angeles had, by far, the highest proportion of hospital admissions for

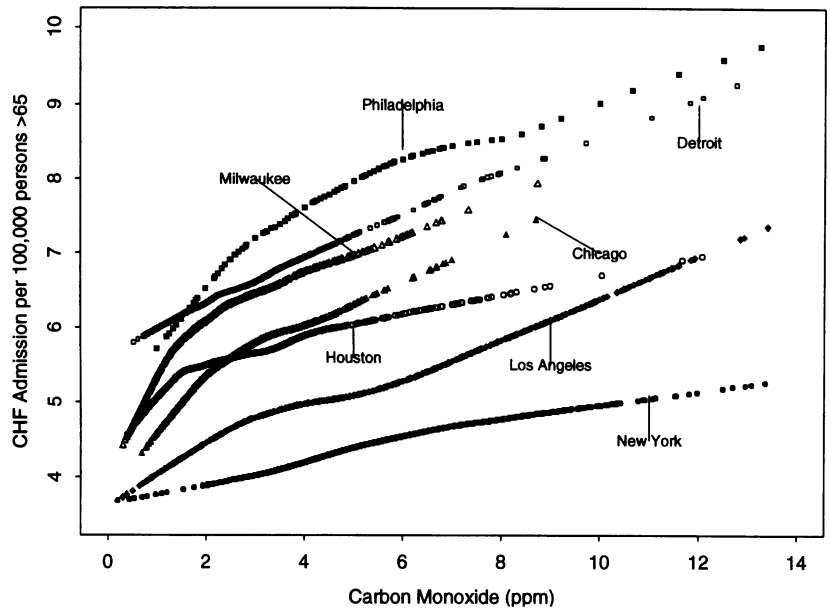

FIGURE 2—Lowess smoothing of the association between ambient levels of carbon monoxide and hospital admissions for congestive heart failure (CHF) among elderly people after adjustment for temperature, month, day of week, and year: 1986 through 1989.

TABLE 3—Hospital Admissions for Congestive Heart Failure over the Study Period (1986 through 1989) and Portion Attributable to Association with Carbon Monoxide (CO)

		No. (%) CO-Related Admissions	
City	Total Admissions	All CO-Related	CO <9 ppm
Los Angeles	57 671	6515 (11.30)	5467 (9.48)
Chicago	49 191	2217 (4.51)	2217 (4.51)
Philadelphia	24 753	762 (3.08)	748 (3.02)
New York	48 230	1806 (3.74)	1604 (3.32)
Detroit	23 770	967 (4.07)	955 (4.02)
Houston	13 551	309 (2.28)	306 (2.25)
Milwaukee	10 819	387 (3.57)	387 (3.57)

congestive heart failure that could be attributed to ambient carbon monoxide (11.30%) (see Table 3). For the other cities, between 2.28% (Houston) and 4.51% (Chicago) of admissions could be attributed to the association with carbon monoxide. Limiting the analysis to values of carbon monoxide below 9 ppm had little impact on these results.

Discussion

This analysis shows a consistent association between increasing levels of ambient carbon monoxide and increasing hospital admissions for congestive heart failure among elderly people. This pattern was consistent across the seven large US cities included in the analysis. These associations persisted after adjustment for seasonal effects, temperature, and other gaseous pollutants, including nitrogen dioxide, sulfur dioxide, and ozone. None of these other pollutants showed consistent, significant associations with congestive heart failure admissions. These results suggest that ambient carbon monoxide levels or factors closely correlated with carbon monoxide levels precipitate or exacerbate congestive heart failure to the extent that hospitalization is required.

It is conceivable that the observed effects reflect the fact that exposure and potential confounders were assessed at an ecological level. Nonrandom misclassification of exposure or time variant confounding variables could explain the observed temporal associations.

The use of ambient monitors to describe exposure to air pollutants represents a relatively crude measure of individual exposure. In particular, outdoor monitors do not accurately reflect indoor exposures, which account for the major portion of exposures for most people. Errors in the measurement of individual exposure will tend to reduce the magnitude of the observed effect. This source of error is not likely to explain the observed associations.

The reasons for the small effect size in New York City, as compared with the other six cities, are unclear. Exposure misclassification was probably greatest in New York City because of the inclusion of three counties in the analysis. In addition, a strong secular trend of decreasing values of carbon monoxide over the 4-year period may have reduced the effectiveness of adjustments for month and season in the analysis. A full explanation of this anomaly is not possible with the available data.

The time series approach has been used extensively to evaluate the adverse health effects of ambient air pollutants.[11-16] This approach limits confounding to those factors that covary in time with levels of air pollutants. Time variant factors with the potential to confound the observed association include temperature, seasonal weather patterns, and outdoor activity patterns. Inclusion of temperature and dummy variables for month in the analysis should control for the potential effects of weather and other factors with major seasonal fluctuation. Exposure to other pollutants may also confound the association between a single pollutant and congestive heart failure. Since carbon monoxide was significant in the multipollutant model, the potential confounders were limited to automotive pollutants not considered in the current study.

Congestive heart failure involves the inability of the heart to adequately perfuse peripheral tissues. Air pollutants may diminish the ability of the lungs to oxygenate the blood or the ability of the blood to deliver oxygen. Carbon monoxide probably does not directly affect the respiratory tract but can alter the ability of hemoglobin to carry oxygen to the peripheral tissues.[17]

One of the compensatory mechanisms for hypoperfusion in cardiac pa-

tients is to shift the oxygen dissociation curve of hemoglobin by increasing 2,3-bisphosphoglycerate levels.[18] Bersin et al. suggest that elimination of this mechanism would necessitate increases of 31% in cardiac output and 57% in coronary blood flow.[19] Normalization of this binding curve may induce myocardial ischemia.[20] Carbon monoxide alters the ability of hemoglobin to transport oxygen to a degree sufficient to induce cardiac disease. High levels of carbon monoxide have caused myocardial infarction,[21] and low levels have been associated with angina in human studies.[22–26] Allred et al. demonstrated a decrease in the time to exercise-induced angina and ST segment depression among subjects with diagnosed coronary artery disease after exposure to carbon monoxide.[24,25] Effects were demonstrated at levels of carboxyhemoglobin within the range associated with ambient carbon monoxide exposure.[25]

The results of Kleinman et al.[26] suggest that carbon monoxide exposure leads to elevations in the systolic blood pressure and, to a lesser extent, the heart rate and respiratory quotient. The ventilatory response to exercise did not show a consistent change after carbon monoxide exposure. This suggests that the compensatory response to elevated carboxyhemoglobin relies more on changes in cardiac function than on changes in respiratory function. Persons with compensated congestive heart failure may become decompensated with this demand for increased cardiac output.

These effects of carbon monoxide may be further exacerbated by the presence of respiratory disease in patients with congestive heart failure. Persons with preexisting left ventricular dysfunction may have some degree of underlying pulmonary edema that could increase their susceptibility to a respiratory insult. More important, perhaps, is the fact that subjects with ventricular dysfunction often suffer from obstructive lung disease. This will further decrease the capacity of these persons to respond to low-level carbon monoxide exposure. The 15% of congestive heart failure cases involving chronic obstructive pulmonary disease may account for a substantial portion of the increase in admissions associated with carbon monoxide.

An alternative mechanism for the induction of congestive heart failure by air pollutants involves direct, myocardial toxicity. It is conceivable that some component of vehicular emissions has direct toxic effects on the heart. This mechanism would require far more specific toxic effects and provides a less likely explanation than impaired oxygen delivery to the peripheral tissues.

In the seven cities analyzed in the current study, approximately 3250 hospital admissions for congestive heart failure (5.7% of all such admissions) each year can be attributed to the observed association with carbon monoxide levels. The average cost for a congestive heart failure admission in these cities, as derived from the Medicare data, was approximately $10 100. Based on this figure, the total annual cost of the attributable admissions in these seven cities was $33 million using only the direct cost of hospital admissions for persons 65 years of age and older.

In summary, this study demonstrates a clear and consistent association between ambient levels of carbon monoxide and hospital admissions for congestive heart failure among elderly people. This effect does not appear to result from the confounding effect of weather or other seasonal factors. Although nitrogen dioxide, sulfur dioxide, and ozone do not explain the apparent effect of carbon monoxide, it is possible that the observed association represents the impact of some other, unmeasured pollutant or group of pollutants covarying in time with carbon monoxide. Further understanding of the factors responsible for the observed increases in hospital admissions for congestive heart failure will prove valuable in the development of sound strategies for public health intervention. □

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