The toll of ozone

Todd M. Umstead[1], David S. Phelps[1], Joanna Floros[1,2]

[1]Center for Host Defense, Inflammation, and Lung Disease (CHILD) Research, Department of Pediatrics,
[2]Obstetrics and Gynecology, Pennsylvania State University College of Medicine, Hershey, PA 17033

Correspondence to:
Joanna Floros, PhD
Evan Pugh Professor of Pediatrics and Obstetrics & Gynecology
Director, CHILD Research Dept of Pediatrics
500 University Drive, H085
Hershey, PA 17033
Tel.: 717 531 6972
Fax: 717 531 0215
e-mail: jfloros@psu.edu

GROUND LEVEL OZONE IS BOTH A REGIONAL AND GLOBAL PROBLEM

Ground level (tropospheric) ozone, an air pollutant and key ingredient of urban smog, has a negative impact on human health worldwide. Ozone consists of three oxygen atoms and is created via a chemical reaction between nitrogen oxides (NOx) and volatile organic compounds (VOCs) in the presence of sunlight. The ozone gas precursors, NOx and VOCs, are produced or emitted by cars, chemical and power plants, refineries, and other industrial sources. Because of its atmospheric transport properties, ozone created in one region can be carried by wind currents to affect individuals hundreds of miles away, therefore making ozone pollution not only a local problem but also a global issue.

In a recent editorial in Pneumon Prof. N. Siafakas pointed out that the World Health Organization (WHO) estimates that half of the world's population lives in areas with poor air quality[1]. One of the main goals of the declaration by the Forum of International Respiratory Societies that 2010 be the "Year of the Lung" was to reaffirm the right of all people to live in unpolluted areas. The highest concentrations of ozone are found in areas of greatest population densities, such as in Central Europe, Eastern China, Northeastern India, Southern Africa, and the Eastern USA[2,3], where it has the potential to affect the greatest numbers of people. Background levels of ozone have been increasing worldwide over the past three decades, with increases of as great as 2%/year measured over the mid-latitudes of the northern hemisphere[4]. In the USA, although ozone pollution has been declining at national[5], state[6], and local[7] levels for the past several decades, due to reduced emissions of precursor gases, many regions still report ozone levels that are at or above the current National Ambient Air Quality Standard of 0.075 ppm for 8 hours[8], and much higher than the newly proposed U.S. Environmental Protection Agency limits of 0.06 ppm[9] for 8 hours and WHO guideline values of 0.05 ppm[2]. Over 150 million people residing in 240 counties across the USA are exposed to ozone at unacceptable levels[10], creating significant local and regional problems in polluted areas where concentrations often exceed 0.2 ppm.

CLIMATE CHANGE AND FUTURE OZONE PROBLEMS

Climate change is expected to significantly influence future ozone levels, with many regions still seeing increases in ozone concentrations despite the implementation of ozone controls[2]. Climate change could alter weather patterns, lengthening the ozone season and increasing the frequency, duration, and concentration of ozone levels[11-13]. Climate change could also increase ozone concentrations by increasing emissions of ozone precursors, changing chemical reaction rates, altering boundary layer heights that affect vertical mixing of pollutants and changing airflow patterns governing the transport of pollution[11,14]. With climate change, many regions could see concentrations of ozone much beyond the ranges of natural historical levels, potentially increasing morbidity and mortality rates due to ozone[11,14,15].

OZONE EFFECTS ON HEALTHY AND SUSCEPTIBLE POPULATIONS

The effects of ozone are felt by everyone. Short-term exposures to ozone can cause increases in respiratory symptoms, reduced lung function, changes in airway responsiveness and increased airway inflammation, even in healthy individuals[9,10,16-18]. Long-term or prolonged exposures can cause asthma in children and lead to permanent lung damage and even death[9,10,16,17,19]. Ozone has the greatest effects on children, the elderly, and people who frequently work or exercise outdoors[10,16,17-24]. Ozone also affects women more than men[20-24] and can even harm the unborn child[25-27]. The most pronounced adverse effects of ozone, however, are seen in the ever-growing population of those with predisposing conditions, such as obesity, diabetes mellitus (DM), asthma, chronic obstructive pulmonary disease (COPD), pneumonia, and other cardiorespiratory diseases[9,16,19,21,24,25-35] (Figure 1). Many studies have reported increases in emergency room visits, hospital admissions, and mortality for patients with these conditions, associated with days of increased ozone[9,10,16,19,30-34,36-38].

However, not all individuals, either healthy or predisposed, exhibit the same level of susceptibility to ozone[18, 35]. Some individuals are sensitive to ozone (even at ambient levels)[35] and remarkable variability in ozone susceptibility is observed among healthy non-smokers engaging in moderate to heavy exercise[39-41]. This indicates that several different factors, acting either alone or in combination, may contribute to the susceptibility of an individual to ozone and to air pollution in general, and that these factors include genetic variability. A genetic basis for ozone response has been suggested in animal studies, where great differences in injury and mortality were observed among different strains[42,43]. For example, the genetic variation present in genes playing a role in oxidative stress, and inflammation, among other functions, may be of particular relevance.

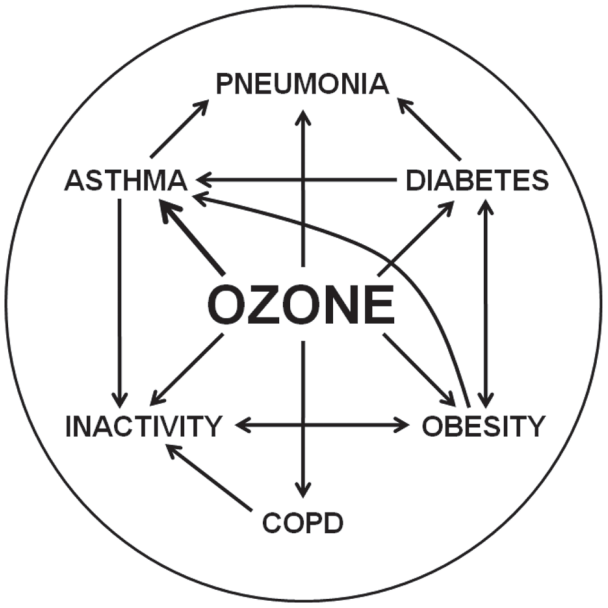

FIGURE 1. The ozone disease snowball. The most pronounced adverse effects of ozone are experienced by individuals whose health is already compromised, including those with pneumonia, diabetes mellitus (DM), obesity, chronic obstructive pulmonary disease (COPD), asthma, and other cardiopulmonary diseases.

THE COSTS OF OZONE POLLUTION

The costs of ozone pollution are enormous and often difficult to measure. The estimated costs include hospital-based costs, medical care expenses, missed school and work days and their economic toll, behaviour modification and inactivity due to restricted activity days, quality of life factors, and premature and increased mortality. For example, failure to meet government air quality standards cost California alone an estimated $193 million in hospital spending between 2005 and 2007, $58 million of which was due solely to ozone[44]. These costs put an increased financial burden on both patients and their

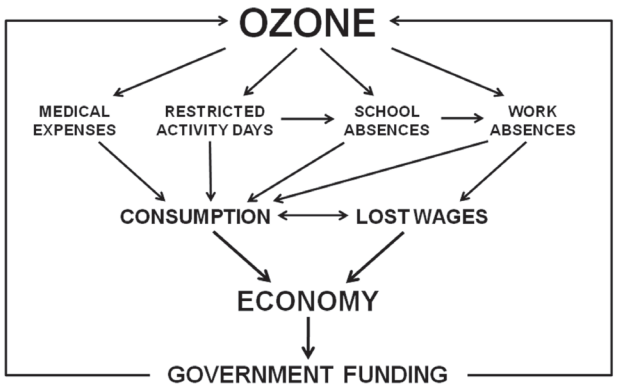

FIGURE 2. The socio-economic effects of ozone pollution. The negative impact of ozone on health results in an increase in medical expenses, restricted activity, and loss of school and work days. All of these factors contribute to a decrease in consumption of goods and lost wages that, in turn, have a negative impact on the economy. This limits, in part, the ability of governments to provide adequate funding for ozone-related works. Such works may include efforts aimed at better understanding of the sources of ozone load, the effects of ozone on health and other aspects.

health care providers. It is estimated that health costs due to ozone pollution globally will reach $580 billion per year by 2050 (in year 2000$), and that mortalities from ozone exposure will exceed 2 million[45]. Aside from the human costs, the socio-economic impact of ozone pollution must be considered. Missed school and work days, and behaviour modification due to restricted activity days, all result in a loss of welfare and consumption (i.e. reduction in purchase of goods due to restricted activity) (Figure 2). A recent study in Europe estimated the annual loss to consumption due to air pollution in 2005 to be €220 billion (in year 2000€) with a total annual welfare loss of €370 billion (~$500 billion) for the continent, 10% of which was linked directly to ozone[46].

COMMENT

Air pollution, and in particular ozone exposure, constitutes a major health and socio-economic burden worldwide. Guidelines for further reduction of air pollution benefit everyone and therefore it should concern all of us that these be continually improved, implemented, and complied with. Research efforts aimed at understanding the mechanisms involved in human disease due to ozone pollution and the basis of individual variability to ozone and air pollution susceptibility are a worthwhile investment that can lead to better human health and better socio-economic conditions worldwide.

Acknowledgments

This work was supported by National Institute of Environmental Health Sciences Grant 1RO1-ES09882.

REFERENCES

1. Siafakas N. The Year of the Lung 2010. Pneumon 2010;23:336-337.
2. Ground-level ozone in the 21st Century: future trends, impacts and policy implications: Science Policy Report 15/08 for the Royal Society; 2008.
3. Fishman J, Wozniak AE, Creilson JK. Global distribution of tropospheric ozone from satellite measurements using the empirically corrected tropospheric ozone residual technique: Identification of the regional aspects of air pollution. Atmos Chem Phys 07/02 2003;3:893-907.
4. Vingarzan R. A review of surface ozone background levels and trends. Atmospheric Environment 2004;38:3431-3442.
5. Ozone Air Quality 1980-2008. Available at http://www.epa.gov/airtrends/ozone.html#oznat.
6. Pennsylvania Air Quality Monitoring 2004 Annual Report: Pennsylvania Department of Environmental Protection. Available at www.depweb.state.pa.us.
7. Ozone Air Quality 1990-2008. Available at http://www.epa.gov/cgi-bin/broker?_service=data&_debug=0&_program=dataprog.maptest_08.sas&parm=44201&stfips=42
8. Ambient Air Quality Standards. Available at www.depweb.state.pa.us/deputate/airwaste/aq/standards/standards.htm.
9. EPA Proposes a Stronger Ozone Standard: American Lung Association January 2010.
10. Pinkerton. Ozone, a malady for all ages. Am J Respir Care Med 2007;176:107-112.
11. EPA report provides an assessment of potential impacts of climate change on US regional ozone concentrations. Science in Action. April 2009. Available at www.epa.gov/ord.
12. Weaver CP, Cooter E, Gilliam R, et al. A Preliminary Synthesis of Modeled Climate Change Impacts on U.S. Regional Ozone Concentrations. Bulletin of the American Meteorological Society 2009;90:1843-1863.
13. Nolte CG, Gilliland AB, Hogrefe C, Mickley LJ. Linking global to regional models to assess future climate impacts on surface ozone levels in the United States. J Geophys Res 07/22 2008;113(D14):D14307.
14. Ebi KL, McGregor G. Climate change, tropospheric ozone and particulate matter, and health impacts. Environ Health Perspect 2008;116:1449-1455.
15. Thomson MC. Seasonal Forecasts, Climatic Change and Human Health: Health and Climate New York: Springer; 2008.
16. Ozone and your patients' health, training for health care providers. Available at www.epa/gov/air/oaqps/eog/ozonehealth/index.html.

17. Schelegle ES, Morales CA, Walby WF, Marion S, Allen RP. 6.6-hour inhalation of ozone concentrations from 60 to 87 parts per billion in healthy humans. Am J Respir Crit Care Med 2009;180:265-272.
18. Kunzili N, Perez L, Rapp R. Air Quality and Health. In: Soc ER, ed. 2010 The year of the Lung; 2010.
19. Protecting your health. Air Quality Partnership. Available at www.aqpartners.state.pa.us/health.htm
20. Alexeeff SE, Litonjua AA, Wright RO, et al. Ozone exposure, antioxidant genes, and lung function in an elderly cohort: VA normative aging study. Occup Environ Med 2008;65:736-742.
21. Kan H, London SJ, Chen G, et al. Season, sex, age, and education as modifiers of the effects of outdoor air pollution on daily mortality in Shanghai, China: The Public Health and Air Pollution in Asia (PAPA) Study. Environ Health Perspect 2008;116:1183-1188.
22. Medina-Ramon M, Schwartz J. Who is more vulnerable to die from ozone air pollution? Epidemiology 2008;19:672-679.
23. Vancza EM, Galdanes K, Gunnison A, Hatch G, Gordon T. Age, strain, and gender as factors for increased sensitivity of the mouse lung to inhaled ozone. Toxicol Sci 2009;107:535-543.
24. Stafoggia M, Forastiere F, Faustini A, et al. Susceptibility factors to ozone-related mortality: a population-based case-crossover analysis. Am J Respir Crit Care Med 2010;182:376-384.
25. Salam MT, Millstein J, Li YF, Lurmann FW, Margolis HG, Gilliland FD. Birth outcomes and prenatal exposure to ozone, carbon monoxide, and particulate matter: results from the Children's Health Study. Environ Health Perspect 2005;113:1638-1644.
26. Hwang BF, Jaakkola JJ. Ozone and other air pollutants and the risk of oral clefts. Environ Health Perspect 2008;116:1411-1415.
27. Smoggy Schools. Environmental Working Group. 04/20/2005; Available at http://ewg.org/reports/caschoolsozone.
28. Henrotin JB, Besancenot JP, Bejot Y, Giroud M. Short-term effects of ozone air pollution on ischaemic stroke occurrence: a case-crossover analysis from a 10-year population-based study in Dijon, France. Occup Environ Med 2007;64:439-445.
29. Lang JE, Williams ES, Mizgerd JP, Shore SA. Effect of obesity on pulmonary inflammation induced by acute ozone exposure: role of interleukin-6. Am J Physiol Lung Cell Mol Physiol 2008;294:L1013-1020.
30. Alexeeff SE, Litonjua AA, Suh H, Sparrow D, Vokonas PS, Schwartz J. Ozone exposure and lung function: effect modified by obesity and airways hyperresponsiveness in the VA normative aging study. Chest 2007;132:1890-1897.
31. Lin S, Liu X, Le LH, Hwang SA. Chronic exposure to ambient ozone and asthma hospital admissions among children. Environ Health Perspect 2008;116:1725-1730.
32. Moore K, Neugebauer R, Lurmann F, et al. Ambient ozone concentrations cause increased hospitalizations for asthma in children: an 18-year study in Southern California. Environ Health Perspect 2008;116:1063-1070.
33. Medina-Ramon M, Zanobetti A, Schwartz J. The effect of ozone and PM10 on hospital admissions for pneumonia and chronic obstructive pulmonary disease: a national multicity study. Am J Epidemiol 15 2006;163:579-588.
34. Chiu HF, Cheng MH, Yang CY. Air pollution and hospital admissions for pneumonia in a subtropical city: Taipei, Taiwan. Inhal Toxicol 2009;21:32-37.
35. Bascom R, Bromberg PA, Costa DA, et al. Health effects of outdoor air pollution. Committee of the Environmental and Occupational Health Assembly of the American Thoracic Society. Am J Respir Crit Care Med 1996;153:3-50.
36. Zanobetti A, Schwartz J. Mortality displacement in the association of ozone with mortality: an analysis of 48 cities in the United States. Am J Respir Crit Care Med 2008;177:184-189.
37. Stieb D, Szyszkowicz M, Rowe B, Leech J. Air pollution and emergency department visits for cardiac and respiratory conditions: a multi-city time-series analysis. Environmental Health 2009;8:25.
38. Jerrett M, Burnett RT, Pope CA, et al. Long-term ozone exposure and mortality. N Engl J Med 2009;360:1085-1095.
39. Horstman DH, Folinsbee LJ, Ives PJ, Abdul-Salaam S, McDonnell WF. Ozone concentration and pulmonary response relationships for 6.6-hour exposures with five hours of moderate exercise to 0.08, 0.10, and 0.12 ppm. Am Rev Respir Dis 1990;142:1158-1163.
40. Devlin RB, McDonnell WF, Mann R, et al. Exposure of humans to ambient levels of ozone for 6.6 hours causes cellular and biochemical changes in the lung. Am J Respir Cell Mol Biol 1991;4:72-81.
41. Kulle TJ, Sauder LR, Hebel JR, Chatham MD. Ozone response relationships in healthy nonsmokers. Am Rev Respir Dis 1985;132:36-41.
42. Kleeberger SR, Bassett DJ, Jakab GJ, Levitt RC. A genetic model for evaluation of susceptibility to ozone-induced inflammation. Am J Physiol 1990;258(6 Pt 1):L313-320.
43. Wesselkamper SC, Prows DR, Biswas P, Willeke K, Bingham E, Leikauf GD. Genetic susceptibility to irritant-induced acute lung injury in mice. Am J Physiol Lung Cell Mol Physiol 2000;279:L575-582.
44. Romley JA, Hackbarth A, Goldman DP. The Impact of Air Quality on Hospital Spending. Santa Monica, CA: RAND Corporation; 2010.
45. Selin NE, Wu S, Nam K-M, et al. Global health and economic impacts of future ozone pollution. Environmental Research Letters 2009;4.
46. Nam K-M, Selin NE, Reilly JM, Paltsev S. Measuring welfare loss caused by air pollution in Europe: A CGE analysis. Energy Policy 2009;38:5059-5071.