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CLIMATE CHANGE AND HEALTH

ASTHMA AND ALLERGIC DISEASES

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Introduction

Climate change is potentially the largest global threat to human health ever encountered. The earth is warming, the warming is accelerating, and human actions are largely responsible. If current emissions continue to increase, the next generations will face more disease, and death related to natural disasters and heat waves, higher rates of climate-related infections, and wide-spread malnutrition, as well as more allergic and air pollution–related morbidity and mortality. The global climate change and anticipated increases in prevalence and severity of asthma and related allergic diseases mediated through worsening ambient air pollution and altered local and regional pollen production are linked to each other. The pattern of change will vary regionally depending on latitude, altitude, rainfall and storms, land-use patterns, urbanization, transportation, and energy production. At best an average warming of 1 to 2°C is certain this century. Thus, anticipation of a higher allergic disease burden will affect clinical practice as well as public health planning.

The burden of disease from asthma and allergies is significant. The World Health Organization estimates that globally 300 million people currently have asthma, and approximately a quarter of a million people die of asthma annually [1]. In the United States, 20 million people, 6.2 million children younger than 18 years and 13.8 million adults, have active asthma [2]. Respiratory allergies are even more prevalent, affecting the quality of life of many millions of individuals worldwide, and often serving as triggers exacerbating asthma. Intergovernmental Panel on Climate Change (IPCC) has extensively and systematically analyzed data from contemporary direct observations, the historical record, and paleoclimatologic studies that led in an international consensus attributing current climate change substantially to human activity and describing anticipated effects on human health and other biological systems [3]. Ambient air pollutants such as nitrogen dioxide (NO_2), ozone, particulate matter (PM), and components of PM including organic carbon and volatile organic compounds (VOCs) have been linked with increased allergic disease and asthma [4,5,6]. Hospitalization for asthma increases after increases in levels of airborne PM [7,8,9]. Ozone exposure also exacerbates asthma, as shown in increased emergency department visits and hospitalizations [4,10]. Ozone exposure may also cause new-onset asthma. A study of a cohort of 3535 Southern California school children with

no history of asthma revealed new asthma cases in 265 of these children over a period of 5 years that were linked to outdoor aerobic activity in areas with increased ozone levels [6].

A British study [11] found that children admitted to the hospital for asthma were more likely to reside in a high–traffic exposure area (>24,000 vehicles/24 h at the nearest segment of main road) than those admitted to the hospital for nonrespiratory reasons ($P < .02$) or children without chronic disease ($P < .002$). A German study [12] of a group of 7509 school children found that increased exposure to traffic correlated with active asthma, cough, and wheeze, and in children exposed to second-hand tobacco smoke, a positive allergen skin test. Measures of exposure to specific pollutants also correlated with cough, wheeze, and asthma in this study. Taken together, these studies demonstrate that exposure to increased levels of ambient air pollutants and pollens exacerbate asthma and respiratory allergic responses, and some may be factors in developing disease.

Climate Change and Human Health

According to the Fourth Assessment Report by the IPCC released in 2007, warming of the global climate system is unequivocal, and there is a >95% certainty that the cause is extrinsic [13]. Human activities have a net warming effect (>90% confidence) that is dominated by greenhouse gas (GHG) emissions [14] . The most important GHG is carbon dioxide (CO_2) released by the burning of fossil fuels and to a lesser extent land use practices, followed by nitrous oxide and methane. Because of the inertia in the climate system and the long residence time of CO_2 in the atmosphere, even if emissions were abruptly reduced to zero, global warming would continue throughout the 21st century and likely persist for hundreds of years [14,15]. Using climate models validated with paleoclimatologic evidence and historical data, the IPCC has developed a suite of future scenarios based on various levels of GHG mitigation, economic development, and population growth. Under the most ambitious reduction scenario, global temperatures are predicted to rise by 1.8°C (90% CI, 1.1-2.9) by 2099 compared with a 4.0°C (90% CI, 2.4-6.4) rise under “business-as-usual,” the scenario that assumes current accelerating emissions and land use trends [14]. The rate and magnitude of anthropogenic GHG emissions are unprecedented in human history and may be pushing the climate system toward

critical thresholds or “tipping points” at which a very small additional change can qualitatively and permanently (on the human time scale) alter the state of major earth systems (eg, altered ocean circulation, loss of Arctic summer sea-ice, exaggeration of El Nino–Southern Oscillation). Several independent analyses suggest that tipping points in some systems could occur with temperature increases of anywhere from +0.5 to +6°C, a range of change that is possible this century [14]. The impact of crossing a tipping point is unknown, but significant sea level rise, massive species extinctions, changes in storm and drought cycles, altered ocean circulation, and redistribution of vegetation including crops are all feasible.

Climate change–related increased burden of disease, specifically from allergy and asthma, is anticipated because of changes in the distribution, quantity, and quality of pollens, and changes in the timing and duration (lengthening) of pollen season. Asthma and allergic disease will also likely be worsened because of interaction between heavier pollen loads and increased air pollution; thunderstorms and extreme precipitation events; worsening heat-related ground-level ozone pollution; increased ambient air pollution from natural and anthropogenic sources; and air pollution related to wildfires.

Climate Change and Pollens

The correlation between climate and pollen distribution is well described. Investigation of abrupt climate change has used a number of techniques including ice core and sediment sampling for isotope shifts, pollen changes, and beetle and midge larval responses. Vegetation changes have proven to be very sensitive indicators of climate change, easily showing responses within a century; and when transitional zones are examined, vegetational responses can occur within a decade of climate change [16]. Paleopalynology, the study of fossil pollens, spores, and algae, provides information about how climate affects the distribution and variety of vegetation from the distant past to the most recent decades [17,18]. This has been shown in the North Atlantic fossil pollen record, with southern encroachment of boreal trees such as fir, larch, and alder with cooling, and replacement with oak and white pine with subsequent warming [16]. Records of aeroallergen sampling give insight into ongoing responses to changing conditions from the more immediate past into the present [19,20].

Floristic zones define the type of native vegetation found in a region, and are in turn defined by several factors including high and low temperatures and average precipitation [21]. Recent shifts in global temperatures have resulted in migration of these zones northward. This demonstrates that current warming has already had an impact on the type of trees and other vegetation likely to survive and thrive at any latitude in a given region. In fact, the IPCC Fourth Assessment Report documents hundreds of studies on tens of thousands of data series that report statistically significant recent changes in climate sensitive traits of biological systems, 90% of which are consistent with warming [22].

Bud set and flowering are intimately linked to accumulated warmth for many herbaceous and woody plants. Anthropogenic global warming, which includes both higher temperatures and higher ambient CO_2 levels, speeds flower development, resulting in earlier blooming. A 2002 study of 385 British plant species found that the average first flowering had advanced by 4.5 days during the previous decade [23]. European pollen monitoring has shown increases over the past 30 years in hazel, birch, and grass counts in Switzerland and Denmark [24,25].

For example the onset of olive flower opening and pollen release is expected to advance by 1 to 3 weeks over the coming century. Assuming temperature increases associated with a doubling of CO_2 levels by the end of the 21st century, pollen season for oaks will start a month earlier, and concentrations will be 50% higher. Similar trends have already been demonstrated, linking climate change with longer pollen seasons, greater exposure, and increased disease burden for late summer weeds such as *Artemisia* (mugwort) and *Ambrosia* (ragweed) [26].

There are several studies evaluating the effects of increased CO_2 and temperature on the allergenicity of plants. A 6-year study of the impact of increased CO_2 on poison ivy in loblolly pine stands showed increased photosynthesis, water use efficiency, and biomass [27]. In Addition, the CO_2-enriched plants produced a greater percentage of unsaturated urushiol, which is more antigenic. Other investigators have reported increased short ragweed (*Ambrosia artemisiifolia*) biomass and an increase in pollen production of 61% to 90% with increased ambient CO_2 [28] Increasing CO_2 also resulted in greater biomass and pollen production, but had a greater impact on later growing cohorts. from year to year at the same site, the question was raised whether increased pollen. There was a gradient of both air temperature and CO_2 level through 4 sites: urban, suburban, semirural, and rural. The urban site averaged 2°C

warmer and a 30% higher CO_2 level than the rural site. As expected, the urban ragweed grew faster with a greater above-ground biomass, flowered earlier, and produced more pollen than the rural site. Although there was an almost 2-fold greater concentration of Amb a 1 per microgram of protein in the rural versus the other sites, there was a greater than 7-fold increase in pollen production from the urban sites, supporting an increased airborne allergenic burden in the urban model for climate change.

There is now a wealth of evidence that climate change has had and will have further impact on a variety of allergenic plants [29]. Increased CO_2 increases plant biomass and pollen production. Increased temperature stimulates earlier flowering and longer pollen seasons for some plants. Increased ambient CO_2 may cause some plant products to become more allergenic. It is conceivable that increases in airborne pollen numbers will increase the efficiency of wind-borne pollination, thereby increasing propagation of such plants. The extent to which these climate-related ecological changes are coupled with worsening air pollution will further add to the burden of allergic disease in exposed populations [30]. The expectation then is that there will be increasing amounts of robust allergenic plants and an increasing aeroallergen burden for patients with inhalant allergy.

Climate Change, Ozone and Air Pollution

Ground level ozone is created by a heat dependent photochemical oxidation of VOCs, nitrogen oxides (NOx), and atmospheric hydroxyl radicals. Higher temperatures favor greater ozone production even without increases in precursor molecules [31,32]. The most abundant atmospheric VOC is methane, but in suburban and urban areas, anthropogenic nonmethane VOC (NMVOC) compounds from combustion of fossil fuels including vehicle exhaust, industrial emissions, and chemical solvents are primary sources contributing to ozone production [33]. The urban heat island effect, a combination of anthropogenic and climatologic heat, can increase urban temperatures as much as 5°C compared with rural locations and further drive the formation of ozone [34].

Given sustained growth in the size and population of urban areas worldwide, continued use of fossils fuels will lead to exposure of more people to higher levels of ozone in the future. Rural

areas will experience an increase in ozone via long-range atmospheric transport of urban ozone, higher temperatures, biogenic VOC release, and agricultural fuel use. Future predictions of ozone production are most closely linked with levels of atmospheric NOx, which is increasing worldwide, and business-as-usual emissions are forecast to more than double from the current amount s by 2100 [35].

NOx is produced when nitrogen reacts with oxygen at high temperatures, usually from fuel burning. In the United States, motor vehicles account for nearly half of all NOx emissions [36]. Although NOx has an atmospheric lifetime of only hours to days, exposure is associated with chronic and acute changes in lung function, including bronchial neutrophilic infiltration, increased proinflammatory cytokine production, and, as mentioned, enhanced response to inhaled allergens [10,11]. The currently forecast business-as-usual levels of NOx emissions will lead to continued increases in ground level ozone, increases in levels of pulmonary proinflammatory mediators (both directly and through ozone production), and increased allergen sensitivity, especially in individuals with asthma.

More than 65% of sulfur oxides released to air comes from coal-burning electric utilities [37] Inhalation of SO_2 has significant bronchospastic effects with rapid onset of symptoms after exposure. Epidemiologic studies have shown decreased lung function in children with increased ambient exposure to SO_2 and to SO_2 mixed with other CAPs [38]. Coal is the most abundant worldwide energy source, much of it with high sulfur content, and worldwide coal use under a business-as-usual scenario is projected to increase by 74% over current levels by 2030 [39]. Coal burning is currently the second largest fuel source of CO_2 emissions worldwide and is projected to become the largest source by 2010. Thus, coal burning will contribute substantial amounts of atmospheric sulfur oxides well into the future, exacerbating human disease and forcing additional climate change.

Atmospheric PM sources are of both natural and anthropogenic origin, but in suburban and urban areas, diesel and fuel-burning vehicles are the major source [40]. PM can remained suspended in the atmosphere for long periods and can be transported thousands of miles before deposition [41,42]. Evidence for the health effects of PM is stronger than that for ozone, and multiple studies have demonstrated that increased exposure to PM worsens asthma and is associated with decreased lung function in both children and adults [43,44].

Anthropogenic PM is a complex mixture of components around a carbonaceous core. Components include sulfates, VOCs (such as toluene and xylene), metals (iron, vanadium, nickel, copper, and zinc), polyaromatic hydrocarbons, pollen, and endotoxin [45]. Industrial point sources of PM have been demonstrated to induce airway inflammation, with an influx of neutrophils, monocytes, and inflammatory mediators [46]. DEPs cause pronounced airway inflammation [12]. DEP exposure studies have demonstrated increased nonspecific airway reactivity, increased bronchial neutrophil and B-lymphocyte infiltration, and increased nasal production of IgE with enhanced allergen response in sensitive individuals. This adjuvant effect of DEPs, coupled with increased pollen production of ragweed in atmospheric conditions of increased temperature and CO_2, preference of ragweed for disrupted soils such as occur in suburban and urban areas, and increased DEP and ozone production in suburban and urban areas will create significant future risk of asthma exacerbations and allergic response among populations living in these areas.

Climate Change, Storms, and Wildfires

In addition to pollen redistribution, the changing climate will very likely lead to increased drought, heat waves, and wildfires in some regions, and increased storms and extreme precipitation events in other regions. These changing regional patterns may exacerbate allergic disease and asthma.

Areas of the world experiencing increased heat and drought will likely experience more wildfires. In addition to the direct loss of life, geographic displacement, disruption of social networks, and economic loss, wildfire smoke contains a complex mixture of carcinogenic and respiratory irritant substances. Wildfire smoke produces large amounts CO, CO_2, NOx, ozone, PM, and VOCs [47]. Smoke plumes can travel thousand of meters upwards in the atmosphere. Population-level epidemiologic studies have shown modest short-term increases in cardiorespiratory hospitalizations caused by acute exposure to wildfire smoke [48].

The IPCC 2007 considers it very likely that heavy precipitation events will increase in most areas, and an increase in tropical cyclones is likely globally. In areas where climate change causes thunderstorms and extreme precipitation events during pollen season, there is reason

to expect that there will be worsening asthma caused by an increased airborne burden of respirable allergen-laden particles released from fragmented pollen grains [49].

Conclusion

Global climate change is now measurably affecting many physical and biological systems that are critical to human health. Effects pertinent to allergic disease and asthma are changes in the distribution, quantity, and quality of aeroallergens; increased ground-level ozone pollution, and further deterioration in air quality. Both individuals with allergy and asthma are at risk of worsening disease, and reduced quality of life as a result of these environmental changes. Further, some data suggest that the incidence of allergic disease and asthma could increase with increased environmental exposures driven by climate change. The magnitude of the increased disease burden is directly linked to the magnitude of climate change. Continued warming of the climate system is certain because of the long residence time of GHG already released into the atmosphere but the magnitude and rate of warming is still modifiable. For clinicians caring for atopic patients and patients with asthma, this means that both adaptation to disease linked to inevitable climate change (secondary prevention) and mitigation of the drivers that will worsen climate change (primary prevention) are important strategies to employ to minimize disease burden.

Improved public health tracking of asthma and allergic disease will help public health officials understand how these illnesses are changing as climate changes and develop appropriate responses. Examples of health protective measures include enacting a transition to clean diesel buses, anti-idling laws for buses and cars, and more stringent controls on power plant emissions.

There is an even greater need for the medical sector to become fully engaged in the development and dissemination of effective GHG mitigation strategies (primary prevention) as part of the public health agenda for the 21st century. The Director General of the World Health Organization states unambiguously that “climate change will affect, in profoundly adverse ways, some of the most fundamental determinants of health: food, air, water. In the face of this challenge, we need champions throughout the world who will work to put protecting human

health at the centre of the climate change agenda [50]. Successful stabilization of the climate before exceeding tipping points with unknown and potentially catastrophic consequences is the responsibility of the current generation of adults who, through action or inaction, will determine the future for generations to come.

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