

Association between Indoor and Outdoor Air Pollution and Adolescent Asthma from 1995 to 1996 in Taiwan

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The study aim was to estimate the contribution of indoor and outdoor air pollution to the 1-year prevalence of adolescent asthma after personal susceptibility and other potential risk factors were taken into account. A large-scaled cross-sectional study was conducted among 165,173 high school students aged 11 to 16 years in the different communities of Kaohsiung and Pingtung in Taiwan, from October 1995 to June 1996. Each student and his/her parents participating in the study completed a video and a written International Study of Asthma and Allergies in Childhood (ISAAC) questionnaire about symptoms of wheezing and allergies, passive smoking, and demographic variables. After adjustment for potential confounders, adolescents exposed to cigarette smoking (odds ratio = 1.29, 95% confidence interval (CI), 1.17–1.42) and environmental tobacco smoke (odds ratio = 1.08, 95% CI, 1.05–1.12) were found to suffer from asthma at an increased frequency. We observed a statistically significant association between outdoor air pollution and asthma, after controlling for potential confound variables. Total suspended particulate, nitrogen dioxide, carbon monoxide, ozone, and airborne dust particles all displayed an independent association with asthma, respectively. There were no selection biases in this community-based study, which provides evidence that passive smoking and long-term, high average outdoor air pollution are independent risk factors of asthma. © 1999

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Key Words: asthma; indoor; outdoor; air pollution; environmental tobacco smoke.

INTRODUCTION

The prevalence of asthma for schoolchildren has been increasing gradually in Taiwan. Air pollution traceable to sources such as industry, traffic, and residential buildings has also increased massively throughout the island during these years. No demarcation exists between plants and residential quarters in Taiwan (Ko, 1996). Although air contaminants may contribute to clinical asthma, there are at present no data on the relation between air pollution exposure and adolescent asthma in Taiwan. It is necessary to study the adverse effects of air pollution on asthma.

There were difficulties in assessing any association between air pollution and health effects for several reasons: (a) individual or population exposure is unknown, (b) the effect of air pollution on health is difficult to assess, as environmental air pollution may cause or worsen asthma, and (c) many confounders, such as occupational exposure, smoking habit, etc., may be involved. Many studies documented the association between short-term, high dose air pollution exposure and acute health effects. Fewer studies addressed the question of long-term air pollution concentration. The Swiss schoolchild study and other cross-sectional surveys suggest an association between respiratory health indicators and long-term air pollution exposure (Braun-Fahrlander *et al.*, 1997; Schwartz *et al.*, 1989). But there is also little evidence in the world literature that asthma prevalence or incidence is related to ambient air pollution exposure. Outdoor exposure such as truck traffic in a residential street was associated with asthma in a German study (Duhme *et al.*, 1998), which was not a proper indicator for assessing outdoor air pollution. The long-term, high average air pollution concentration and increased prevalence of asthma are carried out in this communities-based study.

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Particulate air pollution refers to a mixture of solid and liquid particles suspended in the air. More recent epidemiologic studies have shown that present ambient concentration particles, SO₂, acid aerosols, and other particles are associated with increased respiratory morbidity and mortality (von Mutius *et al.*, 1995). Particulate matter less than 10 µm in aerodynamic diameter (PM₁₀) deposits into the pulmonary region of lung and damages the airways where gas exchange takes place. Ozone is a powerful oxidant and as an air pollutant has been shown to induce pulmonary fibrosis (Chitano *et al.*, 1995) and increased probability of asthma attacks (Whittemore *et al.*, 1980). The most consistent relationship was found with particulate air pollution and ozone. Increasing SO₂ concentration was found associated with prevalence of asthma and respiratory symptoms in school students who lived in areas of severe air pollution (Neas *et al.*, 1995). Some epidemiological data indicated weak or no association between sulfur dioxide and mortality (Dockery *et al.*, 1992). Nitrogen dioxide is a gaseous product of combustion from both stationary sources and motor vehicles. There is a large discrepancy in studies of the effects of exposure to NO₂ on lung function and airway response for healthy subjects and asthmatics. Only a few studies have directly addressed the association between NO₂ concentration in outdoor air and respiratory illness (Duhme *et al.*, 1998). Several studies have examined the adverse effects of CO on spirometric end points (Evans *et al.*, 1988; Lebowitz *et al.*, 1987;). Because the mechanism for the effect on respiratory diseases is not yet well understood, interpretation of these findings must be recognized by biological plausibility.

Concern has arisen in recent years about indoor air pollution as a risk factor of asthma. Pollutants in the home are numerous, frequently from sources (Chang *et al.*, 1989; Dales *et al.*, 1991; Dijkstra *et al.*, 1990; Hosen *et al.*, 1989; Peat *et al.*, 1996;), such as tobacco smoking, dust mites, dampness, and pets. The role of ETS as a cause of asthma, however, remains less certain, especially in adolescents (Cunningham *et al.*, 1996). But many studies have shown a statistically significant relationship between passive smoking and childhood asthma (Forastiere *et al.*, 1992; Newman-Taylor *et al.*, 1995), but some have not (Chinn *et al.*, 1991; Sherman *et al.*, 1990). The exposure to environmental tobacco smoke (ETS) is associated with wheezing symptoms, medical therapy for wheezing, and wheezing-related emergency department visits (Cunningham *et al.*, 1996), especially for children whose mothers smoked (Stoddard *et al.*, 1995).

This is the first study to assess comprehensive risk factors for asthma using the ISAAC questionnaire.

The study aim was to estimate the contribution of indoor and outdoor pollution to the 1-year prevalence of adolescent asthma after personal susceptibility and other potential risk factors were taken into account to reduce the risk of accidental confounding.

MATERIALS AND METHODS

Study Population

Our population sample included the pupils of all three grades in 123 high schools of the Kaohsiung and Pintong areas in Taiwan ($n = 170, 457$). Each student and his/her parents participating in this cross-sectional study completed a video and a written questionnaire between October 1995 and June 1996. In all 165,173 questionnaires were completed by students and their parents.

Written Questionnaire

Respiratory and allergic illness and symptom responses obtained from the written questionnaire were considered. Current wheeze, nocturnal dry cough apart from infection, wheezing after exercise, sneeze, conjunctivitis symptoms and asthma, atopic dermatitis, and rhinitis were diagnosed by a doctor.

Wheezing was defined as a positive response to the question: "Has your child had wheezing or whistling in the chest in the last 12 months?" Nocturnal dry cough required a positive response to the question: "In the past 12 months, has your child had a dry cough at night, apart from a cough associated with a cold or fever infection?" Sneezing was an answer to the question: "In the past 12 months, has your child had problem with sneezing or a runny or blocked nose when he/she did not have a cold or the flu?" Conjunctivitis symptoms were defined as a positive response to the question: "In the past 12 months, has your child had itchy or irritated eyes?"

The questions answered by parents also concerned sociodemographic characteristics, the habits of cigarette smoking and alcohol drinking by the students (yes or no), ETS (at least one family member who lived with the student has a smoking habit), total quantity of family members who smoke (no, less than one pack, more than one packs for 1 day), the daily use of Chinese incense in the home (yes or no), and students exercise habits (no, seldom, usually).

Video Questionnaire

The video questionnaire (Shaw *et al.*, 1992) developed by the International Study and Asthma and Allergies in Childhood (ISAAC) consisted of five

sequences of young people displaying signs of asthma. The scenes depicted:

1. Moderate wheezing at rest,
2. Wheezing and shortness of breath after exercise,
3. Nocturnal waking with wheezing or whistling,
4. Nocturnal waking with cough,
5. Severe wheezing and shortness of breath at rest.

After each sequence, the children were asked to specify whether their breathing had been like the person in the video. Following each scene a question was asked, which was similar in format to the following:

Has your breathing ever been like this at any time in your life? Yes/No

If yes: In the past 12 months? Yes/No

If yes: How many time in every month?

Each question was presented in written form on the screen, and also printed on a one-page answer sheet which was completed during screening the video. The term "asthma" was not mentioned during the video until all five sequences had been completed. The students filled the ISAAC questionnaire after watching the videotape.

The definition of asthma in our study is a positive response to any of questions 1 to 5 in the last year (1996—1-year prevalence) in the video program. The definition of nonasthma is no positive response to questions 1 to 5 throughout life. In order to reduce recall bias, 9890 students who had any one positive response before 1995 but not one during the last year (1995–1996) to the questions will be excluded in this study. Only 155,283 students were included to study the effects of potential risk factors.

Outdoor Air Pollution Monitoring

Air pollution data were extracted from the Taiwanese Environmental Protection Administration's aerometric data bank. Only 24 communities set up the air monitoring stations covering 117,080 students (72.6%) in Kaohsiung and Pintong, excluding sparsely populated rural districts and the aboriginal reservation areas. These small communities which are mostly located in the suburbs did not set up any air pollution station. Carbon monoxide, nitrogen dioxide, PM₁₀, sulfur dioxide, and airborne dust levels were monitored at 16 stations in the Kaohsiung and Pintong areas during the study period. Ozone, total suspended particulate matter, and hydrocarbon compounds were monitored at 15, 18, and 11 stations, respectively. Only students who lived in a community covered by air monitoring stations were included into the study of an association between outdoor air pollution and adolescent asthma.

Average air pollution levels for the year of 1996 were calculated. The cutoff concentrations were determined from the median values among all monitoring stations for the analysis of air pollution effects. The cutoff CO, NO₂, SO₂, airborne dust, O₃, TSP, and hydrocarbon compounds were 0.80 ppm, 0.028 ppm, 0.013 ppm, 7.6 ton/km²/month, 0.022 ppm, 181 µg/m³, and 0.45 ppm, respectively (Table 1). There was collinearity between PM₁₀ and SO₂. The cutoff value of PM₁₀ was taken to be 80 µg/m³. To analyze the association between asthma and air pollution we restricted pollution exposure data to students.

Statistical Analysis

Logistic regression was used to assess the association between possible risk factors and asthma. A multiple logistic regression analysis was used to determine the independent effects of several suspected risk factors of asthma, after adjusting for age, sex, parents' education, and area of residence. Adjusted odds ratio and 95% confidence intervals (CI) for each were calculated from the estimated regression coefficients for the exposure variables and their associated standard errors. Covariates included in the regression Model 1 were indicator variables for the schoolchild's sex, age, resident area, habits of exercise, smoking, and alcohol, parents' educational level, incense use at home, and ETS. The annual average concentration of each pollutant was calculated (Table 1). The cut points of exposure levels for the students were classed according to the median of pollutant values among all air monitoring stations. Pollutant-related odds ratios for asthma were estimated by including Model 1 into the multiple regression analysis (from Models 2 to 8). We used the SAS software package version 6.0 for our computations.

RESULTS

In all 165,173 questionnaires were completed. The response rate was approximately 96.9% in all centers. The self-reported lifetime prevalence of asthma was 18.5% (30,557/165,173), 1-year prevalence of asthma was 12.5% (20,637/165,173), and the rate for multiple attacks within a month was 5.2% (8643/165,173). In order to reduce recall bias, 1-year prevalence of asthma instead of lifetime prevalence of asthma was used in the present study. We analyzed how the 1996 asthma prevalence was related to 1996 air pollution levels and other factors.

TABLE 1
Self-Reported Asthma Prevalence and Air Pollutants (1995—Annual Means) by Study Community

| Community | <i>n</i> (117,080) | Asthma (%) | Population density ^a | CO (ppm) | NO ₂ (ppm) | PM ₁₀ (µg/m ³) | SO ₂ (ppm) | O ₃ (ppm) | Airborne dust (ton/km ² /month) | TSP (µg/m ³) | CH (ppm) |
|-------------------------|-----------------------|------------|------------------------------------|-------------|--------------------------|--|--------------------------|-------------------------|---|-----------------------------|-------------|
| Kaohsiung City | | | | | | | | | | | |
| Tsoying | 6155 | 13.68 | 5.96 | 0.80 | 0.025 | 75.20 | 0.011 | 0.024 | 7.79 | 151.75 | 0.33 |
| Kushan | 2975 | 18.66 | 7.47 | — | — | — | — | — | 7.86 | — | — |
| Nantzu | 6936 | 14.35 | 5.15 | 0.60 | 0.029 | 87.08 | 0.008 | 0.018 | 9.37 | 211.49 | 0.34 |
| Sanmin | 14121 | 15.42 | 16.72 | 0.93 | 0.031 | 72.53 | 0.001 | 0.021 | 9.56 | 237.82 | 1.52 |
| Hsinhsing | 1501 | 12.59 | 34.33 | 1.49 | — | — | — | — | 7.92 | 172.20 | 0.83 |
| Chienchin | 3350 | 15.43 | 20.04 | 0.95 | 0.028 | 90.24 | 0.013 | 0.023 | 7.53 | 180.77 | — |
| Linya | 14289 | 20.74 | 26.46 | — | — | — | — | — | 10.08 | — | — |
| Chiching | 1234 | 9.72 | 23.10 | 0.66 | 0.027 | 107.73 | 0.017 | 0.023 | 7.09 | 192.27 | 0.45 |
| Chienchen | 9677 | 12.17 | 10.70 | — | 0.034 | 97.14 | 0.018 | — | 10.10 | 171.94 | 0.51 |
| Hsiaokang | 7587 | 14.04 | 3.34 | 1.07 | 0.035 | 96.00 | 0.023 | 0.019 | — | — | 0.44 |
| Kaohsiung County | | | | | | | | | | | |
| Fengshan | 13009 | 14.51 | 11.27 | 1.06 | 0.034 | 103.08 | 0.020 | 0.021 | 4.89 | 200.10 | — |
| Meinung | 1907 | 14.79 | 0.42 | 0.55 | 0.016 | 89.95 | 0.004 | 0.031 | — | — | — |
| Linyuan | 3614 | 11.46 | 2.12 | 0.65 | 0.023 | 112.81 | 0.018 | 0.025 | 5.32 | 155.86 | 0.37 |
| Taliao | 3803 | 10.48 | 1.51 | 0.37 | 0.025 | 105.17 | 0.015 | 0.022 | 4.33 | 159.82 | — |
| Jenwu | 2792 | 14.27 | 1.13 | 0.75 | 0.029 | 94.68 | 0.018 | 0.017 | 4.89 | 149.52 | 0.53 |
| Chiaotou | 1456 | 8.04 | 1.45 | 0.66 | 0.023 | 83.86 | 0.008 | 0.017 | 6.60 | — | 0.34 |
| Kangshan | 790 | 16.58 | 1.84 | — | — | — | — | — | — | 226.21 | — |
| Luchu | 1647 | 17.36 | 1.08 | — | — | — | — | — | — | 112.81 | — |
| Yung-an | 452 | 7.96 | 0.56 | — | — | — | — | — | — | 192.93 | — |
| Tashe | 790 | 16.58 | 1.18 | — | — | — | — | — | — | 184.04 | — |
| Pingtung County | | | | | | | | | | | |
| Pingtung | 11447 | 12.95 | 3.30 | 0.82 | 0.028 | 102.92 | 0.007 | 0.026 | 4.94 | 117.77 | 0.36 |
| Chaochou | 2792 | 9.99 | 1.14 | 0.56 | 0.021 | 103.34 | 0.005 | 0.002 | 5.73 | 117.59 | — |
| Hengchun | 954 | 13.10 | 0.23 | 0.21 | 0.001 | 19.40 | 0.000 | 0.032 | — | — | — |
| Wantan | 2254 | 5.28 | 0.92 | — | — | — | — | — | — | 114.59 | — |
| Median | | | | 0.80 | 0.028 | 91.00 | 0.013 | 0.022 | 7.60 | 181.00 | 0.45 |

^a Population density (thousands people/km²).

Demographic Characteristics of Adolescent Asthma

Table 2 displays the univariate analysis of demographic characteristics of young adolescent asthma sufferers. Young boy students whose parents were highly educated and lived in Kaohsiung city showed a significant excess of asthma. There was a dose-response relationship between asthma and parents' reported air pollution. The students' habits of cigarette smoking, alcohol drinking, and infrequent physical exercise were significantly associated with asthma. These variables would be included in the multiple regression to control potential confounders.

Indoor Air Pollution

Passive smoking and using of Chinese incense were included among the indoor pollutants surveyed. The odds ratio was 1.13 (95%, CI=1.07–1.19) among persons who were exposed to more than a pack/day quantity of passive smoking. However, a negative association was observed between adolescent asthma and Chinese incense (Table 3).

Outdoor Air Pollution

Table 4 displays the univariate association of young adolescent asthma and outdoor air pollution. Total suspended particulate, sulfur dioxide, nitrogen dioxide, carbon monoxide, ozone, and airborne dust were all found to be significantly associated with adolescent asthma. But PM₁₀ and hydrocarbon compounds were not. The frequency of high level PM₁₀ concentrations (≥ 80 µg/m³) was lower among asthma patients than among nonasthmatic adolescents.

Multivariate Analysis

Table 5 shows that the demographic characteristics and indoor air pollution factors were included in the same regression model (Model 1). Cigarette smoking and passive smoking were both strongly associated with asthma, if other risk factors were controlled. The effects of demographic variables on asthma were unchanged whether or not covariates were controlled.

Pollutant-related odds ratios for asthma were estimated by including Model 1 into the multiple regression analysis (from Models 2 to 8) (Table 6). The cutoff

TABLE 2
Univariate Analysis of the Characteristic of Adolescent Asthma

| Variables | Asthma n (%) | Non-asthma n (%) | OR ^a | 95% CI ^b |
|--------------------|-----------------|---------------------|-----------------|---------------------|
| Sex | | | | |
| Female | 9422 (12.01) | 69032 (87.99) | 1 | |
| Male | 11215 (14.60) | 65614 (85.40) | 1.25** | (1.22–1.29) |
| Age | | | | |
| 11–12 years | 5217 (14.85) | 29925 (85.15) | 1 | |
| 13–14 years | 13741 (13.05) | 91563 (86.95) | 0.86** | (0.83–0.89) |
| 15–16 years | 1679 (11.32) | 13159 (88.68) | 0.73** | (0.69–0.78) |
| Residence | | | | |
| Pintong County | 3722 (9.58) | 35149 (90.42) | 1 | |
| Kaohsiung County | 6188 (12.92) | 41712 (87.08) | 1.40** | (1.34–1.46) |
| Kaohsiung City | 10727 (15.66) | 57786 (84.34) | 1.75** | (1.69–1.82) |
| Parents' education | | | | |
| Primary school | 3515 (10.86) | 28865 (89.14) | 1 | |
| High school | 12664 (13.25) | 82913 (86.75) | 1.25** | (1.21–1.31) |
| College | 4458 (16.31) | 22869 (83.69) | 1.60** | (1.53–1.68) |
| Exercise habit | | | | |
| No | 3139 (15.19) | 17522 (84.81) | 1 | |
| Seldom | 9961 (13.20) | 65482 (86.80) | 0.85** | (0.81–0.89) |
| Usually | 7487 (12.73) | 51332 (87.27) | 0.81** | (0.78–0.85) |
| Cigarette smoking | | | | |
| No | 19864 (13.17) | 131016 (86.83) | 1 | |
| Yes | 696 (18.49) | 3068 (81.51) | 1.50** | (1.38–1.63) |
| Alcohol drinking | | | | |
| No | 19927 (13.12) | 131943 (86.88) | 1 | |
| Yes | 620 (23.46) | 2023 (76.54) | 2.03** | (1.85–2.22) |

^aOR, odds ratio.

^bCI, confidence interval.

** $P < 0.05$.

concentrations, of the air pollutants were the same as those in Table 4. We found that asthma was significantly related to high levels of total suspended particulate matter, nitrogen dioxide, carbon monoxide, ozone, and airborne dust ($P < 0.01$), upon controls for Model 1. The adjusted odds ratios were 1.29 (95% CI = 1.24–1.34), 1.08 (95% CI = 1.04–1.13), 1.15

TABLE 3
Univariate Analysis of Adolescent Asthma and Indoor Air Pollution

| Variables | Asthma n (%) | Non asthma n (%) | OR | 95% CI |
|-----------------|-----------------|---------------------|--------|-------------|
| ETS | | | | |
| No | 8425 (13.18) | 55493 (86.82) | 1 | |
| Yes | 12212 (13.37) | 79154 (86.63) | 1.02 | (0.99–1.05) |
| Quantity | | | | |
| No | 9106 (13.28) | 59474 (86.72) | 1 | |
| ≤ 1 pack/day | 9800 (13.08) | 65135 (86.92) | 0.98 | (0.95–1.01) |
| ≥ 1 pack/day | 1731 (14.71) | 6841 (86.29) | 1.13** | (1.07–1.19) |
| Chinese incense | | | | |
| No | 11244 (13.99) | 69145 (86.01) | 1 | |
| Yes | 9236 (12.56) | 64297 (87.44) | 0.88** | (0.86–0.91) |

** $P < 0.01$.

(95% CI = 1.10–1.20), 1.11 (95% CI = 1.07–1.15), and 1.17 (95% CI = 1.07–1.27), in this order. However PM₁₀ and sulfur dioxide could not be associated with asthma in this study.

DISCUSSION

Our subjects participating in this study of the association between air pollution and asthma were usually school-aged children. Occupational exposure and regular smoking are causes of asthma that can be readily discounted in the case of primary and junior high school students. Thus all junior high school students in the Kaohsiung and Pintong areas of Tawian formed part of our study population. As response rate in this study was nearly 96.9%, there was little or no selection bias. The characteristics of air pollution in Kaohsiung and Pintong countries are as follows. (a) Severe air pollution: the standard annual average value of TSP in Taiwan was 130 $\mu\text{g}/\text{m}^3$. TSP deposition values were over 130 g/m^3 in 14 monitoring stations located in the Pintong and Kaohsiung areas. The 14 PM₁₀ stations levels exceeded 65 $\mu\text{g}/\text{m}^3$ (PM₁₀ standard annual average value). The other pollutants are the same as above. (b) Pollution was related mostly to factories, which were near residential quarters. Almost 50% of petrochemical factories were located within 100 m of residential areas. Pollution levels in Taiwan at the time of our study were even higher than those observed for Switzerland with moderate average air pollution concentrations (Braun-Fahrlander *et al.*, 1997). The effects of long-term, high average level air pollution to asthma were discussed in this large-scaled study.

According to the video developed by the International Study of Asthma and Allergies in Childhood with high validity, the prevalence of childhood asthma can be compared among different countries (ISSAC steering committee, 1998; Pearce *et al.*, 1993). In comparison lifetime prevalence of asthma was 18.5%; prevalence of asthma in the preceding 12 months was 12.5%; and rate of multiple attacks within a month was 5.2% in the present study using ISAAC questionnaire. We have found that boys suffered from asthma significantly more frequently than girls and there was a significant excess of asthma cases among young children. The association between social class and asthma was somewhat controversial. We detected a significant excess of asthma cases among children whose parents were highly educated, agreeing again with the finding of a previous study (Kaplan *et al.*, 1988). Alcohol drinking has a large effect after adjustment for confounding factors in this present study. Alcohol elevates blood acetaldehyde, which leads to

TABLE 4
Univariate Analysis and Adolescent Asthma and Outdoor Air Pollution

| Variable | Asthma <i>n</i> (%) | Nonasthma <i>n</i> (%) | OR | 95% CI |
|---------------------------------------|---------------------|------------------------|--------|-------------|
| Total suspended particulate | | | | |
| < 181 $\mu\text{g}/\text{m}^3$ | 6156 (12.99) | 41234 (87.01) | 1 | |
| $\geq 181 \mu\text{g}/\text{m}^3$ | 8890 (16.43) | 45216 (83.57) | 1.32** | (1.27–1.36) |
| PM ₁₀ | | | | |
| < 80 $\mu\text{g}/\text{m}^3$ | 3719 (15.32) | 20559 (84.68) | 1 | |
| $\geq 80 \mu\text{g}/\text{m}^3$ | 12610 (14.64) | 73548 (85.36) | 0.95** | (0.91–0.99) |
| Sulfur dioxide | | | | |
| < 0.013 ppm | 7504 (14.46) | 44400 (85.54) | 1 | |
| ≥ 0.013 ppm | 8825 (15.08) | 49707 (84.92) | 1.05** | (1.02–1.09) |
| Nitrogen dioxide | | | | |
| < 0.028 ppm | 3791 (13.47) | 24344 (86.53) | 1 | |
| ≥ 0.028 ppm | 12538 (15.23) | 69763 (84.77) | 1.15** | (1.10–1.20) |
| Carbon monoxide | | | | |
| < 0.80 ppm | 3645 (13.11) | 24151 (86.89) | 1 | |
| ≥ 0.80 ppm | 11695 (15.70) | 62773 (84.30) | 1.23** | (1.19–1.28) |
| Ozone | | | | |
| < 0.022 ppm | 7430 (14.59) | 43483 (85.41) | 1 | |
| ≥ 0.022 ppm | 7721 (15.49) | 42130 (84.51) | 1.07** | (1.04–1.11) |
| Carbon hydrogen compound | | | | |
| < 0.45 ppm | 6118 (14.12) | 37209 (85.88) | 1 | |
| ≥ 0.45 ppm | 3943 (13.85) | 24530 (86.13) | 0.98 | (0.94–1.02) |
| Airborne dust particles | | | | |
| < 7.6 ton/km ² /month | 6131 (13.39) | 39667 (86.61) | 1 | |
| ≥ 7.6 ton/km ² /month | 8915 (16.01) | 46783 (83.99) | 1.23** | (1.19–1.28) |

Note. The median value of the 1995 levels for CO, NO₂, SO₂, airborne dust, O₃, TSP, and hydrocarbon compounds were used to analyze the association between asthma and air pollution.

** $P < 0.01$.

degranulation of mast cells and releases histamine, induce asthma (Shimoda *et al.*, 1996). The mechanisms of alcohol-induced bronchial asthma are suggested.

Exposure to air pollution was estimated in this study from outdoor levels monitored at stations set up in 24 districts located in the Kaohuiung and Pintong areas. The relationship between outdoor air pollution and asthma are performed in this study after other risk factors were controlled. Multiple regression analysis indicated that long-term exposure from TSP, NO₂, CO, O₃, and airborne dust was associated with increased prevalence of asthma. Airborne particulate matter has been documented to be associated with a variety of adverse health impacts in children. These included a rise in very severe episodes, increased incidence of respiratory symptoms, and worsening impairment of lung function (Duhme *et al.*, 1998; von Mutius *et al.*, 1995). In a German study (Duhme *et al.*, 1998), in which 1854 9- to 11-year-old students were screened for upper respiratory symptoms, nitric oxide, TSP, and sulfur dioxide were suggested to be related to asthma either independently or synergistically. In our study, SO₂, and PM₁₀ contributed little to the prevalence of asthma. Sulfur dioxide was found to be significantly associated with adolescent asthma

before controlling confounders. Asthmatics are particularly sensitive to NO₂, with decrements in lung function demonstrated at levels < 0.3 ppm (Bauer *et al.*, 1986). A 10 mg/m³ increase in average home outdoor and personal exposure to NO₂ was associated with a change in average FVC by –0.59% and –0.74%, respectively (Schindler *et al.*, 1998). Respiratory rate increased, epithelial lung permeability of the airway increased (Abramson *et al.*, 1995), mucociliary clearance was altered (Foster *et al.*, 1987) after exposure to ozone, and so did some pulmonary function indices, such as the FEV₁ in 10–20% of persons who inspired O₃ (Hazucha *et al.*, 1987). Exposure to ozone and NO₂ is associated with the symptoms of impaired lung function, bronchial hyperresponsiveness, and hospital presentations for asthma (Abramson *et al.*, 1995).

People spend most of their time indoors (about 78%–90%). Therefore, in addition to the effects of outdoor air pollution, it is important to consider the effects that exposure to indoor air pollution may have on adolescent asthma. We have shown that smoking or exposure to secondary smoke increases the likelihood of contracting asthma in childhood, as indicated by the dose-response relationship between asthma

TABLE 5
Multivariate Analysis of the Demographic Characteristics and Indoor Air Pollution for Adolescent Asthma (Model 1)

| Variables | Asthma n (%) | Nonasthma n (%) | AOR ^a | 95% CI |
|---------------------------|-----------------|--------------------|------------------|-------------|
| Sex | | | | |
| Female | 9422 (12.01) | 69032 (87.99) | 1 | |
| Male | 11215 (14.60) | 65614 (85.40) | 1.31** | (1.27–1.36) |
| Age | | | | |
| 11–12 years | 5217 (14.85) | 29925 (85.15) | 1 | |
| 13–14 years | 13741 (13.05) | 91563 (86.95) | 0.87** | (0.84–0.90) |
| 15–16 years | 1679 (11.32) | 13159 (88.68) | 0.75** | (0.70–0.79) |
| Residence | | | | |
| Pintong County | 3722 (9.58) | 35149 (90.42) | 1 | |
| Kaohsiung County | 6188 (12.92) | 41712 (87.08) | 1.35** | (1.30–1.41) |
| Kaohsiung City | 10727 (15.66) | 57786 (84.34) | 1.60** | (1.54–1.67) |
| Parents' education | | | | |
| Primary school | 3515 (10.86) | 28865 (89.14) | 1 | |
| High school | 12664 (13.25) | 82913 (86.75) | 1.18** | (1.14–1.23) |
| College | 4458 (16.31) | 22869 (83.69) | 1.41** | (1.34–1.48) |
| ETS | | | | |
| No | 8425 (13.18) | 55493 (86.82) | 1 | |
| Yes | 12212 (13.37) | 79152 (86.63) | 1.08** | (1.05–1.12) |
| Chinese incense | | | | |
| No | 11244 (13.99) | 69145 (86.01) | 1 | |
| Yes | 9236 (12.56) | 64297 (87.44) | 0.95** | (0.92–0.98) |
| Exercise habit | | | | |
| No | 3139 (15.19) | 17522 (84.81) | 1 | |
| Seldom | 9961 (13.20) | 65482 (86.80) | 0.82** | (0.78–0.85) |
| Usually | 7487 (12.73) | 51332 (87.27) | 0.72** | (0.69–0.76) |
| Cigarette smoking | | | | |
| No | 19864 (13.17) | 131016 (86.83) | 1 | |
| Yes | 696 (18.49) | 3068 (81.51) | 1.29** | (1.17–1.42) |
| Alcohol drinking | | | | |
| No | 19927 (13.12) | 131943 (86.88) | 1 | |
| Yes | 620 (23.46) | 2023 (76.54) | 1.85** | (1.67–2.05) |

^aAOR, adjusted odds ratio.

** $P < 0.01$.

and passive smoking reported in previous studies (Cunningham *et al.*, 1996; Keil *et al.*, 1992; Newman-Taylor *et al.*, 1995; Sherman *et al.*, 1990). The way passive smoking affects asthma is still a mystery. Thus to prevent childhood asthma or its exacerbation, the elimination of passive smoking from children's environment is essential. In addition to exposure to tobacco smoke, the presence of dampness, molds, dust mites, pets, and mosquito incense are frequent causes of allergy in asthmatic persons (Chang *et al.*, 1989; Dales *et al.*, 1991; Dijkstra *et al.*, 1990; Hosein *et al.*, 1989; Peat *et al.*, 1996). Chinese incense, however, seems to have a protective effect for people liable to suffer from asthma, even though according to Lin (Lin *et al.*, 1993) it includes traces of formaldehyde, a suspected allergen. This curious phenomenon is worthy of study.

The appropriateness of pollution measurement is worth discussion. In this study, the outdoor air

pollution concentrations were measured at 24 stations. The students who lived in the same community have the same air monitoring exposure levels from the same air station. Individual air pollution exposure was not assessed. The students who lived in the areas without monitoring stations in sparsely populated rural districts and the aboriginal reservation areas were excluded in this study; 72.6% effect size was observed for the association between asthma and outdoor air pollution. These areas have almost no air monitoring stations located in remote suburban and rural districts with a low asthma prevalence rate, low population density, few factories, and light traffic. The population densities are almost lower than 1000 people/km², even as low as 5 people/km². The pollutant-related odds ratio is not large biased.

The studies suggested that a viral infection of the respiratory system may cause asthma (Folkerts *et al.*, 1998); therefore it may be an infectious chronic inflammatory disease. The influence of diet in asthma control remains unclear. Dietary antioxidants may influence the expression of asthma and have a modulatory effect on bronchial reactivity (Woods *et al.*, 1996). Genetic heredity (Sandford *et al.*, 1996; Holgate *et al.*, 1997) had been proposed as a important etiological factor.

CONCLUSION

Our data demonstrate significant relationships between passive smoking, long-term outdoor air pollution, and adolescent asthma. We found that asthma was significantly related to high levels of nitrogen dioxide, ozone, carbon monoxide, airborne dust particles, and total suspended particulate with an 8 to

TABLE 6
Multivariate Analysis of Adolescent Asthma and Outdoor Air Pollution

| Model | Variables included | AOR ^a | 95% CI |
|-------|--|------------------|-------------|
| 1 | Exercise + smoking + alcohol+incense using + ETS | | |
| 2 | Model 1 + total suspended particulate | 1.29** | (1.24–1.34) |
| 3 | Model 1 + PM ₁₀ | 1.00 | (0.96–1.05) |
| 4 | Model 1 + sulfur dioxide | 0.98 | (0.95–1.02) |
| 5 | Model 1 + nitrogen dioxide | 1.08** | (1.04–1.13) |
| 6 | Model 1 + carbon monoxide | 1.15** | (1.10–1.20) |
| 7 | Model 1 + ozone | 1.11** | (1.07–1.15) |
| 8 | Model 1 + airborne dust particles | 1.17** | (1.07–1.27) |

Note. There were adjustments for age, sex, resident area, and parents education level for Model 1 to Model 8.

^aAOR, adjusted odds ratio of air pollution related.

** $P < 0.01$.

29% increase of asthma risk, after controlling for potential confound variables. To improve asthmatic children's health status a public health approach is required that emphasize disease prevention rather than a traditional medical approach. Protective standards must be laid down, involving the improvement of social cultural, and environmental conditions in which children live.

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REFERENCES

- Abramson, M. J., Marks, G. B., and Pattemore, P. K. (1995). Are non-allergenic environmental factors important in asthma? *Med. J. Australia* **163**(10), 542–545.
- Bauer, M. A., Utell, M. J., Morrow, P. E., Speers, D. M., and Gibb, F. R. (1986). Inhalation of 0.3 ppm nitrogen dioxide potentiates exercise-induced bronchospasm in asthmatics. *Am. Rev. Respir. Dis.* **134**, 1203–1208.
- Braun-Fahrlander, C., Vuille, J. C., Sennhauser, F. H., Neu, U., Kunzle, T., Grize, L., Minder, G. C., Schinder, C., Varonier, H. S., Wuthrich, B., and the Scarpol team (1997). Respiratory health and long term exposure to air pollutants in Swiss schoolchildren. *Am. J. Respir. Crit. Care Med.* **155**, 1042–1049.
- Chang, Y. C., and Hsieh, K. H. (1989). The study of house dust mites in Taiwan. *Ann. Allergy* **62**, 101–106.
- Chinn, S., and Rona, R. J. (1991). Quantifying health aspects of passive smoking in British children aged 5–11 years. *J. Epidemiol. Community Health* **45**, 188–194.
- Chitano, P., Hosselet, J. J., Mapp, C. E., and Fabbri, L. M. (1995). Effect of oxidant air pollutants on the respiratory system; insight from experimental animal research. *Eur. Respir. J.* **8**, 1357–1371.
- Cunningham, J., O'Connor, G. T., Dockery, D. W., and Speizer, F. E. (1996). Environmental tobacco smoke, wheezing and asthma in 24 communities. *Am. J. Respir. Crit. Care Med.* **153**, 218–224.
- Dales, R. E., Zwanenburg, H., Burnett, R., and Franklin, C. A. (1991). Respiratory health effects of home dampness and moulds among Canadian children. *Am. J. Epidemiol.* **134**, 196–203.
- Dockery, D. W., Scewartz, J., and Spengler, J. D. (1992). Air pollution and daily mortality: Associations with particulates and acid aerosols. *Environ. Res.* **9**, 362–373.
- Duhme, H., Weiland, S. K., Rudolph, P., Wienke, A., Kramer, A., and Keil, U. (1998). Asthma and allergies among children in West and East Germany: A comparison between Munster and Greifswald, using the ISAAC phase I protocol. *Eur. Respir. J.* **11**, 840–847.
- Evans, R., Webb, K., Homan, S., and Ayres, S. M. (1988). Cross-sectional and longitudinal changes in pulmonary function associated with automobile pollution among bridge and tunnel officers. *Am. J. Int. Med.* **14**, 25–36.
- Folkerts, G., Busse, W. W., Nijkamp, F. P., et al. (1998). Virus induced airway hyperresponsiveness and asthma. *Am. J. Respir. Crit. Care Med.* **157**, 1708–1720.
- Forastiere, F., Corbo, G. M., Michelozzi, P., Pistelli, R., Agabiti, N., Brancato, G., Ciappi, G., and Perucci, C. A. (1992). Effects of environment and passive smoking on the respiratory health of children. *Int. J. Epidemiol.* **21**, 66–73.
- Foster, W. M., Costa, D. L., and Langenback, E. G. (1987). Ozone exposure alters tracheobronchial mucociliary function in human. *Am. J. Physiol.* **63**, 996–1002.
- Hazucha, M. J. (1987). Relationship between ozone exposure and pulmonary function changes. *J. Appl. Physiol.* **62**, 1671–1680.
- Holgate, S. T. (1997). Asthma genetics: Waiting to exhale. *Nature Genet.* **15**, 227–229.
- Hosein, H. R., Corey, P., and Robertson, J. M. (1989). The effect of domestic factors on respiratory symptoms and FEV. *Int. J. Epidemiol.* **18**, 390–396.
- Kaplan, B. A., and Mascie-Taylor, C. G. N. (1988). Asthma and wheezy bronchitis in adolescents: Biosocial correlates. *J. Asthma* **25**, 125–129.
- Keil, U., and Weiland, S. K. (1992). International asthma and allergy study. *Lancet* **340**, 46.
- Ko, Y. C. (1996). Air pollution and its health effects on residents in Taiwanese communities. *Kaohsiung J. Med. Sci.* **12**, 657–669.
- Lebowitz, M. D., Collins, L., and Holberg, C. J. (1987). Time series analysis of respiratory response to indoor and outdoor environmental phenomena. *Environ. Res.* **43**, 332–341.
- Lin, J. M., and Yao, Y. H. (1993). Formaldehyde in conventional homes in Taiwan. *Environ. Int.* **19**, 561–568.
- Neas, L. M., Dockery, D. W., and Koutrakis, P. (1995). The association of ambient air pollution with twice daily peak expiratory flow rate measurements in children. *Am. J. Epidemiol.* **141**, 111–122.
- Newman-Taylor, A. (1995). Environmental determinants of asthma. *Lancet* **345**, 296–299.
- Pearce, N., Weiland, S., Keil, U., Langridge, P., Anderson, H. R., Strachan, D., Bauman, A., Young, A., Gluyas, P., Ruffin, D., Crane, J., and Beasley, R. (1993). Self-reported prevalence of asthma symptom in children in Australia, England, Germany and New Zealand: An international comparison using the ISAAC protocol. *Eur. Respir. J.* **6**, 1455–1461.
- Peat, J. K., Tovey, E., Toelle, B. G., Haby, M. M., Gray, E. J., Mahmic, A., and Woolcock, A. J. (1996). House dust mite allergens: A major risk factor for childhood asthma in Australia. *Am. J. Respir. Crit. Care Med.* **153**, 141–146.
- Samet, J. M., Marbury, M. C., and Spengler, J. D. (1987). Health effects and sources of indoor air pollution, Part I. *Am. Rev. Respir. Dis.* **136**, 1486–1508.
- Sandford, A., Weir, T., and Pare, P. (1996). The genetics of asthma. *Am. J. Respir. Crit. Care Med.* **153**, 1749–1765.
- Schindler, C., Ackermann-Liebrich, U., Leuenberger, P., et al. (1998). Association between lung function and estimated average exposure to NO₂ in eight areas of Switzerland. The SAPALDIA team. Swiss study of Air Pollution and Lung Diseases in Adults. *Epidemiology* **9**(4), 405–411.
- Schwartz, J. (1989). Lung function and chronic exposure to air pollution: A cross-sectional analysis of NHANES II. *Environ. Res.* **50**, 309–321.
- Shaw, R. A., Crane, J., Pearce, N., Burgess, C. D., Bremner, P., Woodman, K., and Beasley, R. (1992). Comparison of a video questionnaire with the IUATLD written questionnaire for measurement asthma prevalence. *Clin. Exp. Allergy* **22**, 561–568.
- Sherman, C. B., Tosteson, T. D., Tager, I. B., Speizer, F. E., and Weiss, S. T. (1990). Early childhood predictors of asthma. *Am. J. Epidemiol.* **132**, 83–95.

- Shimoda, T., Kohno, S., Takao, A., Fujiwara, C., Matsuse, H., Sakai, H., Watanabe, T., Hara, K., and Asai, S. (1996). Investigation of the mechanism of alcohol-induced bronchial asthma. *J. Allergy Clin. Immunol.* **97**, 74–84.
- Stoddard, J. J., and Miller, T. (1995). Impact of parental smoking on the prevalence of wheezing respiratory illness in children. *Am. J. Epidemiol.* **141**(2), 96–102.
- The international study of asthma and allergies in Childhood (ISAAC) steering committee. (1998). Worldwide variation in prevalence of symptoms of asthma, allergic rhinoconjunctivitis, and atopic eczema: ISAAC. *Lancet* **351**, 1225–1232.
- von Mutius, E., Sherrill, D. L., Fritzsche, C., Martinez, F. D., and Lebowitz, M. D. (1995). Air pollution and upper respiratory symptoms in children from East Germany. *Eur. Respir. J.* **8**, 723–728.
- Woods, R. K., Weiner, J., Abramson, M., Thien, F., and Walter, E. H. (1996). Patients perceptions of food-induced asthma. *Australian N. Zealand J. Med.* **26**, 504–512.