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Pulmonary Health Effects of Air Pollution

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Abstract

Purpose of the review—Air pollution continues to be a major public health concern affecting nine out of ten individuals living in urban areas worldwide. Exposure to air pollution is the ninth leading risk factor for cardiopulmonary mortality. The aim of this review is to examine the current literature for the most recent updates on health effects of specific air pollutants and their impact on asthma, chronic obstructive pulmonary disease (COPD), lung cancer and respiratory infection.

Recent findings—A total of 53 publications were reviewed to establish new insights as to how air pollution is associated with pulmonary morbidity and mortality. Considerable past evidence suggests that air pollution is an important factor that enhances pulmonary disease, while also causing greater harm in susceptible populations, such as children, the elderly and those of low socio-economic status worldwide. Asthma, COPD, lung cancer and respiratory infections all seem to be exacerbated due to exposure to a variety of environmental air pollutants with the greatest effects due to particulate matter (PM), ozone and nitrogen oxides. New publications reviewed reaffirm these findings.

Summary—Continued vigilance will be essential to lessen the effects of air pollution on human health and pulmonary disease. Cooperation at a multi-national level will be required on the part of governments, industry, energy-based enterprises and the public working together to solve our air quality issues at the local, national and global level.

Keywords

particulate matter; ozone; criteria pollutants

1. Introduction

Ambient air pollution is a major global public health problem, affecting both developing and developed countries. Many developing countries derive energy from natural, inexpensive

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Conflicts of interest

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sources for industrial, commercial and living purposes, but do not have sufficient technologies to mitigate potential air pollution arising from these energy sources. According to the World Health Organization (WHO) Ambient Air Pollution database, derived from measurements taken in 1600 cities in 91 countries, almost nine out of ten individuals living in urban areas are affected by air pollution [1]. Exposure to outdoor air pollution is the ninth leading risk factor for mortality, and outdoor air pollution is responsible for 3.2 million deaths each year [2]. Recent studies show that exposure to air pollution is associated with acute and chronic cardiopulmonary mortality and all cause mortality [3-5]. The aim of this review is to examine the current literature for the most recent updates on health effects of specific air pollutants and their impact on asthma, chronic obstructive pulmonary disease (COPD), lung cancer and respiratory infection. A total of 53 publications were assessed and included in the review to relay the current state of knowledge as to how air pollution is associated with pulmonary morbidity and mortality. The included literature covers epidemiologic, controlled human, and animal toxicologic studies.

2. Components of modern day ambient air pollution

Current air pollution frequently found in urban areas is a dynamic and complex mixture of both man-made (anthropogenic) pollutants and natural sources. Six common ambient air pollutants are particulate matter (PM), ozone (O₃), sulphur dioxide (SO₂), nitrogen oxides (NO_x), carbon monoxide (CO), and lead. In the United States, these primary air contaminants are classified as “criteria” pollutants by the Environmental Protection Agency. National Ambient Air Quality Standards have been set for each of these pollutants, by law, which must undergo an extensive literature review update every five years to ensure adequate health protection of the public. These same pollutants are found worldwide to differing degrees, but all are associated with adverse human health, as discussed below.

A recent review of global premature mortality due to outdoor air pollution by Lelieveld et al., found that fine PM (PM_{2.5}) is estimated to cause 3.3 million deaths per year worldwide[6]. PM is mainly formed through industrial processes and traffic-related sources (gasoline and diesel), coal and oil fuel combustion, farming and road construction. PM is commonly subdivided into three size classifications: coarse particles with diameters 2.5 to 10 µm (PM₁₀), fine particles with diameters less than 2.5 µm (PM_{2.5}), ultrafine particles with diameters less than 0.1 µm (UF). Traffic-related sources of PM are thought to be responsible for approximately 20% of air pollution-related mortality in Germany, the United Kingdom and the United States [6]. Coarse particles are often caused by disturbances of crustal materials (dust) and are a problem in the Middle East and other desert areas due to dust storms. Throughout the world residential and commercial energy use is linked to premature mortality, but is especially prevalent in Asia, where biofuel used for heating and cooking produces high levels of fine PM[6]. The potency of PMs in causing an adverse health impact is dependent, in part, on their deposition in the airways and the composition of their surface components[7]

As urban centers increase in size and the global climate continues to change, it is estimated that ground level ozone (ozone smog) will become an even greater of health hazard. Ozone smog forms when nitrogen oxides and volatile organic compounds from vehicle, power, and

other sources mix with sunlight and heat. As such, as the temperature increases, ozone formation increases. Other criteria pollutants, such as SO₂, NO_X, and CO, which are produced by fossil fuel combustion will continue to contribute to air pollution in large urban areas as well, especially in dense cities, such as those in Asia.

3. Influences in the distribution of today's air pollution

Indoor air pollution can also be a source of exposure to air contaminants, made up of multiple pollutants, including environmental or secondhand smoke, combustion of solid fuels for home heating and cooking, formaldehyde, volatile organic compounds, and intrusion of ambient air pollution. A primary source for global household air pollution is the incomplete combustion of biofuels resulting in high levels of chemical components such as carbon monoxide, sulfur oxides, nitrogen oxides, particulates, benzene, formaldehyde, polyaromatic compounds, arsenic, and lead. Its relative contribution to human exposure can be relatively high, based on the time spent indoors.

A more recent concern has been the atmospheric findings of transport of PM, ozone and even infectious components over large distances, including dust from Mongolia to the Western United States as well as Saharan dust crossing the Atlantic to deposit in countries of the Caribbean. Climate change and air quality are also closely related. Recent data suggest that climate change is associated with elevations of both ozone and PM in the atmosphere[8].

4. Pulmonary Health Effects

4.a. Lifestages for susceptibility to air pollution

Children and adolescents are more susceptible to the effects of air pollution than adults. The human respiratory system develops *in utero* to adolescence. Although lung function development continues in girls until their late teens and in boys until their early 20s, from birth to approximately 6 years of age represents the greatest period of postnatal development, with formation of more than 80% of new alveoli following birth. Susceptibility to the adverse health effects of environmental and chemical toxicants may vary in different lung development stages. Environmental exposures can alter the development of both immune function and lung mechanics, including lung injury and repair [9]. Due to smaller airways, immature detoxification and metabolic systems, as well as frequent exposure to outdoor air, children are often more susceptible to airway toxicants than adults [10]. The good news is that long-term improvements in air quality have recently been shown to result in statistically and clinically significant positive effects on lung-function growth in children and also adolescents from 11 to 15 years of age reported by Gauderman and colleagues in 2015 [11].

The elderly population has also been shown to be more susceptible to inflammation and respiratory complications due to air pollution. In the elderly, particle clearance might be less efficient or impaired by other dysfunctions.

4.b. Asthma

A 2015 study by Carosino et al demonstrated using an animal model that exposure to PM exacerbates allergic inflammation in the lung [12]. Ozone has also been shown to cause oxidative stress, inflammatory responses and immunologic disease in laboratory animals [13]. Li et al. have demonstrated that SO₂ affects the airway inflammatory and immune responses of asthmatic rats and enhances their susceptibility by aggravating inflammatory responses in the lung [14].

Exposure to air pollutants can lead not only to inflammation, but also changes in lung function. In 2013 Rice et al using The Framingham Heart Study found short-term exposure to PM_{2.5}, ozone, and NO₂ were associated with a lower FEV1 and FVC in nonsmoking adults [15]. In children Mölter et al. have reported that lifetime exposure to PM₁₀ and NO₂ may be associated with reduced growth in FEV1 [16]. A longitudinal cohort study reported in 2015 showed that long-term NO₂ and PM₁₀ exposure decreased lung function parameters (FEV1, FVC) [17]. Two studies of Chinese schoolchildren in 2013 and 2014, found long-term exposure to ambient air pollution was associated with a number of adverse effects, such as wheezing, cough or phlegm. Of interest was that PM₁₀ may be the most relevant pollutant associated with adverse effects as well as with impaired lung function [18, 19].

A large body of evidence also demonstrates an association between short-term exposure to air pollutants and the incidence of asthma exacerbations and hospital admissions. Short-term exposure to ozone has been shown to be significantly associated with increased hospitalizations in children [20]. Ierodiakonou and colleagues also recently found exposure to ambient air pollutants was associated with reduced lung function and increased airway responsiveness in asthmatic children [21].

Poor air quality due to high levels of ozone has been shown to not only contribute to the exacerbation of asthma, but to also be a cause in the development of asthma [22]. It is less clear what are the effects of other sources of air pollutants in asthma development, such as traffic-related emissions. However, a systematic review published in 2015 suggests that exposure in early childhood to traffic-related air pollution (TRAP) containing PM_{2.5} is associated with an increased incidence of asthma up to the age of 12 years [23]. However, the European Study of Cohorts for Air Pollution Effects (ESCAPE) found conflicting findings of no association between PM_{2.5}, PM₁₀ or NO₂ and the prevalence of childhood asthma [24]. This difference might be due to study design and/or multiple other causes of asthma in children. A Korean study published in 2015 demonstrated long-term exposure to TRAP may be associated with an increased risk of asthma, allergic sensitization and decreased lung function in schoolchildren depending on the proximity of their residence to a major road [25]. A study from Japan in 2014 of 10,069 children aged 6-9 years found TRAP associated with development of asthma [26]. Finally, in a recent review article of 2014, Trevor et al. shows a consistent relationship between biomass smoke and asthma symptoms [27].

Air pollution leading to adult-onset asthma still remains unclear. However, Young et al. in 2014 reported that PM_{2.5} exposure increases the risk of developing asthma in adult women [4]. In addition, a large 2015 European study of 23,704 adults followed ten years from eight

countries to show an association between TRAP (PM_{2.5}) exposure and increased asthma incidence in adults [28].

4.c. COPD

Chronic obstructive pulmonary disease (COPD) is most commonly associated with smoking, however, a new study of 2015 estimated the prevalence of COPD among nonsmokers varies from 1.1% to 40% in different countries [29]. The high incidence of COPD among non-smokers is in large measure associated with indoor air pollution from biomass combustion [30] and second-hand tobacco smoke. A recent 2014 study demonstrated that improving air quality in the home decreases the incidence of COPD [31]. Other risk factors for COPD include occupational exposures and outdoor air pollution. The fraction of COPD attributable to occupation in a study of 2015 was 31.1% among nonsmoking workers [29]. There are some epidemiologic studies showing an association between outdoor air pollution and COPD from both developing and developed countries [3, 32]. A 2014 meta-analysis study reported that outdoor air pollution was associated with an increase of COPD incidence and prevalence [33]. In the same review, the authors mentioned that a 10 µg/m³ increase of PM₁₀ in outdoor air can induce significant acute exacerbations of and mortality from COPD. A recent European review suggests a role of ambient air pollution and COPD[34]. Tsai SS. in 2013 that there is a strong relationship between air pollution and acute exacerbations of COPD-related hospital admission[35]. However, two cohort studies in 2014 and 2015 demonstrate limited evidence of associations between outdoor air pollution and COPD incidence[36, 37].

4.d. Lung Cancer

Cigarette smoking is considered the most important cause of lung cancer. However, cigarette smoking is not the sole cause for lung cancer; additional risk factors include environmental and occupational exposures. Yu et al. in a study published in 2015 found somatic genomic mutations attributed to household air pollution (associated with coal combustion) in tumor and adjacent normal lung tissues and peripheral blood samples from 164 patients with previously untreated non-small cell lung cancer (NSCLC) compared to patients also with NSCLC from other regions with low levels of household air pollution (coal combustion) [38]. In October 2013, the International Agency for Research on Cancer (IARC) accepted outdoor air pollution and related PM as a class I human carcinogen based on data from human, animal and mechanistic studies[39]. Concurrent epidemiological studies in 2013 and 2014 indicate a positive correlation between air pollutants and lung cancer after adjustment for cigarette smoking [40, 41]. A European study also reported an association between incidence of adenocarcinoma and air pollution [41]. A recent 2015 meta-analysis shows that ambient exposure to nitrogen oxides, SO₂, and PM_{2.5} from vehicle emissions significantly increases the risk of lung cancer [42]. Other studies also report that NO₂ exposures are positively associated with lung cancer risk [41, 43, 44] and have the strongest associations with all-cause mortality and lung cancer [45]. As with PM_{2.5}, positive correlations are reported based on a wide variety studies [46, 47]. A meta-analysis found that for each 10 µg/m³ increase in PM_{2.5}, a meta-relative risk for lung cancer of 1.09 occurred [48]. In a case-control study from Canada, a mixed exposure to PM_{2.5} and NO₂ was related with a larger risk for adenocarcinomas compared with other cancer subtypes

[49]. In a recent study and review in 2012 and 2015 found professional drivers exposed to diesel engine exhaust have an elevated risk of lung cancer [50, 51].

4.e. Respiratory infections

Only a limited number of studies have examined the relationship between air pollution and respiratory infections. Vulnerable populations appear to be children, the elderly and people with chronic illness. Two recent epidemiological studies published in 2012 and 2014 demonstrate associations between short-term air pollution (traffic-related PM, ozone and organic carbon-based PM_{2.5}), enhanced respiratory infection symptoms and increased emergency department visits by children [52, 53].

5. Conclusions

Concern for air pollution and its health implications continue to be a world-wide problem today. Air pollution remains a complex mixture of anthropogenic pollutants and natural sources. Of the six pollutants, PM and ozone represent the most widespread health threats for cardiopulmonary disease. Air pollution once thought of as purely a local or regional problem, now is recognised as a global issue with potential long distance atmospheric transport. Air pollution is an important contributor to respiratory complications, especially for developing countries who use biomass fuels and coal for heating and cooking in the home. It is essential that local, national and global efforts are undertaken by government, industry and the private sector to lessen the burden of air pollution to provide better respiratory health protection for everyone.

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Key points

- Almost nine of ten individuals living in urban areas worldwide are affected by air pollution.
- The lack of a fully developed pulmonary metabolic capacity in children make them more susceptible to air pollutants compared to adults.
- Air pollution continues to be associated with reduced lung function and enhanced airway reactivity in children suffering from asthma.
- Prolonged exposure to air pollution exposes children to an increased risk of developing asthma.
- Air pollution and ambient exposure to nitrogen oxides, SO₂, and PM_{2.5} from vehicle emissions significantly increase the risk of lung cancer.
- Short-term episodes of air pollution in children can heighten respiratory infection symptoms and the frequency of emergency room visits.