

This article was downloaded by: [Advanced Institute of Sanita]

On: 28 January 2010

Access details: Access Details: [subscription number 908033408]

Publisher Taylor & Francis

Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



International Journal of Environmental Health Research

Publication details, including instructions for authors and subscription information:

<http://www.informaworld.com/smpp/title~content=t713425582>

Relationship between ambient ozone concentrations and daily hospital admissions for childhood asthma/atopic dermatitis in two cities of Korea during 2004-2005

Jong-Tae Lee ^a; Yong-Sung Cho ^b; Ji-Young Son ^c

^a College of Health Science, Department of Environmental Health, Korea University, Seoul, Republic of Korea ^b Department of Epidemiology, School of Public Health, UCLA, Los Angeles, USA ^c Hanyang University, Seoul, Republic of Korea

Online publication date: 25 January 2010

To cite this Article Lee, Jong-Tae, Cho, Yong-Sung and Son, Ji-Young(2010) 'Relationship between ambient ozone concentrations and daily hospital admissions for childhood asthma/atopic dermatitis in two cities of Korea during 2004-2005', International Journal of Environmental Health Research, 20: 1, 1 – 11

To link to this Article: DOI: 10.1080/09603120903254033

URL: <http://dx.doi.org/10.1080/09603120903254033>

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: <http://www.informaworld.com/terms-and-conditions-of-access.pdf>

This article may be used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

Relationship between ambient ozone concentrations and daily hospital admissions for childhood asthma/atopic dermatitis in two cities of Korea during 2004–2005

Jong-Tae Lee^{a*}, Yong-Sung Cho^b and Ji-Young Son^c

^aCollege of Health Science, Department of Environmental Health, Korea University, Seoul, Republic of Korea; ^bDepartment of Epidemiology, School of Public Health, UCLA, Los Angeles, USA; ^cHanyang University, Seoul, Republic of Korea

(Received 15 March 2009; final version received 7 July 2009)

The objective of this study was to estimate the association between ambient ozone levels and hospitalization for asthma/atopic dermatitis among children younger than 15 years old living in Seoul and Ulsan, Korea, in the years 2004–2005. Estimated relative risks of hospital admissions associated with an interquartile range (IQR) increase in ozone concentration were calculated using a generalized additive Poisson model. For childhood asthma, the effect of an ozone increase on the relative risks in Ulsan [1.21 (95% CI, 1.10–1.34)] was higher than that in Seoul [1.05 (95% CI, 0.99–1.11)]. The relative risks for childhood atopic dermatitis were also found to be higher in Ulsan [1.38 (95% CI, 0.80–2.36)] than in Seoul [1.28 (95% CI, 1.04–1.58)]. These results support previously reported findings and also indicate that ozone concentrations at levels below the standards in the Republic of Korea can be correlated with asthma hospital admissions in children.

Keywords: ozone; childhood asthma/atopic dermatitis; hospital admission

Introduction

During the past several decades, Korea has seen a great deal of economic growth and development. Despite this prosperity, however, several negative issues have arisen, including various problems related to the environment (Lee et al. 1999). In order to resolve some of these issues, in September 2005 the Ministry of Environment of Korea announced a long-term project entitled “A 10-year plan for preventing environment-related disease” whose goal was to protect public health from such environmental diseases as asthma, atopic dermatitis, eczema, and some forms of cancer. The project also included provisions aimed at maintaining the health of persons particularly susceptible to environmental hazards, including children.

During the past decade, numerous epidemiological studies have demonstrated that children with a history of asthma or wheezing exhibit increased rates of bronchitis when exposed to higher levels of air pollution (Dockery et al. 1989; Sunyer et al. 1997; Linaker et al. 2000). Furthermore, the World Health Organization

*Corresponding author. Email: jtleee@korea.ac.kr

(WHO) presented that even if the guideline value for air pollutants is achieved, the possibility of adverse health effects remains and there is increasing evidence that air pollution levels at ever lower concentrations than the standards of each country have significant associations with adverse health effects (WHO 2005).

Ozone is generally regarded as one of the most toxic components of the photochemical air pollution mixture. Hubbell et al. (2005) systematically summarized the literature, including articles about the associations between ozone and respiratory-related hospital admissions, missed school days, restricted activity days, asthma-related emergency department visits, and premature mortality. Ozone has also been associated with the use of asthma medication by asthmatic schoolchildren (Gent et al. 2003). Recently Lee et al. (2002) reported finding an association between hospital admissions for asthma in children and ambient air pollution at levels below the current air quality standards of Korea.

We obtained the records of all hospital admissions for children living in two different study areas in Korea, the cities of Seoul and Ulsan, as well as the records of weather conditions and daily levels of ambient ozone for the years 2004 and 2005. There are few studies that have investigated the effect of ambient ozone on atopic dermatitis exacerbation in Korea. The objective of this study was to estimate the association between ambient ozone levels and the increase in hospital admissions for asthma/atopic dermatitis among children younger than 15 years old.

Methods

Study area and subjects

Two of the largest cities in Korea, Seoul and Ulsan, were selected as the study areas (Figure 1). Seoul, located centrally in the Korean peninsula, is the largest city in the country. The mean number of children in Seoul during the study period was 1.6 million, and the major air pollution sources were caused by automobile exhausts, field burning, incineration, and power plants that use fossil fuels. Ulsan is a highly industrialized city located on the southeastern part of the Korean Peninsula



Figure 1. The location and population of the study areas.

near the Bay of Ulsan. There are two enormous industrial complexes within the borders of the city, the Ulsan petrochemical complex and the Ulsan Mipo industrial complex.

We obtained all hospital admission records for children younger than 15 years old living in the two different study areas who were admitted for asthma or atopic dermatitis during the study period. Seoul and Ulsan have a four-season climate and an annual temperature range of -14.0 – 30.4°C and -6.8 – 30.6°C , respectively.

Hospital admissions and weather data

The Korea Medical Insurance Corporation (KMIC) collects standardized reports from every hospital in the country for each admission of any resident of Korea. Membership in KMIC is mandatory for all citizens. Using these data, we assembled daily counts of admissions for childhood asthma (ICD-10 codes J45-J46) and childhood atopic dermatitis (ICD-10 codes L20) from 1 January 2004 to 31 December 2005. In this analysis, the subjects were selected as only hospital admissions because out patient visits may result in the same patient being counted more than once. Information regarding the 24-h average temperature ($^{\circ}\text{C}$) and relative humidity (%) was available for each day during this period from the Korean Meteorological Administration.

Ambient ozone data using monitoring stations

Ambient ozone data were provided by the Korean Ministry of Environment. Exposure measurements during the study period had been taken at 27 monitoring sites in Seoul and 13 monitoring sites in Ulsan, with the measurements being made hourly. Those monitoring sites adequately cover the cities of Seoul and Ulsan. All monitoring data for each city were aggregated to generate hourly mean ozone values for each city. From those hourly values, we determined for each day the maximum eight-hour ozone value by comparing all 16 of the day's 8-h moving averages.

Statistical analysis

We applied generalized additive models (GAM) that use a non-parametric smoothing approach to allow for a highly flexible fitting of seasonality and long-term time trends, as well as for non-linear associations between hospital admissions and weather variables such as air temperature and relative humidity (Pope and Schwartz 1996). Our GAM, therefore, included the locally weighted running-line smoother (LOESS) function of time to capture seasonal and long-term trends. Our modeling strategy followed a systematic approach, progressing from simple to more complicated models with an increasing number of covariates (Table 1).

First, non-linear time and weather terms were incorporated into the generalized additive models. After controlling for time and weather, we included the ambient ozone concentration in the model. Furthermore, we used with a more stringent convergence criterion (than the default values of S-plus) in our generalized additive models in order to avoid biased estimates of the regression coefficient and the

Table 1. Schematic procedure for building a model to describe the variation in the daily hospital admissions of asthmatic children under 15 years of age in Seoul and Ulsan, 2004–2005.

Seoul		Ulsan	
Description of model	AIC	Description of model	AIC
Time		Time	
T ₁ : smoothed function of date	1688.198	T ₁ : smoothed function of date	1217.408
T ₂ : T ₁ + indicator variables for day of week	1678.569	T ₂ : T ₁ + indicator variables for day of week	1210.785
Weather		Weather	
W: T ₂ + smoothing function of TEMP + HUMD	1649.620	W: T ₂ + smoothing function of TEMP + HUMD	1205.370
Pollutant		Pollutant	
P: W + O ₃ (lag1 + 2)	1637.279	P: W + O ₃ (lag1)	1192.400

AIC, Akaike's information criterion; TEMP, concurrent-day of air temperature; HUMD, concurrent-day of relative humidity.

standard error (Dominici et al. 2002; Ramsay et al. 2003). The resulting model took the following form:

$$\text{Log}[E(Y)] = \beta_0 + \sum S_i(X_i) + \beta_1(P_1), \quad (1)$$

where Y is the daily number of hospital admissions for childhood asthma/atopic dermatitis; X₁ is the indicator for the day of week; X₂ is the air temperature; X₃ is the relative humidity; S_i are the smoothing functions; and P₁ is the ozone concentration. The linear effects of pollution on the log relative risk of hospitalization for childhood asthma/atopic dermatitis were determined and are reported in the units of their interquartile ranges (IQR) of their maximum 8-hour moving average of ozone levels. Because previous studies have indicated that an acute effect can be observed on the same day or within 1–7 days of exposure to air pollution, we selected a lag time for the ozone concentration that maximized the association with the number of hospital admissions for childhood asthma/atopic dermatitis. Akaike's Information Criterion (AIC) was used as a measure of how well the model fit the data (Akaike 1970; Hastie and Tibshirani 1986). Smaller AIC values indicate a better fit. All analyses were carried out using both SAS (SAS Institute, Cary, NC, USA) and S-plus (Statistical Sciences, Seattle, WA, USA).

Results

Table 2 contains descriptive statistics of the daily hospital admissions for childhood asthma and childhood atopic dermatitis and the corresponding weather information for both Seoul and Ulsan from 1 January 2004 to 31 December 2005. The daily ozone concentrations were below the current recommended level (60 ppb by daily maximum 8-h mean) in Korea and averaged 6 ppb higher in Ulsan than in Seoul over the study period. As the population of Seoul is about seven times larger than that of Ulsan, we can see that the hospital admission rate for asthma in Ulsan seems to have been a little bit higher, but the admission rates for atopic dermatitis do not seem to have differed.

Table 2. Descriptive statistics for the daily ozone concentration in ambient air, weather, and childhood hospital admissions in Seoul and Ulsan, 2004–2005.

Percentile	Min	25th	50th	75th	Max	Mean
Seoul						
O ₃ concentration (ppb)	1.95	15.43	23.64	34.01	95.07	26.09
Air temperature (°C)	−14.00	3.87	14.47	22.03	30.43	12.74
Relative humidity (%)	21.08	49.04	61.71	72.08	95.75	61.33
Daily # of asthma	0.00	6.00	9.00	14.00	48.00	10.68
Daily # of atopic dermatitis	0.00	0.00	0.00	0.00	4.00	0.25
Ulsan						
O ₃ concentration (ppb)	3.56	23.62	29.51	38.93	78.13	32.05
Air temperature (°C)	−6.75	7.36	15.68	21.90	30.60	14.77
Relative humidity (%)	17.54	42.38	59.71	71.08	92.25	57.28
Daily # of asthma	0.00	0.00	2.00	3.00	11.00	1.97
Daily # of atopic dermatitis	0.00	0.00	0.00	0.00	2.00	0.04

Min, minimum; Max, maximum; daily # of asthma, the daily counts of the hospital admissions for childhood asthma; daily # of atopic dermatitis, the daily counts of the hospital admissions for childhood atopic dermatitis. The numbers of day in this study are 731 days. The numbers of population under age 15 in Seoul and Ulsan are 1,619,296 persons and 231,322 persons, respectively.

Figure 2 shows that clear seasonal patterns could be discerned in ozone levels and childhood asthma. Figure 2 also shows that the hospital admission counts for childhood asthma increased over the 2-year period of the study. However, the hospital admission counts for childhood atopic dermatitis did not show any yearly trend because of the extremely small sample size.

The estimated relative risk and the 95% confidence intervals for childhood asthma and atopic dermatitis hospital admission versus the interquartile range increases in the daily ozone concentration were obtained after controlling for temporal trends, weather conditions, and days of the week, using a single-pollutant model for the cities of Seoul and Ulsan (Table 3). Increases in the level of ozone from one quartile to the next had a significant effect on the relative risk of both childhood asthma and childhood atopic dermatitis, and the relative risks in Ulsan [1.21 (95% CI, 1.10–1.34) and 1.38 (95% CI, 0.80–2.36), respectively] were higher than those in Seoul [1.05 (95% CI, 0.99–1.11) and 1.28 (95% CI, 1.04–1.58), respectively].

Figure 3 shows the exposure-response relationship, calculated over the 2-year period, between the 8-h maximum ozone levels and the daily hospital admission ratio for childhood asthma at the best-lagged day (2-day moving average) as estimated by the LOESS model. From the figure it is evident that a threshold point exists at around 30 ~ 35 ppb of ozone level. Above the threshold point, risks increased in a manner characterized by a linear positive relationship between the log relative risk and the ozone level.

Discussion

We investigated the association between ambient ozone levels and hospital admissions for asthma and atopic dermatitis among children under 15 years of age in Seoul and Ulsan, Korea during the years of 2004 and 2005. Our findings showed that increased levels of ambient ozone concentration were correlated with an increased risk of childhood asthma in Seoul and Ulsan. However, compared to our

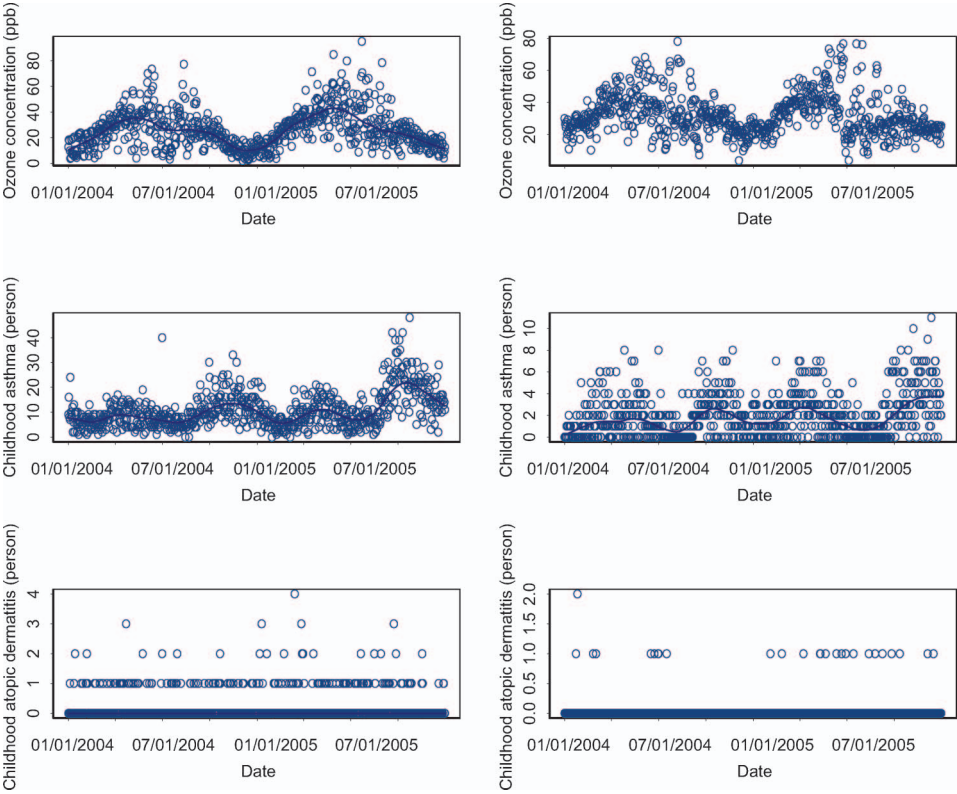


Figure 2. Daily averaged ozone concentrations, number of hospital admissions for childhood asthma and atopic dermatitis in Seoul (left) and Ulsan (right) using long-term trends from 2004–2005.

Table 3. Relative risks (RR) with 95% confidence intervals of childhood asthma and atopic dermatitis hospital admissions by an interquartile increase in daily average of O_3 with a best lag time selected using single-pollutant model, in Seoul and Ulsan, 2004–2005.

City	Childhood asthma			Childhood atopic dermatitis		
	RR [lag time] (95% CI)	AIC	df	RR [lag time] (95% CI)	AIC	df
Seoul	1.05 [lag 1 + 2] (0.99–1.11)	1637.28	729	1.28 [lag 1] (1.04–1.58)	593.08	730
Ulsan	1.21 [lag 1 + 2] (1.10–1.34)	1192.40	727	1.38 [lag 7] (0.80–2.36)	131.98	723

RR, relative risk; AIC, Akaike’s information criterion; df, degree of freedom. The model included the following variables: an intercept; indicator variables for day of week; and smooth functions for date, temperature, and humidity.

results about childhood asthma, we could not indicate a significant association between ozone levels and atopic dermatitis because of the insufficiency of the sample size. According to the results, there is a U-shaped relationship in which lower levels of ozone concentration were associated with a clear trend of an increasing number of childhood asthma admissions. This study supports the hypothesis that exposure to air pollutants such as ozone increases the risk of childhood asthma at relatively low ambient levels.

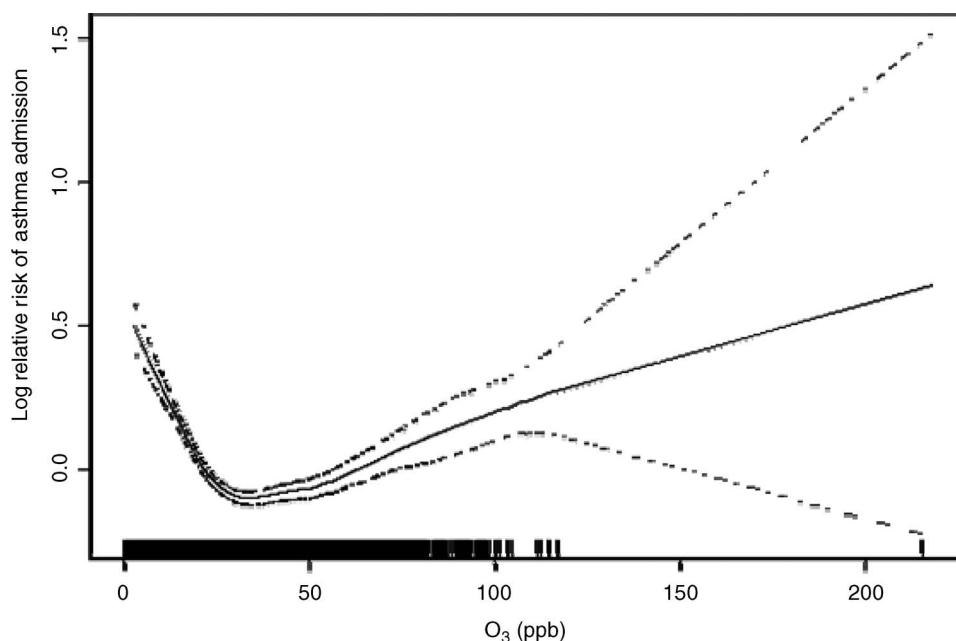


Figure 3. Log relative risk of hospital admission counts for childhood asthma vs. the concentration of O_3 using single-pollutant model adjusted for long-term time trends and weather information in Seoul, 2004–2005. The dashed lines give 95% confidence limits and the vertical lines along the x-axis indicate the number of observations.

Many studies have demonstrated significant associations between outdoor ozone concentrations and morbidity or mortality. Furthermore, short-term exposures to high ambient ozone concentrations have been linked to increased numbers of hospital admissions and emergency room visits for respiratory problems (Weisel et al. 1995). Children are more at risk of developing respiratory illness from ozone exposure than adults are since their respiratory systems are still developing (Chen et al. 2004).

The results of this study support these previous findings and also indicate that ozone levels below the Korean National Ambient Air Quality Standards (60 ppb) are associated with an increase in asthma hospital admissions in children. These findings also are consistent, including the results of the present study and comparing the previous study using two-pollutant model with ozone levels, and indicate that the associations of respiratory illness with ozone concentrations are probably not attributable to confounding by other pollutants (Lee et al. 2000).

The results shown in Figure 3 suggest a U-shaped relationship between childhood asthma admissions and ozone levels from 0 to about 100 ppb. There is a threshold point at around 30 ~ 35 ppb of ozone concentrations and we found that relative risk estimates of hospital admission for childhood asthma associated with daily changes in ozone levels below air quality regulatory standard in Korea. The other hand, a number of recent studies have investigated the details of this U-shaped relationship. Several studies in Korea have shown a possibly nonlinear association between ozone levels and health effects. Kim et al. (2004) estimated the effects of ozone beyond the threshold by calculating the slope of the line above the threshold. The percentage

increase in the estimated relative risk of total deaths corresponding to a 1-h maximum ozone level of 21.5 ppb from the threshold model is 3.4% ($RR = 1.034$). The other study reported that there was a clear change of direction in the relationship at approximately 23 ppb ozone concentration, suggesting that there is a threshold for the effects of ozone on mortality (Hong et al. 1999). In this study, it is evident that a threshold point existed at somewhere between 25 and 35 ppb of ozone during the study period (Figure 3).

The key factors affecting asthma and atopic dermatitis can be divided into genetic factors and environmental factors (e.g. housing conditions, indoor air pollution, and outdoor air pollution). A number of researchers have investigated the role that ambient air pollution, particularly ozone, plays in urban areas as a risk factor for asthma (Neas et al. 1996; Schwartz 1996; Jones 1998). Recently, attention concerning childhood asthma and atopic dermatitis has shifted to the role of indoor environmental risk factors, especially at home and in school, but there are few studies on the correlation between childhood atopic dermatitis and outdoor air pollution. This could be the first study that reports data on the relationship between ambient ozone and hospitalization for atopic dermatitis among children.

Generally speaking, a person's average daily intake of ozone will be determined by a combination of variables, including the concentration of ozone, the duration of the exposure, and the frequency of the exposure. These variables depend on human activity patterns and on the time spent at each activity and location. "Exposure" to an air contaminant in a given microenvironment has been defined as the concentration of a pollutant in that microenvironment times the amount of time an individual spends there (National Academy of Sciences [NAS] 1991). Children are likely to be exposed to elevated ambient levels of ozone during outdoor exercise and, therefore, are at greater risk of experiencing adverse health effects. Children are most at risk from ozone exposure because they typically are active outside, playing and exercising, during the summer when ozone levels are highest. For example, summer camp studies in the United States and Canada have reported significant reductions in lung function in children who are active outdoors (Spektor et al. 1988; Raizenne et al. 1989; Burnett et al. 1990; Higgins et al. 1990; Spektor et al. 1991). According to the results of a 2004 national survey by the Korean Medical Insurance Corporation, asthma and atopy prevalence were 4.7% and 2.6%, respectively, for all age groups, while the prevalences of asthma and atopy in children under 4 years of age were found to be much higher (31.5% and 41.2%, respectively) (Hyun 2004). These results indicate that children may be in the greatest danger from these environmental diseases.

The biological mechanism underlying the relationship between childhood atopic dermatitis and ambient ozone is still unknown. Ozone, a secondary pollutant, may be derived from various primary pollutants, such as nitrates, hydrocarbons, and volatile organic compounds, through exposure to ultraviolet radiation (Gillani 1987). The term "photochemical oxidants" refers to ozone and other secondary oxidants that are formed from these reactions. Noticeable effects from photochemical oxidants include eye and skin irritation (Weschler 2006). Among photochemical oxidants, the compounds that have been identified as irritants include formaldehyde ($HCHO$), acrolein (CH_2CHCHO), volatile organic compounds (VOCs), and members of the family of peroxyacyl nitrates (Seinfeld 1986). Oxidants, including ozone, enter the indoor environment when outdoor air infiltrates the interior of a building. Reported reductions in the outdoor air concentrations of

oxidants (due to deposition and reactions) range from 20% to a maximum of 80% (Weschler et al. 1989; Sundell and Zuber 1996). It has been proposed that reactions between unsaturated VOCs and oxidants (e.g. terpenes and ozone) produce chemically reactive products that are more likely to be responsible for eye, skin, and airway irritation than the chemically non-reactive VOCs that are usually measured indoors (Wolkoff et al. 1997). Epidemiological studies of airway irritation symptoms support the hypothesis that ozone, in combination with unsaturated VOCs (e.g. emitted from building products), contribute to nasal resistance which is related to difficulty breathing through the nose (Höppe et al. 1995). Moreover, Brinke et al. (1998) reported that exposure to low levels of VOCs was a statistically significant predictor of skin irritations [adjusted OR = 2.2 (95% CI, 1.3–3.7)].

This study has some limitations. There are a variety of indoor factors (e.g. smoking status, the presence of pets, and the condition of the heating/cooling in the household, etc.) and different socio-economic status that could be confounded in our results. In addition, there are other limitations in applying the time-series design to evaluate the association between air pollution and health outcomes that measurements from outdoor stationary monitors may not determine individual exposure. Thus, these studies may be called the ecological study and may have some limitations such as the ecological fallacy (Künzli and Tager 1997). However, because the health outcomes of the hospital admissions for childhood asthma and atopic dermatitis in this study were measured in individuals, this study generally could be called as the semi-ecologic study. Measurement error for air pollution in this study was probably non-differential with respect to the hospital admissions for childhood asthma and atopic dermatitis. Therefore, our estimated association would be underestimated from its true association which indicates the actual risk may be higher than our estimated risk.

Despite the limitations, the results of this study support previously reported findings and also indicate that ozone concentrations at levels below the Korean National Ambient Air Quality Standards can correlate with asthma hospital admissions in children.

Acknowledgements

This research was supported by the Korean Ministry of Environment as part of “The Eco-technopia 21 Project”.

References

- Akaike H. 1970. Statistical predictor identification. *Ann Inst Stat Math.* 22:203–217.
- Brinke JT, Selvin S, Hodgson AT, Fisk WJ, Mendell MJ, Koshland CP, Daisey JM. 1998. Development of new volatile organic compound (VOC) exposure metrics and their relationship to “Sick Building Syndrome” symptoms. *Indoor Air.* 8:140–152.
- Burnett R, Raizenne M, Krewski D. 1990. Acute health effects of transported air pollution: A study of children attending a residential summer camp. *Can J Stat.* 18:365–367.
- Chen LL, Tager IB, Peden DB, Christian DL, Ferrando RE, Welch BS, Balmes JR. 2004. Effect of ozone exposure on airway responses to inhaled allergen in asthmatic subjects. *Chest.* 125:2328–2335.
- Dockery DW, Speizer FE, Stram DO, Ware JH, Spengler JD, Ferris BG. 1989. Effects of inhalable particles on respiratory health of children. *Am Rev Respir Dis.* 139:587–594.
- Dominici F, McDermott A, Zeger SL, Samet JM. 2002. On the use of generalized additive models in time-series studies of air pollution and health. *Am J Epidemiol.* 156:193–203.

- Gent JF, Triche EW, Holford TR, Belanger K, Bracken MB, Beckett WS, Leaderer BP. 2003. Association of low-level ozone and fine particles with respiratory symptoms in children with asthma. *JAMA*. 290:1859–1867.
- Gillani NV. 1987. Ozone formation in pollutant plumes: a reactive plume model with arbitrary crosswind resolution. Research Triangle Park, NC: USEPA.
- Hastie T, Tibshirani R. 1986. Generalized additive models. *Stat Sci*. 1:297–318.
- Higgins ITT, D'Arcy JB, Gibbons DI, Avol EL, Gross KB. 1990. Effects of exposures to ambient ozone on ventilatory lung function in children. *Am Rev Respir Dis*. 141:1136–1146.
- Hong YC, Leem JH, Ha EH, Christiani DC. 1999. PM10 exposure, gaseous pollutants, and daily mortality in Inchon, South Korea. *Environ Health Perspect*. 107:873–878.
- Höppe P, Praml G, Rabe G, Linder J, Fruhmarm G, Kessel R. 1995. Environmental ozone field study on pulmonary and subjective responses of assumed risk groups. *Environ Res*. 71:109–121.
- Hubbell BJ, Hallberg A, McCubbin DR, Post E. 2005. Health-related benefits of attaining the 8-hr ozone standard. *Environ Health Perspect*. 113:73–82.
- Hyun AJ. 2004. A proposed report of the National Assembly using the statistics of asthma and atopy from the Korea Medical Insurance Corporation.
- Jones AP. 1998. Asthma and domestic air quality. *Soc Sci Med*. 47:755–764.
- Kim SY, Lee JT, Hong YC, Ahn KJ, Kim H. 2004. Determining the threshold effect of ozone on daily mortality: an analysis of ozone and mortality in Seoul, Korea, 1995–1999. *Environ Res*. 94:113–119.
- Künzli N, Tager IB. 1997. The semi-individual study in air pollution epidemiology: a valid design as compared to ecologic studies. *Environ Health Perspect*. 105:1078–1083.
- Lee JT, Kim H, Song H, Hong YC, Cho YS, Shin SY, Hyun YJ, Kim YS. 2002. Air pollution and asthma among children in Seoul, Korea. *Epidemiology*. 13:481–484.
- Lee JT, Kim H, Hong YC, Kwon HJ, Schwartz J, Christiani DC. 2000. Air pollution and daily mortality in seven major cities of Korea, 1991–1997. *Environ Res*. 84:247–254.
- Lee JT, Shin D, Chung Y. 1999. Air pollution and daily mortality in Seoul and Ulsan, Korea. *Environ Health Perspect*. 107:149–154.
- Linaker CH, Coggon D, Holgate ST, Clough J, Josephs L, Chauhan AJ, Inskip HM. 2000. Personal exposure to nitrogen dioxide and risk of airflow obstruction in asthmatic children with upper respiratory infection. *Thorax*. 55:930–933.
- National Academy of Sciences (NAS). 1991. Human exposure assessment for airborne pollutants. Washington (DC): National Academy Press.
- Neas LM, Dockery DW, Burge H, Koutrakis P, Speizer FE. 1996. Fungus spores, air pollutants, and other determinants of peak expiratory flow rate in children. *Am J Epidemiol*. 143:797–807.
- Pope CA III, Schwartz J. 1996. Time series for the analysis of pulmonary health data. *Am J Respir Crit Care Med*. 154:s229–233.
- Raizenne ME, Burnett RT, Stern B, Franklin CA, Spengler JD. 1989. Acute lung function responses to ambient acid aerosol exposures in children. *Environ Health Perspect*. 79:179–185.
- Ramsay TO, Burnett RT, Krewski D. 2003. The effect of concurvity in generalized additive models linking mortality to ambient particulate matter. *Epidemiology*. 14:18–23.
- SAS Institute Inc. 1993. SAS Technical Report P-243. SAS/STAT software version 9.1. Cary (NC): SAS Institute.
- Schwartz J. 1996. Air pollution and hospital admissions for respiratory disease. *Epidemiology*. 7:20–28.
- Seinfeld JH. 1986. Atmospheric chemistry and physics of air pollution. New York: John Wiley & Sons. p. 58–59.
- Spektor DM, Lippmann M, Liou PJ, Thurston GD, Citak K, James DJ, Bock N, Speizer FE, Hayes C. 1988. Effects of ambient ozone on respiratory function in active, normal children. *Am Rev Respir Dis*. 137:313–320.
- Spektor DM, Thurston GD, Mao J, He D, Hayes C, Lippmann M. 1991. Effects of single- and multiday ozone exposures on respiratory function in active normal children. *Environ Res*. 55:107–122.
- Sundell J, Zuber A. 1996. Ozone and other photochemical oxidants in ambient and indoor airsources and concentrations. *Scand J Work Environ Health*. 22(S3):5–14.

- Sunyer J, Spix C, Quenel P, Ponce-de-Leon A, Ponka A, Barumandzadeh T, Touloumi G, Bacharova L, Wojtyniak B, Vonk J, Bisanti L, Schwartz J, Katsouyanni K. 1997. Urban air pollution and emergency admissions for asthma in four European cities: the APHEA project. *Thorax*. 52:760–765.
- Weisel CP, Cody RP, Lioy PJ. 1995. Relationship between summertime ambient ozone levels and emergency department visits for asthma in central New Jersey. *Environ Health Perspect*. 103(S2):97–102.
- Weschler CJ. 2006. Ozone's impact on public health: contributions from indoor exposures to ozone and products of ozone-initiated chemistry. *Environ Health Perspect*. 114:1489–1496.
- Weschler CJ, Shields HC, Naik DV. 1989. Indoor ozone exposures. *J Air Pollut Control Assoc*. 39:1562–1568.
- WHO. 2005. WHO air quality guidelines global update 2005. Report on a working group meeting. 2005 Oct 18–20; Bonn, Germany.
- Wolkoff P, Clausen PA, Jensen B, Nielsen GD. 1997. Are we measuring the relevant indoor pollutants? *Indoor Air*. 7:92–10.