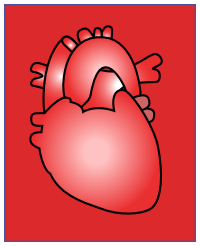
# 4. *Coal's Effects on the Cardiovascular System*



The American Heart Association (AHA), along with other organizations, has issued guidelines designed to aid health professionals as they seek to achieve primary and secondary prevention of the morbidity and mortality due to diseases of the cardiovascular system. Traditionally, these guidelines have focused on the control of hypertension, cholesterol levels, smoking, and other factors. More recently, these guidelines have been expanded to deal with lifestyle choices, such as diet, exercise, and avoidance of second-hand smoke. Controlling these risk factors has been the most important factor in the declines in death rates attributable to coronary heart disease over the past decades. However, because of accumulating evidence and a persistent concern that air pollutants are also linked to adverse cardiovascular health outcomes, the AHA convened an expert panel to evaluate this threat. The results of their deliberations, the single most authoritative review of this topic, were published in 2004.[1] In this section, we build on that prior publication, including studies published since it was written.

## CARDIOVASCULAR DISEASE

Although death rates from coronary heart disease (CHD) have declined substantially during the past several decades, CHD remains a leading cause of death in the United States. Tables 4.1 and 4.2 summarize incidence rate and prevalence data from the National Heart Lung and Blood Institute 2009 Chartbook.[2] By any standard, the control of risk factors associated with CHD has important public health consequences even though the incidence and prevalence of CHD have fallen.

Figure 4.1 summarizes the pathophysiological mechanisms by which air pollutants, particularly particulate matter (PM), cause cardiovascular disease. Pulmonary inflammation and the presence of reactive oxygen species (ions, free radicals formed from oxygen) are both thought to be important mechanisms in the pathogenesis of cardiovascular disease. By convention, and for purposes of monitoring air to evaluate compliance with air quality standards, the PMs of greatest concern are those with a diameter of 2.5 μm or less ($PM_{2.5}$). These

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### Table 4.1: Cardiovascular disease prevalence in the U.S. population, 2004 data

| | |
|---|---|
| Hypertension | 79,400,000 |
| Coronary heart disease | 15,800,000 |
| Acute myocardial infarct | 7,900,000 |
| Angina pectoris | 8,900,000 |
| Congestive heart failure | 5,200,00 |

Source: National Heart Lung and Blood Institute 2009

### Table 4.2: Cardiovascular disease incidence rate and recurrence rate in the U.S. population, 2004 data (per year)

| | |
|---|---|
| Myocardial infarct | 1,200,000 |
| First event | 700,000 |
| Recurrent event | 500,000 |
| Congestive heart failure | 550,000 |
| First event | 550,000 |

Source: National Heart Lung and Blood Institute 2009

small particles are the most likely to penetrate deeply into the lungs, reach the alveoli, and initiate the pathophysiological sequences leading to acute and chronic manifestations of CHD.

The mechanisms depicted in Figure 4.1 suggest numerous possible therapeutic interventions. Reducing the exposure to airborne pollutants is the most obvious of these and forms the rationale for PSR's Code Black campaign to prevent the licensing and construction of new coal-fired power plants. Substantial efforts, beyond the scope of this report, are being invested in controlling the immunological and inflammatory responses and oxidative stress associated with the inhalation of pollutants.

## IMMEDIATE IMPACTS OF AIR POLLUTANTS ON THE CARDIOVASCULAR SYSTEM

In a study supporting the hypothetical pathogenic mechanisms outlined in Figure 4.1, Brook, et al., evaluated the effects of fine particles and ozone on the diameter of the brachial artery in 25 healthy adults.[3] The behavior of brachial arteries is thought to be representative of the behavior of coronary and cerebral arteries. This double-blind, randomized, crossover study evaluated the cardiovascular response to a two-hour inhalation of fine particles (approximately 150 $\mu g/m^3$) and ozone (120 ppb). These concentrations, which are encountered routinely in urban settings, resulted in a significant reduction in the diameter of the brachial artery, implying narrowing of other arteries. In spite of this evidence, important questions remain, e.g., are these participants representative of the population at greatest risk (screened healthy controls versus patients with significant coronary artery disease)?

Animal studies are well suited to studying pulmonary inflammation and oxidative stress, mechanisms that may be important in cardiac disease pathogenesis. Roberts, et al., instilled particles into the lungs of animals pretreated with a drug (dimethylthiourea) believed to blunt the response to reactive oxygen species.[4] The treated animals showed less evidence of pulmonary injury, as evidenced by a blunted inflammatory response and other markers of pulmonary damage. There was also a reduction in the activity of genes controlling cytokines. Cytokines, molecules involved in cellular signaling and communication, are critical in the development and control of immunological responses. In a similar study, Rhoden, et al., instilled standardized urban air particles into the lungs of rats and measured the formation of superoxide ions, a reactive oxygen species.[5] Again, pretreatment with an inhibitor blocked the adverse effects of the particles, as shown by measured reductions in the level of several markers of lung inflammation. In a study of hyperlipidemic rabbits, Suwa, et al., found that a four-week exposure to $PM_{10}$ was associated with acceleration of atherosclerosis, an increase in the turnover of cells in atherosclerotic

## Figure 4.1: Pathophysiological mechanisms by which air pollution causes cardiovascular disease

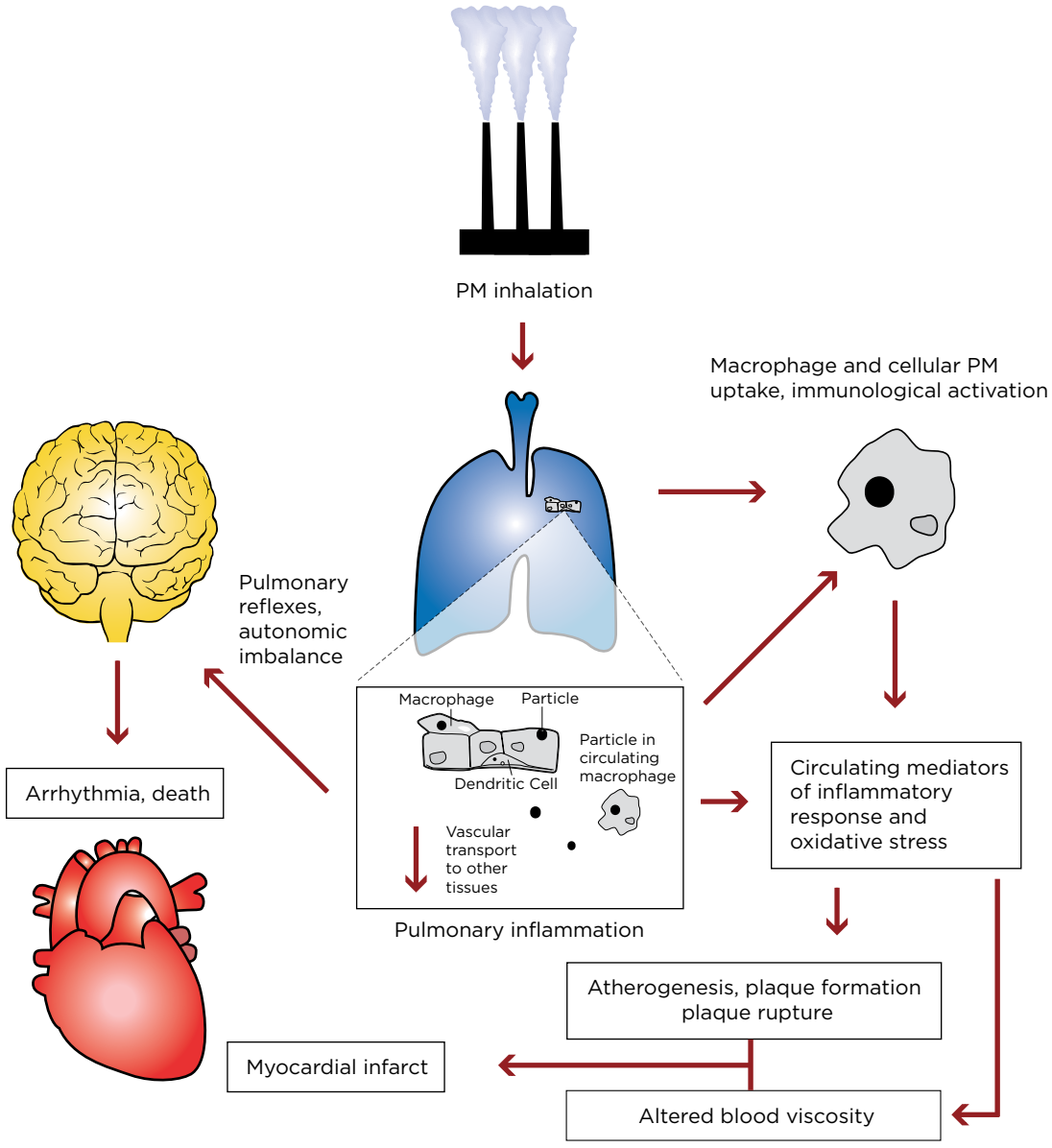


Figure legend:

Particles produced by burning coal are inhaled. Small particles, particularly those that are 2.5 μm or less in diameter, travel deep into the lungs, reaching the alveoli. Particles in the alveoli may have one of several fates: uptake by macrophages with subsequent stimulation of the inflammatory response and the immune system; uptake by dendritic cells, another pathway to immune system activation; or direct entry into the vascular compartment and subsequent transfer to other organs. Pulmonary reflexes, stimulated by inflammation, lead to imbalance of the autonomic nervous system and may potentiate cardiac arrhythmias such as ventricular fibrillation and atrial fibrillation. Inflammation and oxidative stress are important elements in the production and rupture of atherosclerotic plaques in coronary and cerebral arteries and may lead to myocardial or cerebral infarction. Increases in the viscosity of the blood also increase the risk of infarction of the heart or brain.

plaques, and an increase in the total lipid content of aortic lesions.[6] These selected studies show that pollutants produced by the combustion of coal have powerful effects on physiological processes that lead to disease endpoints, such as arterial occlusion and infarct formation.

Acute outcome studies typically focus on a single event, e.g., admission due to acute myocardial infarction or the discharge of an implanted cardioverter defibrillator (ICD). These events have a distinct time-of-occurrence that can found in hospital emergency room records or examination of defibrillator data extracted after a discharge. By examining these data in relationship to air quality data collected by monitoring stations, researchers have been able to examine the relationship between air pollution and hospital admissions for cardiovascular disease. Because of such studies, Peters, et al., hypothesized that there might be a link between transient increases in pollutant levels and therapeutic discharges of ICDs.[7] ICDs are permanently implanted in patients judged to be at risk for sudden death due to cardiac arrhythmias. These devices monitor heart rhythms continuously. When a rhythm disturbance such as ventricular fibrillation or ventricular tachycardia is detected, the ICD begins to pace or defibrillate the heart. Defibrillation is transient but quite painful, and patients are instructed to seek medical attention after an event. Modern ICDs typically include memory chips that store information for variable times. When the patient seeks medical attention after a discharge, technicians are able to retrieve relevant data, including the nature and time of the arrhythmia and the ICD discharge. Peters and her colleagues analyzed the ICD records from 100 events recorded in a single clinic in eastern Massachusetts and sought links between events and peaks in pollutant levels measured in that region. They considered daily average pollutant levels on the day of the event and one, two, and three days prior to the event. They found that an increase in the $NO_2$ concentration was followed by an increase in the probability of an ICD discharge two days later (odds ratio 1.8, 95% confidence interval (CI) = 1.1–2.9). Patients who experienced 10 or more ICD discharges (presumably an indication of more severe disease) exhibited associations with $NO_2$, CO, black carbon, and $PM_{2.5}$. Although they regarded this as a pilot study, they concluded that peaks in air pollution levels were associated with fatal or potentially fatal cardiac arrhythmias. They buttressed this claim by reviewing the results of animal studies linking pollutants to cardiac arrhythmias.

*By examining how defibrillator discharges relate to air quality, researchers can explore how cardiovascular disease relates to air pollution.*


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Peters and her colleagues also investigated the relationship between acute myocardial infarctions (MI) and air pollutants.[8] In this study, a total of 772 records of patient interviews conducted within four days of an acute MI (a step that minimizes recall bias) were evaluated in the context of air

pollutant concentrations. By pairing the data from the day of the MI with three other control sets measured at exactly the same time of the day (on days when the subject did not have an MI), patients served as their own controls. Compared to control periods, there was an increase in the probability of an MI in association with elevations in $PM_{2.5}$ levels measured two hours before the MI (odds ratio for an increase in $PM_{2.5}$ of 25 µg/m³ was 1.48, 95% CI = 1.09–2.02). In addition, there was a delayed response to a peak occurring a full day before an event (odds ratio for the same increase in $PM_{2.5}$ was 1.69, 95% CI = 1.13–2.34).

Two large studies using health outcomes such as mortality in relation to day-to-day changes in ambient air pollution levels have been critical in defining the health effects associated with pollutants. In a U.S. study, Dominici, et al., used ambient $PM_{2.5}$ concentrations and hospital admission rates in the Medicare National Claims History Files to look for associations between particulate levels and admissions for ischemic heart diseases, disturbances of heart rhythm, and congestive heart failure.[9] The data included 204 urban counties with a total of 11.5 million Medicare enrollees who lived an average of 5.9 miles from a $PM_{2.5}$ monitor. Using injuries as control, they found increases in all categories, with the largest found for congestive heart failure, where a 1.28% increase was found for an increase of 10 µg/m³ in $PM_{2.5}$ concentration. Increases in admissions for ischemic heart disease, heart failure, and disturbances of heart rhythm tended to be higher in those 75 years or older than in those 65–74. Additional details are shown in Table 4.3. The greatest effects were observed in the northeastern U.S. where coal-fired power plants are most plentiful. Although the increases in the rates appear small, on the order of a single percent, the large number of Medicare enrollees translates the result into a very large effect when measured in terms of total hospital admissions, patient morbidity and mortality, and the cost of health care and lost opportunities.

Katsouyanni, et al., reported the short-term effects of $PM_{10}$ on the health of the residents of

**Table 4.3: Percent change in hospitalization rate per 10 µg/m³ increase in $PM_{2.5}$ for all Medicare enrollees age > 65 years**

| Admission diagnosis | Lag days* | Percent rate increase (95% confidence interval) |
|---|---|---|
| Ischemic heart disease | 2 | 0.44 (0.02–0.86) |
| Heart rhythm abnormality | 0 | 0.57 (-0.01–1.15) |
| Heart failure | 0 | 1.28 (0.78–1.78) |

* Number of days between peak and greatest effect of $PM_{2.5}$

Source: Dominici F, Peng RD, Bell ML et al. Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases. JAMA 2006; 295(10):1127–1134.

29 European cities with a total population of over 43 million, extending over a period of approximately 5 years.[10] Unlike the U.S. study, they included all age groups. However, the results were remarkably similar to those observed in the U.S. Medicare population. They report a 0.6% increase (95% CI = 0.4–0.8%) in the daily number of deaths for a 10 µg/m³ increase in the $PM_{10}$ concentration. They also found important modifiers of the $PM_{10}$-associated death rate, particularly with regard to $NO_2$ levels. Cities with high $NO_2$ concentrations had death rates that were approximately four times higher than found in cities with low $NO_2$ concentrations. Death rates in cities with warm climates were about 2.8 times higher than in cities with cold climates.

These examples extracted from the literature describing the effects of air pollution on acute morbidity and mortality are consistent: the small studies focused on individuals as well as large studies that rely on data extracted from large databases show adverse effects of pollutants on indicators of acute cardiovascular illness.

## LONG-TERM IMPACT OF AIR POLLUTANTS ON THE CARDIOVASCULAR SYSTEM

Two studies linking the chronic effects of air pollutants on cardiovascular mortality are particularly relevant. The first of these is the Harvard Six Cities

study, reported by Dockery, et al.[11] This prospective cohort study followed over 8,100 adults for 14–16 years. The mortality rate in the most polluted city was 1.26% higher than the rate in the least polluted city (95% CI = 1.08–1.47%). This elevated rate persisted after controlling for important lifestyle confounders, including smoking cigarettes. Pope, et al., linked individual risk factor data from about 500,000 adults, metropolitan area air pollution data, and vital statistics and cause-of-death data. They found that an increase in the particulate concentration of 10 μg/m$^3$ was associated with a 6% increase in the risk of death due to cardiopulmonary causes. Because coal is a significant source of particulate pollution, these studies indicate that coal combustion has serious long-term impacts on the cardiovascular health of the U.S. population.

## MITIGATING THE EFFECTS OF AIR POLLUTION

With the passage of the Clean Air Act in 1955 (with major revisions in 1970, 1977, and 1990), the U.S. embarked on a process to improve air quality in order to improve health. Pope, et al., evaluated the effects of the regulations and corresponding improvements in health in a recent paper.[12] In this study, the authors compared life expectancy in the late 1970s–early 1980s to life expectancy in the late 1990s–early 2000s in 211 counties in 51 metropolitan areas where fine particulate concentration data were available. They report a 0.61 + 0.20 year (+ standard error) increase in life expectancy after a decrease of 10 μg/m$^3$ in fine particle concentration. The two cities with the largest changes were Pittsburgh, PA, and Buffalo, NY, where major steel industries that consumed large amounts of coal were closed. A number of variables that could have confounded the results, such as smoking and socioeconomic class, did not have significant effects. This study showed that significant and measurable improvements in life expectancy followed the improvements in air quality mandated by the Clean Air Act.

## NOTES


1 Brook RD, Franklin B, Cascio W et al. Air pollution and cardiovascular disease: a statement for healthcare professionals from the Expert Panel on Population and Prevention Science of the American Heart Association. Circulation 2004; 109(21):26552671.

2 National Heart Lung and Blood Institute. Morbidity & mortality: 2007 chart book on cardiovascular, lung, and blood diseases. 2009. NHLBI.

3 Brook RD, Brook JR, Urch B, Vincent R, Rajagopalan S, Silverman F. Inhalation of fine particulate air pollution and ozone causes acute arterial vasoconstriction in healthy adults. Circulation 2002; 105(13):1534–1536.

4 Roberts ES, Richards JH, Jaskot R, Dreher KL. Oxidative stress mediates air pollution particle-induced acute lung injury and molecular pathology. Inhal Toxicol 2003; 15(13):1327–1346.

5 Rhoden CR, Ghelfi E, Gonzalez-Flecha B. Pulmonary inflammation by ambient air particles is mediated by superoxide anion. Inhal Toxicol 2008; 20(1):11–15.

6 Suwa T, Hogg JC, Quinlan KB, Ohgami A, Vincent R, van Eeden SF. Particulate air pollution induces progression of atherosclerosis. J Am Coll Cardiol 2002; 39(6):935–942.

7 Peters A, Liu E, Verrier RL et al. Air pollution and incidence of cardiac arrhythmia. Epidemiology 2000; 11(1):11–17.

8 Peters A, Dockery DW, Muller JE, Mittleman MA. Increased particulate air pollution and the triggering of myocardial infarction. Circulation 2001; 103(23):2810–2815.

9 Dominici F, Peng RD, Bell ML et al. Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases. JAMA 2006; 295(10):1127–1134.

10 Katsouyanni K, Touloumi G, Samoli E et al. Confounding and effect modification in the short-term effects of ambient particles on total mortality: results from 29 European cities within the APHEA2 project. Epidemiology 2001; 12(5):521–531.

11 Dockery DW, Pope CA, III, Xu X et al. An association between air pollution and mortality in six U.S. cities. N Engl J Med 1993; 329(24):1753–1759.

12 Pope CA, III, Ezzati M, Dockery DW. Fine-particulate air pollution and life expectancy in the United States. N Engl J Med 2009; 360(4):376–386.