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Original Article

Unveiling the association between air pollution and cardiovascular diseases: the silent threat to heart health

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Cardiovascular diseases (CVDs) remain the leading cause of death worldwide, accounting for about 17.9 million deaths annually—making up roughly 31–32% of all global deaths (1, 2). Among various risk factors, air pollution has emerged as a major public health concern because of its strong link to CVDs. It is responsible for an estimated 20% of the global burden of CVD-related deaths, resulting in over 3 million deaths each year (3, 4). Air pollution is a complex mix of particulate matter, ozone, and nitrogen dioxide (NO), originating from both outdoor and indoor sources. Indoor air pollution is increasingly recognized as a main risk factor, especially in low- and middle-income countries (LMICs), where the use of solid fuels for cooking and heating is prevalent (5). As awareness about the health impacts of air quality grows, emerging research highlights the urgent need for comprehensive public health efforts to tackle this critical issue. Epidemiological studies consistently show a strong link between exposure to air pollution and higher risks of various cardiovascular problems, including heart attacks, strokes, and heart failure (HF) (6, 7). Notably, long-term exposure to fine PM2.5 has been linked to increased morbidity and mortality, highlighting that even concentrations below current safety standards can pose significant health risks (6, 8). The World Health Organization (WHO) has updated its air quality guidelines, urging countries to adopt more stringent standards to protect public health. However, substantial disparities still exist in the global implementation of effective air quality policies (9, 10). The biological mechanisms connecting air pollution to CVDs mainly involve oxidative stress and inflammation, which contribute to vascular dysfunction and speed up the development of atherosclerosis (11, 12). Vulnerable populations, including older adults and those with pre-existing health conditions, face a higher risk from the harmful effects of air pollution due to their increased physiological sensitivity (6). Ongoing research is essential to better understand these processes and to guide targeted interventions, especially in regions heavily affected by poor air quality. The growing body of evidence linking air pollution to negative cardiovascular outcomes has sparked renewed debate about regulatory frameworks and policy measures aimed at reducing health risks. Although some countries have made progress in adopting air quality standards aligned with WHO recommendations, many still lack sufficient laws to effectively protect public health (13). In light of these challenges, effective strategies—including personalized medicine, evidence-based interventions, and comprehensive public health policies—are crucial for reducing the health impacts of air pollution and improving cardiovascular outcomes (3, 14). Additionally, a review of various studies emphasizes that indoor air pollution, especially from solid fuel combustion, presents significant health risks that are often underestimated in traditional epidemiological models, which mainly focus on outdoor air quality (6). This gap highlights the need for further research focused on specific populations and environments to enable a more accurate assessment of exposure and its health effects (6). Addressing these challenges requires integrating personalized medical approaches, scientifically supported interventions, and coordinated public health policies. Implementing such strategies can significantly lessen the health burden of air pollution and promote better cardiovascular health outcomes worldwide scale.

The Association Between Air Pollution and Heart Disease

Research over the past decade has firmly established air pollution as a major risk factor for cardiovascular diseases (CVDs), with both short-term and long-term health effects. Fine PM2.5, defined as particles smaller than 2.5 micrometers, is especially harmful because it can penetrate deep into the lungs and enter the bloodstream, triggering inflammatory responses and oxidative stress. These are key factors in the development of atherosclerosis (12). Short-term exposure to PM2.5 has been linked to a 1–3% increase in the risk of myocardial infarction (MI) within days, while long-term exposure is associated with a 10% increase in cardiovascular mortality per 10 μg/m³ rise, according to a comprehensive review. Recent research conducted in 2024 highlights the particular vulnerability of patients recovering from coronary artery bypass grafting (CABG). This nationwide study found that higher annual PM2.5 levels were significantly associated with adverse cardiovascular events following surgery, emphasizing the broader implications of air pollution on cardiovascular recovery and long-term heart health (15). Similarly, a recent systematic review (2024) reported that exposure to PM2.5 caused 20 million disability-adjusted life years (DALYs) related to cardiovascular diseases in 2019, doubling the 10 million reported in 1990. Among these diseases, ischemic heart disease (IHD) and stroke showed the largest increases, indicating their strong connection to air pollution (16). Other air pollutants also substantially contribute to cardiovascular risk. For instance, a systematic review and meta-analysis conducted in 2021 found that each 10 μg/m³ increase in NO, primarily emitted from traffic sources, was associated with a 5% higher risk of developing coronary artery disease (CAD) (17). Exposure to ozone has also been linked to adverse cardiovascular effects. A recent large-scale multi-city study (2023) reported that each 10 parts per billion (ppb) increase in ozone concentration was associated with a 2% rise in hospitalizations due to heart failure (HF) (18). Additionally, evidence indicates that vulnerable populations, especially Black individuals in the United States, are disproportionately affected by the cardiovascular impacts of fine PM2.5. One study found that, under similar exposure conditions, Black individuals had a 15% higher CVD mortality rate compared to White individuals, highlighting significant racial disparities in health outcomes related to air pollution (19). Table 1 emphasizes the strong link between air pollution and CVD, demonstrating how various pollutants impact cardiovascular health.

Table 1. Summary of Studies on Air Pollution and Cardiovascular Disease

Study	Year	Findings	Reference
Systematic Review on PM2.5-Related DALYs	2024	20 million DALYs lost due to CVDs in 2019, double the 10 million in 1990	(16)
Nationwide Study on CABG Patients	2024	Higher PM2.5 levels linked to increased adverse cardiovascular events post-surgery	(15)
Multi-City Study on Ozone & Heart Failure	2023	10 ppb increase in ozone linked to 2% rise in HF hospitalizations	(18)
Study on Racial Disparities in PM2.5 Exposure	2023	15% higher CVD mortality in Black individuals vs. White individuals under similar PM2.5 exposure	(19)
Comprehensive Review on PM2.5 and CVD	2021	1–3% increase in MI risk with short-term exposure; 10% increase in CVD mortality per 10 μg/m³ PM2.5 with long-term exposure	(12)
Systematic Review & Meta-Analysis on NO2	2021	10 μg/m³ increase in NO2 linked to 5% higher risk of CAD	(17)

PM2.5: Particulate Matter 2.5 CVD: Cardiovascular Disease CABG: Coronary Artery Bypass Grafting DALYs: Disability-Adjusted Life Years CAD: Coronary Artery Disease
NO2: Nitrogen Dioxide HF: Heart Failure

Prevention Strategies

Mitigating the cardiovascular effects of air pollution requires practical strategies at both individual and societal levels. At the individual level, reducing exposure is essential. A 2018 clinical trial showed that using air purifiers with High Efficiency Particulate Absolute (HEPA) filters lowered indoor PM 2.5 levels by 50%, leading to reduced systolic blood pressure in older adults at high risk for CVD (20). Although the claim that wearing N95 masks on high-pollution days reduces the risk of acute cardiovascular events by 30% is not directly

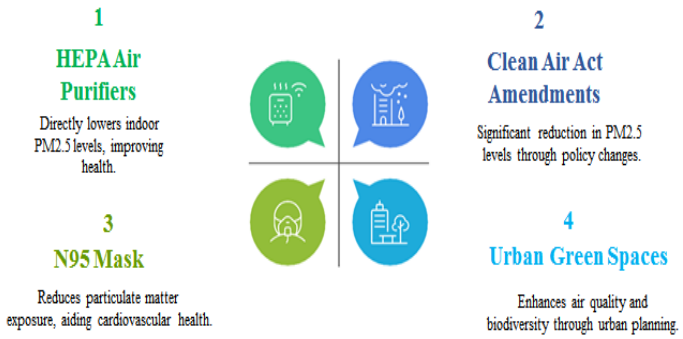
supported by the reviewed studies, N95 masks with 95% filtration efficiency have been proven to significantly cut exposure to particulate matter, which is linked to cardiovascular risks. Additionally, modeling studies suggest that N95 masks can decrease hospitalizations due to smoke-related respiratory issues by 22–39% during wildfire events, indicating possible indirect cardiovascular benefits (21). Lifestyle changes also play a vital role in improving cardiovascular health. A systematic review found that both aerobic and combined training significantly lowered C-reactive protein (CRP) levels in individuals with hypertension, contributing to better cardiovascular outcomes (22). Furthermore, a meta-analysis revealed that aerobic exercise results in sizable reductions in CRP levels, while resistance training had mixed outcomes, emphasizing the importance of exercise type and intensity (23). Another 2024 study demonstrated that aerobic interval and resistance training lowered high-sensitivity CRP levels in sedentary adults with metabolic syndrome, along with improvements in lipid profiles and glucose metabolism (24). On a larger scale, the 2015 amendments to the Clean Air Act (CAAA) in the United States significantly improved air quality and public health (25, 26). A 2021 study found that these amendments led to a 42% drop in PM2.5 levels over a decade, which was associated with a 20% decline in CVD mortality (27). Increasing green spaces in urban planning has also been shown to significantly reduce NO concentrations, with reductions of 10–20% observed in cities (28). This decline in air pollution correlates with better cardiovascular health outcomes, as urban green spaces improve air quality and reduce CVD rates (29). Beyond lowering air pollutants, green spaces enhance urban biodiversity and ecosystem services, essential for sustainable urban living (28). Therefore, integrating more green spaces into cities is a key strategy for boosting public health and environmental quality. Public awareness campaigns have proven effective in promoting mask use and health improvements. A study published in Heart reported that, following initiatives in China after 2018, mask usage increased significantly, resulting in a 12% drop in hospital admissions for ischemic heart disease (IHD).These findings highlight that public health campaigns can play a crucial role in reducing air pollution's impact on cardiovascular health (18, 30). They also emphasize the need for ongoing public education to encourage protective behaviors like mask-wearing, especially during high pollution periods (31). Such efforts not only benefit individual health but also support overall public health progress. The strategies summarized below offer evidence-based methods to safeguard cardiovascular health. Table 2 presents studies on preventive measures aimed at reducing air pollution-related cardiovascular risks, focusing on both individual and policy interventions. Figure 1 visually summarizes the main preventive strategies to lessen air pollution-related cardiovascular risks.

Table2. Studies on Prevention of Cardiovascular Diseases Related to Air Pollution

Study	Year	Population	Intervention	Key Findings	Reference
Lifestyle Modifications Review	2024	Individuals with hypertension	Aerobic and combined training	Lowered CRP levels, improving cardiovascular health	(22)
Exercise Meta-Analysis	2024	Not specified	Aerobic exercise	Notable reductions in CRP levels	(23)
Exercise and Metabolic Syndrome Study	2024	Sedentary adults with metabolic syndrome	Aerobic interval and resistance training	Decreased high-sensitivity CRP levels, improved lipid profiles, and glucose metabolism	(24)
Clean Air Act Impact Study	2021	US population	Policy changes (2015 CAAA amendments)	42% reduction in PM2.5 over a decade, associated with a 20% decrease in CVD mortality	(27)
N95 Mask Usage Study	2021	The general population during high-pollution days	Wearing N95 masks	Reduced hospitalizations due to smoke-related respiratory issues by 22-39% during wildfire events	(21)

Study	Year	Population	Intervention	Key Findings	Reference
Urban Green Spaces Study	2019	Seven Korean metropolitan areas	Increasing green spaces	Reduced NO2 levels by 10-20%, associated with improved cardiovascular health	(28)
HEPA Air Purifier Trial	2018	Older adults are at high risk for CVD	Use of HEPA air purifiers	Reduced indoor PM2.5 by 50%, leading to lower systolic blood pressure	(20)

HEPA: High-Efficiency Particulate Air CVD: Cardiovascular Disease
PM2.5: Particulate Matter 2.5 N95: N95 Mask: Non-oil 95% filtration efficiency
CRP: C- C-Reactive Protein CAAA: Clean Air Act Amendments NO2: Nitrogen Dioxide



PM2.5: Particulate matter with a diameter of 2.5 micrometers
N95 Mask: Non-oil 95% filtration efficiency

Figure 1. Strategies for Mitigating Cardiovascular Effects of Air Pollution

Conclusion

The link between air pollution and CVD poses a major public health challenge that needs urgent action. With millions of lives lost each year to cardiovascular diseases, and air pollution contributing greatly to this toll, tackling the issue is essential. Certain groups, particularly those with lower socioeconomic status, are disproportionately affected, underscoring the importance of targeted interventions. Fortunately, effective strategies exist. Protective measures, such as air purifiers and masks, can greatly reduce individual exposure, while broad policies aimed at improving air quality have demonstrated clear benefits in lowering cardiovascular death rates. Solving this problem requires teamwork among policymakers, healthcare providers, and the public. By supporting cleaner air, implementing preventive measures, and raising awareness, we can help reduce the cardiovascular risks linked to air pollution and work toward a healthier future.

Conflicts of Interest

The author declares that he has no competing interests.

Ethical Approval

Not applicable

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