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Cardiovascular Dangers of Air Pollution

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Abstract

Cardiovascular diseases are the leading cause of global morbidity and mortality. Besides imparting a tremendous amount of human suffering, they also inflict huge direct and indirect financial costs on the worldwide society. With the ready availability of affordable therapeutics globally and the lack of newer innovations, preventive interventions are gaining increasing importance in the management of cardiovascular diseases. Air pollution is often a modifiable risk factor, and clean air can reduce the global burden of cardiovascular diseases. However, almost nine out of ten people on this earth are exposed to unacceptable levels of toxic air pollution. This paper reviews the effects of air pollution on cardiovascular diseases.

Key words: cardiovascular diseases; air pollution; $PM_{2.5}$; PM_{10}; CO; O_3; SO_2; NO_2

Introduction

Air pollution, both ambient and indoor, is a major global health problem [1]. It is responsible for considerable morbidity and disability, and an enormous number of premature deaths annually [2]. According to WHO, almost 91% of the world's population lives in places where the air is polluted [3]. Cities tend to be densely populated and bear the major brunt of ambient air pollution, as more than half the world's population resides in cities [4,5].

Common outdoor sources of ambient air pollution are vehicular and airplane traffic, power generation units, industrial facilities, or municipal and agricultural waste sites [6]. Indoor air pollution is primarily related to cooking (burning of oil, wood, coal, and food) and cigarette smoke, while house dust, mold spores, common consumer products such as cleaning materials and electronic appliances, and emissions from building materials also contribute [7-9]. Household air quality can be 2 to 5 times worse than outdoor air quality and people spend almost 90% of their time indoors (home or workplace) [10]. Air quality measurements are typically reported in terms of daily or annual mean concentrations of PM particles per cubic meter of air volume (m^3). Routine air quality measurements typically describe such PM concentrations in terms of micrograms per cubic meter ($\mu g/m^3$). WHO air quality guideline values, according to a document of May 2, 2018, are: 10 $\mu g/m^3$ annual mean and 25 $\mu g/m^3$ 24-hour mean for fine particulate matter ($PM_{2.5}$) and 20 $\mu g/m^3$ annual mean and 50 $\mu g/m^3$ 24-hour mean for coarse particulate matter (PM_{10}) [6].

The air pollutome is a complex mixture of gases and particulate matter (PM)n [11,12]. Gases include carbon monoxide (CO), sulfur dioxide (SO_2), nitrogen oxide (NO_2), and ozone (O_3)[1]. Particulate matter includes nitrates, sulfates, elemental and organic carbon, organic compounds, several biological compounds, and various metals [12]. Although both gaseous and particulate pollution is harmful to human health [13], PM exposure appears to be more dangerous [14]. PM is commonly classified based on size as coarse (aerodynamic diameter <10 μm; PM_{10}), fine (diameter <2.5 μm; $PM_{2.5}$), or ultrafine (<0.1 μm; $PM_{0.1}$) [15]. Coarse particles often appear as dust or haze and may affect the upper airways and cause mucosal irritation and cough. Finer particles are invisible and

toxic. While fine particles reach the lung alveoli, ultrafine particles easily cross the alveolar-capillary membrane and enter the bloodstream, causing not only vascular inflammation and endothelial dysfunction, but also deleteriously affecting virtually all cells in the body [15].

The Global Burden of Disease (GBD) study has recognized air pollution (both ambient and household) as a major risk factor for, morbidity, disability-adjusted life-years, and premature mortality [16-18]. Ambient and household air pollution affect nine out of ten people, globally [19]. Air pollution leads to several non-communicable diseases including cardiovascular diseases (CVD), respiratory diseases, neurodevelopmental disorders, birth defects, skin ailments, and many kinds of cancers [20]. Cohen and group estimate that air pollution is responsible for over 100 million years of life lost, adjusted to the number of years lived with disability [21] WHO reports that the combined effects of ambient (outdoor) and household air pollution results in almost seven million premature deaths every year [22] According to the Lancet Commission on pollution and health, these represent three times more premature deaths than AIDS, tuberculosis, and malaria combined [23]. Air pollution has also caused 15 times more deaths than all wars and other violent causes combined [23]. A recent GBD report ranked ambient air pollution eighth in a list of 79 mortality risk factors [24]. Air pollution-related health burden leads to a significant direct and indirect cost for the community [25].

Air pollution is an important preventable and modifiable risk factor of cardiovascular disease [26].

Discussion

CVDs are a major cause of non-communicable diseases in the world [27]. They are also the number one killer globally, being responsible for at least 19 million of the 56 million annual deaths worldwide [18,28].

Air pollution causes harm to multiple bodily organs with the cardiovascular system often the main target of its harmful effects [29,30]. Air pollution also increases cardiovascular mortality [30-32]. The Women's Health Initiative Observational Study found that every 10 $\mu g/cm^3$ increase in $PM_{2.5}$ was associated with a 76% increase in fatal cardiovascular events [31]. The Nurses' Health Study found that every 10 $\mu g/cm^3$ increase in PM_{10} was associated with a 43% increase in fatal coronary heart disease [32]. The Global Burden of Diseases study estimated that in 2015, air pollution accounted for 19% of all cardiovascular death, 21% of deaths due to stroke, and 24% deaths due to ischemic heart disease [30].

Pollution exposure not only deleteriously affects the lipids, but also increases vascular oxidative stress, endothelium dysfunction, atherosclerosis, and thrombo-inflammation [33-36]. It is also associated with autonomic imbalance, disturbed cardiovascular hemodynamics, and electrical instability [37-39].

CVDs include coronary artery/heart disease (CAD/CHD) high blood pressure (HTN), stroke, heart failure (HF), cardiac arrhythmias (including sudden cardiac death (SCD)), congenital heart disease (CoHD), peripheral arterial disease (PAD), vasculogenic erectile dysfunction (ED) and venous thromboembolism (VTE) [29].

Pollution and HTN

HTN is a major public health problem worldwide [40]. It is responsible for an enormous cardiovascular disease burden and was associated with 10.4 million deaths in 2017 [41-42].

Several studies from all over the world have shown that air pollution significantly increases the incidence of hypertension [43]. A study from China found an association of both gaseous and particulate air pollutants to be associated with hypertension in men [44]. A study from Canada reported that an increase of 10 $\mu g/m^3$ of $PM_{2.5}$ significantly increased the incidence of hypertension in Ontario [45]. A study from Switzerland demonstrated that even short-term exposure to low levels of air pollution (PM_{10}) was associated with a significant increase of systolic and pulse pressure [46]. Studies implicate indoor air pollution and exposure to road traffic pollution as major risk factors for the development of hypertension [47,48]. Exposure to PM has also been shown to increase the risk of gestational hypertension and pre-eclampsia [49].

Pollution and Coronary Disease

CAD/CHD is an atherosclerotic process progressing to plaque formation in the coronary arteries [50]. This can cause a non-fatal or fatal myocardial infarction, even if the lesion is non-stenotic [51].

Several observational studies indicate an association between PM exposure and subclinical atherosclerosis [52]. Studies have documented the enhancing effects of air pollution on the development of high-risk coronary plaques, coronary artery calcification, and myocardial infarction [53-55]. An increase in myocardial infarction has been seen after both short-term and long-term exposure [56.57]. An association with CHD mortality has also been noted with $PM_{2.5}$ exposure [58,59].

Pollution and Stroke

Stroke is a leading cause of long-term disability and the second leading cause of death in the world [60]. The lifetime risk of stroke is on the increase [61].

The strong association between air pollution and the increased incidence of stroke is well established [62]. Both short-term and long-term exposure to air pollution increases stroke [63,64]. A meta-analysis of 94 studies, found that short-term exposures to $PM_{2.5}$ (per 10 $\mu g/m^3$ increase during the prior few hours-to-days) increased the risk for stroke by 10% [65]. A recent prospective cohort study from China (117,575 individuals) found that residential exposure to $PM_{2.5}$ over the long term increased the risk of incident stroke by 13%, ischemic stroke by 20%, and hemorrhagic stroke by 12%, for each increase of 10 $\mu g/m^3$ [66]. Air pollution exposure also leads to an increased risk of stroke-related hospital admission and mortality [67].

Pollution and Heart Failure

Heart failure (HF) affects 26 million people globally and is responsible for considerable suffering [68,69]. These patients are prone to recurrent hospitalizations and have poor survival [70,71]. Its prevalence is on the rise [72]. HF has an estimated annual cost of $108 billion, globally [73].

Several meta-analytic studies have linked $PM_{2.5}$ exposure with heart failure [74]. In humans, short-term air pollution exposure, to carbon monoxide, sulfur dioxide, nitrogen dioxide, or particulate matter <2.5 μm is associated with increased HF hospitalization and mortality [74,75]. Ward-Caness and group estimated that an increase of 1 $\mu g/m^3$ in annual average $PM_{2.5}$ at the patient's residence is associated with a 13% higher mortality risk in heart failure patients [76]. Shah et al estimated that almost 8000 heart failure-related hospitalizations in the USA can be prevented by reducing median daily $PM_{2·5}$ concentrations by a mean of 3·9 $\mu g/m^3$ [74].

Pollution and Arrhythmias

Cardiac arrhythmia is defined as any change from the normal sequence of electrical impulses [77]. Arrhythmia is a common cardiovascular event and is associated with increased cardiovascular health risks, such as heart failure and stroke, resulting in reduced quality of life, increased disability, high rate of premature mortality, and increased medical care costs [78,79].

Air pollution has been implicated in the pathogenesis of heart rhythm disturbances, both of supraventricular and ventricular origin [80,81]. Several gases, including NO_2, O_3, and CO have all been shown to be hazardous to the cardiac rhythm [82,83]. Particulate matter, especially $PM_{2.5}$ has also been linked to an increased risk of arrhythmias and appears to have a stronger deleterious effect than gaseous pollution [84,85]. In a meta-analysis of 23 studies. Song et al found that short-term exposures to $PM_{2.5}$ (10 $\mu g/m^3$ or more increase during the prior few hours-to-days) significantly increased the risk for arrhythmia [86]. Ventricular pro-arrhythmic activity related to air pollution has been described, in healthy participants. older participants, heavy alcohol drinkers, diabetics, those with BMI >25, and the physically inactive [86-89]. About 15% of all deaths and 50% of deaths due to CVD are caused by sudden cardiac death (SCD), and approximately 80% of these SCDs are due to ventricular arrhythmias [90]. In a study conducted on >5000 individuals in Rome, both PM and CO on the day of exposure predicted SCD [91]. A study conducted in Sao Paulo also reported that ventricular tachycardia and fibrillation were also positively associated with increases in CO, NO_2, and PM_{10} in the ambient air [92]. Other studies have noted similar associations, including in patients with implantable cardioverter-defibrillators [93-95]. Both particulate and gaseous components in the air pollutome are associated with increased cardiac arrest and cardiac mortality [96].

Pollution and Valvular Diseases

Valvular heart disease may be due to congenital, rheumatic, or degenerative heart diseases [97]. Valvular diseases often lead to the development of cardiac arrhythmias and heart failure [98]. They are associated with high rates of disability and increased mortality [99].

Excessive exposure to $PM_{2.5}$ appears to result in an increased progression of mitral annular calcification [100]. Road traffic-related air pollution is harmful for ventricular function and is therefore associated with an increased prevalence of tricuspid and mitral regurgitation [101].

Congenital Heart Disease

Congenital heart defects are common and may lead to intra-uterine or immediate post-birth death [102,103]. Because of advances in care and treatment, most of the live births with CoHD now survive into adulthood [104].

Ritz and associates found a relationship between exposure to CO with ventricular septal defects and exposure to O_3 with valvular, aortic, and truncal defects [105].

Heart Transplant

Heart transplantation not only improves the quality of life but provides additional 10.7 years of survival to terminal HF patients [106].

Air pollution can have a detrimental effect on these patients also. In a study by Al-Kindi et al, annual exposure to $PM_{2.5}$ per $10ug/m^3$ increment increased mortality by an average of 26% in heart transplant patients [107].

Pollution and PAD

PAD, diagnosed by an ABI <90, is an indication of systemic atherosclerosis and is associated with a 2-fold increased risk (over 10 years) of all-cause mortality, cardiovascular mortality, and major coronary event rate. It also results in a significant functional decline [108-110].

Air pollution exposure, including that from road traffic, is strongly associated with atherosclerosis [111]. Ward-Caviness and group noted that individuals living closer to road traffic exhibited a higher risk of PAD [112]. Hoffmann et al determined that the safe distance for significantly avoiding exposure to road traffic-related air pollution may be 200 meters away from a major road [113]. They found that living within 50 meters of a major road increased the risk of PAD by 77% when compared to those living 200 meters away [113].

Pollution and Erectile Dysfunction

Erectile dysfunction (ED), defined as the inability of a man to achieve or maintain an erection [114]. It is a common disorder in men, often associated with conditions such as diabetes mellitus and other cardiovascular diseases [115,116]. ED often leads to depression and reduced quality of life [117,118].

ED shares several common risk factors implicated in other cardiovascular diseases, including air pollution [119]. Exposure to $PM_{2.5}$ is associated with increased oxidative stress, vascular inflammation, endothelial dysfunction, and atherosclerosis

[120,121]. Endothelial dysfunction and atherosclerosis are both strongly associated with ED [122]. Tallon et al, found in their research that exposure to $PM_{2.5}$ was consistently associated with higher odds of developing ED [123]. Gasoline vehicular exhaust exposure has also been deleteriously linked with ED [124].

Pollution and Venous Disease

Venous thromboembolism (VTE) comprises deep-vein thrombosis (DVT) and pulmonary embolism (PE) [125-127]. DVT, besides being associated with PE, may result in post-thrombotic syndrome which is associated with significant health impairment and leads to frequent long-term major disability [128]. PE is an extremely dangerous condition with a high fatality rate [129].

Several animal studies show that air pollution is associated with an increase in thrombus formation [130]. Air pollution is associated with higher blood viscosity, elevated homocysteine levels, increased platelet aggregation, increased coagulation activity, and decreased prothrombin time [131-135]. However, the association between air pollution and VTE remains somewhat inconsistent [136,137]. A systematic review of 11 studies found a positive association between air pollution and VTE risk [136], while another meta-analysis involving several studies involving 700.000 events found no significant association [137].

Pollution and CVD risk factors

Pollution is also associated with many other CVD risk factors, such as diabetes mellitus, dyslipidemia, metabolic syndrome, obstructive sleep apnea, and atherosclerosis [138-143].

Conclusion

Air pollution is a major health concern all over the world. Common sources are industrial facilities, heat and power generation units, industrial and agricultural waste sites, vehicular and airplane traffic, cigarette smoke, and residential use of polluting fuels. These emit several environmental air pollutants including carbon monoxide, nitrogen dioxide, sulfur dioxide, ozone, and particulate matter. Particulate matter is made up of nitrates, sulfates, and organic carbon, organic compounds, endotoxin, cell fragments, and a variety of metals. Particulate matter is broadly defined as coarse (PM_{10}:<10 µm) or fine ($PM_{2.5}$:<2.5 µm) according to their aerodynamic diameter. Both acute and chronic exposure to these, especially $PM_{2.5}$ or smaller particles, increases the risk of cardiovascular morbidity and mortality. Air pollution is a potentially modifiable cardiovascular risk factor.

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