Climate change and air pollution

Effects on pollen allergy and other allergic respiratory diseases

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Summary

The observational evidence indicates that recent regional changes in climate, particularly temperature increases, have already affected a diverse set of physical and biological systems in many parts of the world. Allergens patterns are also changing in response to climate change and air pollution can modify the allergenic potential of pollen grains especially in the presence of specific weather conditions.

Although genetic factors are important in the development of asthma and allergic diseases, their rising trend can be explained only by changes occurring in the environment and urban air pollution by motor vehicles has been indicated as one of the major risk factors responsible for this increase.

Despite some differences in the air pollution profile and decreasing trends of some key air pollutants, air quality is an important concern for public health in the cities throughout the world.

Due to climate change, air pollution patterns are changing in several urbanized areas of the world with a significant effect on respiratory health. The underlying mechanisms of all these interactions are not well known yet. The consequences on health vary from decreases in lung function to allergic diseases, new onset of diseases, and exacerbation of chronic respiratory diseases. In addition, it is important to recall that an individual's response to pollution exposure depends on the source and components of air pollution, as well as meteorological conditions. Indeed, some air pollution-related incidents with asthma aggravation do not depend only on the increased production of air pollution, but rather on atmospheric factors that favor the accumulation of air pollutants at ground level.

Associations between thunderstorms and asthma morbidity of pollinosis-affected people have also been identified in multiple locations around the world (**Fig. 1**).

A factor clouding the problem is that laboratory evaluations do not reflect what happens during natural exposition.

Considering these aspects, governments worldwide, international organizations, and cooperations such as the World Health Organization (WHO) and the European Health Policy of the European Union (EU) are facing a growing problem of the respiratory effects induced by gaseous and particulate pollutants arising from motor vehicle emissions.

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Abbreviations

BALF	Bronchoalveolar lavage fluid
CO_2	Carbon dioxide
DEP	Diesel exhaust particle
EU	European Union
GM-CSF	Granulocyte-macrophage colony-stimulating factor
IL	Interleukin
IPCC	Intergovernmental Panel on Climate Change
NAAQS	National Ambient Air Quality Standards
O_3	Ozone
PAH	Polycyclic aromatic hydrocarbons
PM	Particulate matter
SO_2	Sulphur dioxide
UFPM	Ultrafine particulate matter
WHO	World Health Organization

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Fig. 1: Under wet conditions or during thunderstorms pollen grains may, after rupture by osmotic shock, release part of their cytoplasmic content into atmosphere.

Introduction

Global earth's temperature has markedly risen over the last 50 years due to the increase in greenhouse gas emissions, largely from anthropogenic sources. Changes are also occurring in the amount, intensity, frequency, and type of precipitation as well as in the increase of extreme events like heat waves, droughts, floods, thunderstorms, and hurricanes and these are a real and daunting problem [1–10].

The massive increase of air pollution due to economic and industrial growth during the last century led to a first order environmental problem in a large number of European and North American countries and is currently becoming an emerging problem in other regions of the world [1–43].

Air pollution is convincingly associated with many signs of asthma aggravation (increased bronchial hyper-responsiveness, visits to emergency departments, hospital admissions, increased medication use, etc.) [1, 8, 9, 16–19]. Moreover, sensitive techniques to analyze time-series data have shown that there are clear adverse effects on mortality rates due to current levels of air pollution [2, 3, 15].

Furthermore, several air pollutants, in particular carbon dioxide (CO_2) and ozone (O_3), are in the list of greenhouse gases which are involved in global warming [2–4, 7–9].

It is unlikely that global climate change can be explained without anthropogenic forcing. As stated in the Working Group I Report of the Intergovernmental Panel on Climate Change (IPCC) "most of the observed increase in globally averaged temperatures since the mid-20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations" [2, 3]. A rapid rise in the number of hot days was also observed and severe meteorological events such as the 2003 and 2012 heat waves with temperatures up to 35 °C and higher resulted in excess deaths in Europe [5, 6, 20]. Moreover, climate scenarios for the next century predict that the warming will be associated with more frequent and more intense heat waves in wide areas of our planet with increased risk of wildfires and desertification. In urban areas, the effects are higher since climate change influences outdoor air pollution because of a strict correlation between generation and dispersion of air pollution and local patterns of temperature, wind, and precipitation.

Climate change has also led to water deprivation in certain areas often associated with population migration and the effects on health as a result of mass population movement.

Atopy and asthma are more prevalent in industrialized countries compared with undeveloped and less affluent countries. The effect on health of migration is age-related and time-dependent: younger persons and an increasing duration in the new environment increases the likelihood of developing atopy and asthma.

Climate changes will contribute to the development of atopy and respiratory diseases [8, 21].

A number of reports on time trends in allergic respiratory diseases and bronchial asthma have shown a substantial increase in the prevalence of these diseases since the early 1960s [1, 12–14].

There is also a link between climate changes and air pollution and the individual's response to the source and components of air pollution and to climatic factors [4, 7–11]. Some air pollution-related episodes of rhinitis and asthma exacerbation are caused by climatic factors that favor the accumulation of air pollutants (e.g., O_3) at ground level. However, the effects of air pollutants on lung function depend on the one hand on the environmental concentration and duration of the pollutants and on the other hand on the duration of exposure.

Greenhouse gas emissions

The key determinants of greenhouse gas emissions are energy production, house heating, transportation, agriculture and food production, and waste management. Attempts at mitigating climate change will need to address each of them. However, while there is some uncertainty about predicting future meteorological trends, whatever interventions may be put in place to ameliorate climate change, it is likely that the world will have more hot days, fewer frost days, and more periods of heavy rain and consequent flooding [2–4]. Paradoxically it is likely, that there will be more periods of drought. A huge increase in CO_2 concentrations during the last two decades was measured. However, it is important to consider that after reduction of CO_2 emissions and stabilization of atmospheric concentrations the surface air temperature will continuously and slowly rise for at least one century.

The most abundant components of air pollution in urban areas are NO_2, O_3, and particulate matter (PM). SO_2 is particularly abundant in industrial areas. More than 50 % of the population of the United States are estimated to live in areas where levels of NO_2, O_3, SO_2, and particulates exceed the current National Ambient Air Quality Standards (NAAQS), as monitored by the US Environmental Protection Agency [2, 3]. With its particulate and gaseous emissions, road traffic contributes to air pollution in most urban areas. Although associations between air pollution and respiratory diseases are complex, recent epidemiological studies have led to an increased recognition of the emerging importance of traffic-related air pollution in both developed and less-developed countries [2, 3]. A number of experimental and epidemiological studies confirmed the negative effect of urban air pollution on human health and on allergic respiratory diseases [1, 7–11, 21, 22] and projections of climate variability suggest an increase in these effects during the next decades.

Nitrogen dioxide

Car, truck, and power plant exhausts are the most significant sources of outdoor NO_2, which is a precursor of photochemical smog found in urban and industrial regions. Also, in conjunction with sunlight and hydrocarbons NO_2 results in the production of O_3. Like O_3, NO_2 is an oxidizing pollutant, but with a lower chemical reactivity than O_3. NO_2 exposure is associated with increased emergency room visits, wheezing, and medication use among children with asthma [23]. Controlled exposure studies on asthmatics have shown that NO_2 can enhance the allergic response to inhaled allergens and NO_2 concentrations in ambient air are also reportedly associated with cough, wheezing, and shortness of breath in atopic subjects [7–11, 22].

Ozone

O_3 is generated at ground level by photochemical reactions involving NO_2, hydrocarbons, and UV radiation. O_3 inhalation induces epithelial damage and consequent inflammatory responses in the upper and lower airways as shown by increased levels of inflammatory cells and mediators in nasal and bronchoalveolar lavage [23].

About 40–60 % of inhaled O_3 is absorbed in the nasal airways, the remainder reaching the lower airways. Exposure to increased atmospheric levels of O_3 induces reduction of lung function, increased airway hyperreactivity to bronchoconstrictor agents, and is related to an increased risk of asthma exacerbations in asthmatic subjects [8–11, 22]. Epidemiologic studies have provided evidence that high ambient concentrations of this air pollutant are associated with an increased rate of asthma exacerbations, increased hospital admissions, and/or emergency department visits for respiratory diseases, including asthma. Furthermore, several studies suggest that O_3 increases asthma morbidity by enhancing airway inflammation and epithelial permeability [7–11].

O_3 exposure significantly increases levels of inflammatory cells (in particular neutrophils) and mediators such as Interleukin(IL)-6, IL-8, granulocyte-macrophage colony-stimulating factor (GM-CSF), and fibronectin in bronchoalveolar lavage fluid (BALF) of asthmatic subjects [21, 22].

It has been speculated for a long time that O_3 and other pollutants may render allergic subjects more susceptible to the antigen they are sensitized [7–9]. It has been observed that the incidence of new diagnoses of asthma is associated with heavy exercise in communities with high concentrations of O_3, thus, air pollution and outdoor exercise could contribute to the development of asthma [21, 22].

However, it is important to take into account that physical exercise in polluted areas results in greater deposition of air pollutants, including allergen-carrying particles, in the lower airways.

The acute health effects of exposure to ambient O_3 have been examined in many geographical regions. Potential adverse effects include decrease in lung function, airway inflammation, symptoms of asthma, increases in hospitalization due to respiratory diseases, and excess mortality. O_3 exposure has both a priming effect on allergen-induced responses and an intrinsic inflammatory action in the airways of allergic asthmatics [4, 9–11, 22].

In the long term, continuous exposure to high O_3 levels impairs respiratory function and causes or exacerbates airway inflammation in healthy subjects and atopic asthmatics. At the population level, long-term exposure to O_3 may reduce lung function in schoolchildren and adults and increase the prevalence of asthma and asthmatic symptoms [21, 22]. In addition, studies have shown that asthma can be exacerbated by O_3, as measured by increased visits to emergency departments on days with higher levels of O_3 and other pollutants [7–9].

Traffic-related air pollution, particulate matter, and diesel exhaust particles

There is evidence that living near high-traffic roads is associated with impaired respiratory health including asthma [16–19]. First, McConnell et al. [21] observed that the incidence of newly diagnosed asthma in children is associated with physical exercise in areas with high concentrations of O_3 and PM. Since then, other prospective cohort studies have indicated that long-term exposure to traffic pollution could contribute to the development of asthma-like symptoms and allergic sensitization in children

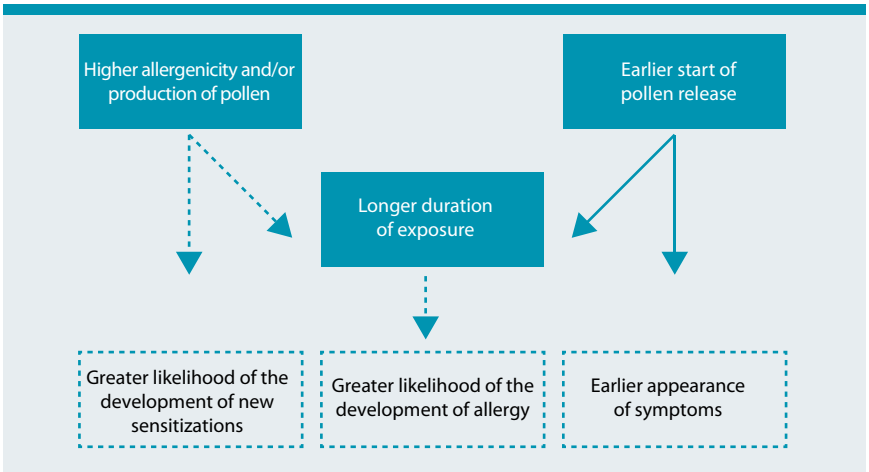

Fig. 2: Observed (solid arrows) and projected (dotted arrows) effects of climate change on pollen allergy

[18, 19]. Potential long-term effects of traffic exhaust on the development of allergic sensitization were only assessed in the four European birth cohorts.

Long-term exposure to outdoor air pollutants had no association with sensitization in ten-year-old schoolchildren in Norway [24]. These studies, however, are flawed by the fact that no objective assessment of air pollution concentrations was available. Individual exposure was estimated by the distance from the highways.

PM is a mixture of organic and inorganic solid and liquid particles of different origins, size, and composition. It is a major component of urban air pollution and has the greatest effect on health. Penetration of the tracheobronchial area is related to particle size and the efficiency of airway defence mechanisms. Ultrafine particulate matter (UFPM), with diameters of 0.1 µm or less, is a major component of vehicles' emissions. These particles accumulate into larger fine PM with a diameter of ≤ 2.5 mm ($PM_{2.5}$, particulate matter with a diameter of 2.5 mm or less), within short distances from the point of release. PM_{10} consists of $PM_{2.5}$ and larger particles of mainly crustal or biological origin including many aeroallergens. On the basis of epidemiological and laboratory studies, $PM_{2.5}$ appears to be a more potent agent for the development of respiratory and cardiovascular disease compared with PM_{10} [16, 17, 25]. PM_{10} can penetrate the lower airways, $PM_{2.5}$, is thought to constitute a notable health risk since it can be inhaled more deeply into the lungs at the alveoli level. While human lung parenchyma retains $PM_{2.5}$, particles larger than 5 µm. Particles smaller than 10 µm reach the proximal airways only, where they are eliminated by mucociliary clearance if the airway mucosa is intact [7–9].

A large portion of urban PM originates from diesel engines, as diesel exhaust particles (DEPs) which includes other components such as polycyclic aromatic hydrocarbons (PAH). DEPs account for up to 90 % of airborne PM in the world's largest cities and are composed of fine (2.5–0.1 µm) and ultrafine (0.1 µm) particles, which can also can coalesce to form aggregates of varying sizes [25].

PM_{10} levels have been associated with early respiratory exacerbations in children with persistent asthma and with higher prevalence rates even after having considered the dispersion of the particles. Although there is compelling evidence that ambient air pollution exacerbates existing asthma, the link with the development of the asthma syndrome is still less well established, as few studies provide extensive exposure data. Researches have elucidated the mechanisms whereby fine particles induce adverse effects; they appear to affect the balance between antioxidant pathways and airway inflammation. Gene polymorphisms involved in antioxidant pathways can modify responses to air pollution exposure. Acute exposure to diesel exhaust causes specific effects like irritation of nose and eyes, headache, lung function abnormalities, respiratory changes, fatigue, and nausea, while chronic exposure is associated with cough, sputum production, and diminished lung function [16–19, 25].

Studies have demonstrated inflammation in the airways of healthy individuals after exposure to diesel exhaust and DEPs and elevated expression and concentrations of inflammatory mediators have similarly been observed in the respiratory tract after diesel exhaust and DEP exposure [19, 25]. Even if an increased sensitivity of asthmatic individuals to the pro-inflammatory effects of DEPs has not been confirmed, some studies show a bigger effect of exposure to high-traffic roads in asthmatics compared to non asthmatic subjects, also accompanied by increases in levels of biomarkers of neutrophilic inflammation.

Effect of climate change on allergic respiratory diseases

A body of evidence suggests that major changes involving the atmosphere and the climate, including global warming induced by human activity, have an impact on the biosphere and human environment [2, 3].

Current knowledge on the worldwide effects of climate change on respiratory allergic diseases is provided by epidemiological and experimental studies on the relationship between asthma and environmental factors, like meteorological variables, airborne allergens, and air pollution.

Pollen allergy is frequently used to study the interrelationship between air pollution and allergic re-

spiratory diseases, e. g., rhinitis and asthma (**Fig. 2**). Epidemiologic studies have demonstrated that urbanization, high levels of vehicle emissions, and westernized lifestyle are correlated to an increase in the frequency of pollen-induced respiratory allergy prevalent in people who live in urban areas compared to those who live in rural areas [8–11].

Meteorological factors (temperature, wind speed, humidity, thunderstorms etc.) along with their climatic regimes (warm or cold anomalies and dry or wet periods etc.) can affect both biological and chemical components of this interaction. In addition, by inducing airway inflammation, air pollution overcomes mucosal barrier priming allergen-induced responses.

Climate changes might induce negative effects on respiratory allergic diseases favoring the increased length and severity of pollen season, the higher occurrence of heavy precipitation events, and the increasing frequency of urban air pollution episodes.

However, the relationship between air pollution, pollen exposure, and respiratory allergy is based on an individual's response to air pollution, which depends on the source and components of the pollution as well as on climatic agents and genetic constitution.

Thunderstorm-related allergic respiratory diseases and bronchial asthma in pollinosis subjects

There are observations that thunderstorms occurring during pollen season can induce severe asthma attacks in pollinosis patients [20, 43–67].

According to current climate change scenarios, there will be an increase in intensity and frequency of heavy rainfall episodes, including thunderstorms, over the next few decades, which can be expected to be associated with an increase in the number and severity of asthma attacks both in adults and in children.

Associations between thunderstorms and asthma morbidity have been identified in multiple locations around the world [43–67]. So called "thunderstorm asthma" is characterized by asthma outbreaks possibly caused by the dispersion of more respirable allergenic particles derived from pollen and spores by osmotic rupture.

The most prominent hypotheses for thunderstorm-related asthma are linked with bioaerosols and involve the role of rainwater in promoting the release of respirable PM [45, 57, 61].

After hydratation and rupture by osmotic shock during the beginning of a thunderstorm, pollen grains may release in atmosphere part of their cytoplasmic content, including inhalable, allergen-carrying paucimicronic particles such as starch granules and other cytoplasmic components.

Thunderstorm-related asthma outbreaks have been described in various geographical zones such as Birmingham [43], London [48–50], and Melbourne [44].

Thunderstorm-related asthma was observed in Naples, Italy, on June 3 and 4, 2004 [60, 61], when six adults and one child received treatment in emergency departments. One patient was admitted to an intensive care unit for a very severe bronchial obstruction and acute respiratory insufficiency. All individuals were outdoors when the thunderstorm struck. In one severe case, a female sensitized only to Parietaria pollen allergen, soon began to show symptoms of intense dyspnoea, which gradually worsened. She was taken to hospital where she was intubated and given high intravenous doses of corticosteroids. She was discharged a few days later. This patient had previously suffered from seasonal asthma but had been asthma-free for the past few years and did not need continuous therapy. None of the other six persons regularly took anti-allergic and/or anti-asthma drugs. All seven patients were sensitized with allergic respiratory symptoms upon exposure to Parietaria pollen but were not sensitized to grasses. Parietaria is an Urticacea that is widespread in the Naples area of Italy with a spring and summer pollen season that is, in part, coexistent with that of grasses. During the thunderstorm, the concentration of airborne Parietaria pollen grains was particularly high with a peak of 144 grains/m^3 being recorded on June 3, 2004 [60, 61]. Air pollution levels for both gaseous and particulate components based on the hourly concentrations of NO_2, O_3, and respirable PM were not particularly high in Naples on June 3 and 4, 2004. Subjects with sensitization to Parietaria who were indoors in Naples with closed windows during the night between June 3 and 4, 2004, did not experience asthma attacks. No moulds or viruses were involved in the Naples epidemics. However, there is a risk of relapse of thunderstorm-related asthma [20, 68].

In summary, the occurrence of these epidemics is closely linked to thunderstorm and they are limited to late spring and summer with high levels of airborne pollen grains. There is a close temporal association between the arrival of the thunderstorm, a major rise in the concentration of pollen grains, and the onset of epidemics. As a consequence, subjects affected by pollen allergy should be alert to the danger of being outdoors during a thunderstorm in the pollen season.

Conclusions

Exposure to air pollutants is largely beyond the control of individuals and requires action by public authorities at national, regional, and international levels. A multisectorial approach, engaging such relevant sectors as transport, housing, energy production, and industry is needed to develop and effec-

tively implement long-term policies to reduce the risks of air pollution to health. In other words, strategies to reduce climate changes and air pollution are political in nature, but citizen, in particular health professionals, and societies must continuously and persistently raise their voices in the decision process to give strong support for clean policies on both national and international levels [69, 70].

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Conflict of interest
The authors declare that they have no competing interests.

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