Association between exposure to particulate matter and school absences in Korean asthmatic adolescents

Seongmin Jo 1, Kiook Baek 1, Joon Sakong 1,2, and Chulyong Park 1,2*

1Department of Occupational and Environmental Medicine, Yeungnam University Hospital, Daegu, Korea
2Department of Preventive Medicine and Public Health, Yeungnam University College of Medicine, Daegu, Korea

ABSTRACT

Background: Because particulate matter (PM) and asthma are closely related, the prevalence of school absence among adolescents with asthma can be affected by the concentration of PM. We aimed to investigate the relationship between school absences due to asthma and the total number of days that the PM concentration exceeded the standard.

Methods: We used the data from the 16th Korea Youth Risk Behavior Survey and the PM levels of 17 metropolitan cities and provinces gathered from the AirKorea. Information on the characteristics of asthmatic adolescents and the prevalence of school absence was obtained using a questionnaire, while the PM levels based on the total number of days with poor and very poor PM grades were collected from the AirKorea website. Both χ² test and logistic regression analysis were performed using the weights presented in the original dataset.

Results: In the case of particulate matter of 10 microns in diameter or smaller (PM10), the odds ratio (OR) after adjusting for confounders (sex, school year, body mass index, smoking history, diagnosis of allergic rhinitis, diagnosis of atopic dermatitis and city size) was 1.07 (95% confidence interval [CI]: 1.01 – 1.13) for absents due to asthma when the total days of poor and very poor PM10 grades (81 μg/m³ or higher) increased by 1 day. In the analysis of particulate matter of 2.5 microns in diameter or smaller (PM2.5), the OR after adjusting for confounders was 1.01 (95% CI: 1.00– 1.03) for absents due to asthma when the total number of days with poor and very poor PM2.5 grades (36 μg/m³ or higher) increased by 1 day.

Conclusions: A significant association was observed between the total number of days of poor and very poor PM10 and PM2.5 grades and school absence due to asthma; PM can cause asthma exacerbation and affect the academic life.

Keywords: Adolescent; Air pollution; Asthma; Asthma exacerbation; Particulate matter

BACKGROUND

The annual average concentration of particulate matter (PM) in major cities in Korea is decreasing overall, but is still higher than that of major cities in other Organization for Economic Co-operation and Development (OECD) countries, such as New York and London.1 Several studies have reported that particulate matter of 10 microns in diameter or smaller (PM10) and particulate matter of 2.5 microns in diameter or smaller (PM2.5) can...
PM: particulate matter; PM10: particulate matter of 10 microns in diameter or smaller; PM2.5: particulate matter of 2.5 microns in diameter or smaller; SE: standard error; Th: T helper.

Competing interests
The authors declare that they have no competing interests.

Author Contributions
Conceptualization: Jo S, Park C. Data curation: Jo S. Formal analysis: Jo S. Investigation: Jo S. Methodology: Jo S, Baek K. Project administration: Park C. Supervision: Baek K, Sakong J, Park C. Writing - original draft: Jo S. Writing - review & editing: Baek K, Sakong J, Park C.

Previous studies of PM and asthma in adolescents have been limited to schools or cities and studies analyzed by combining surveys of adolescents nationwide and atmospheric data measured nationwide were also insufficient. In addition, the emphasis was on clinical approaches, such as hospitalization or emergency room visits due to worsening asthma. This study aimed to identify the relationship on a national scale by analyzing the relationship between school absences due to asthma and PM using the Korea Youth Risk Behavior Survey (KYRBS) data of 57,925 students, and to infer the deterioration of asthma, which is difficult to understand outside the current medical system, through school absences due to asthma. Furthermore, this study aimed to investigate the effect of PM on the daily and academic lives of adolescents diagnosed with asthma.

METHODS

Study population and participants
KYRBS is an annual survey conducted in Korean middle and high school students by the Korea Disease Control and Prevention Agency (formerly Korea Centers for Disease Control and Prevention) in 2005. In this survey, various questionnaires were administered to evaluate the Korean adolescents’ health behavior and calculate the health indicators necessary for planning and evaluating the youth health promotion programs, including management of asthma-related symptoms or promotion of lifestyle changes.  

This study was based on the 16th Korea Youth Risk Behavior Survey 2020. Multi-stage cluster sampling of 57,925 students from 800 schools (400 middle schools and 400 high schools) in 17 provinces in Korea was conducted online from August to November 2020. The sampling process can be divided into population stratification, sampling allocation, and sampling stages. In the stratification stage, the population was divided into 117 layers using 39 regional groups and school levels as stratification variables to minimize sample errors. In the sample distribution stage, the sample size was set to 400 middle schools and 400 high schools, and five middle and high schools were allocated first by the 17 cities and provinces. The proportional allocation method was applied to match the population and sample composition ratios for each stratified variable. For sampling, a stratified colony extraction
method was used. The primary extraction unit was a school selected by the permanent random number extraction method, and the secondary extraction unit was a class randomly extracted for each grade. Students who were absent for a long time, unable to participate in the survey by themselves, and students with difficulty deciphering text were excluded from the sample. The details are described elsewhere.23,24

School absence due to asthma
In this study, those who answered “Yes” to the question “Have you ever been diagnosed with asthma by a doctor since you were born?” were selected as the study participants. Those who responded “1–3 days”, “4–6 days”, and “7 days or more” to the question “In the last 12 months, how many days have you been absent due to asthma?” were classified as having experienced school absence due to asthma.

Participant characteristics
The characteristics of the participants were sex, school year, and body mass index (BMI) based on the self-reported height and weight, smoking history, diagnosis of allergic rhinitis, diagnosis of atopic dermatitis, and city size. School year was divided into middle school and high school. Patients with a BMI of 25 kg/m² were regarded as obese. If the participants answered “Yes” to any of the three questions (“Have you ever smoked one or two sips of regular cigarettes?”, “Have you ever used liquid e-cigarettes containing nicotine?”, and “Have you ever used heat-not-burn tobacco products?”), they were considered to have a smoking history. The presence of allergic rhinitis and atopic dermatitis was evaluated using the questions “Have you ever been diagnosed with allergic rhinitis by a doctor since you were born?” and “Have you ever been diagnosed with atopic dermatitis by a doctor since you were born?” If the study participants had missing values in the aforementioned variables, they were excluded from the analysis. Cities were divided into large cities including metropolises, medium-to small cities, and counties including regions which did not fit the other classifications.

PM analysis
PM exposure was assessed based on the data obtained from the AirKorea website,1 which has released data on outdoor air quality levels nationwide on a real-time basis since 2002. A total of 794 monitoring stations are operated by the Ministry of Environment and local governments nationwide. The β-ray absorption method is used to measure PM₁₀ and PM₂.₅. The mass concentration of particulate matter was measured using β-ray intensity which is measured as they are emitted from a source, and again after passing through particulate matter filtered from the air over a set period of time. The difference in intensity is used to calculate the mass concentration of the particulate matter.25 Only statistical data satisfying an effective processing ratio of 75% were obtained.26

Use of air quality index to evaluate participants’ PM exposure
A modified air quality index, known as the comprehensive air quality index (CAI), was used. The CAI is used to describe the ambient air quality about SO₂, CO, O₃, NO₂ and PM based on the health risk of air pollution. In this study, only PM₁₀ and PM₂.₅ were targeted, the explanation of CAI was written based only on PM. The CAI of PM was classified into four grades (good, moderate, poor, and very poor). With regard to the PM₁₀ levels, the daily average of 0–30 μg/m³ was classified as good, 31–80 μg/m³ as moderate, 81–150 μg/m³ as poor, and 151 μg/m³ or higher as very poor. In terms of PM₂.₅ levels, the daily average of 0–15 μg/m³ was classified as good, 16–35 μg/m³ as moderate, 36–75 μg/m³ as poor, and 76 μg/m³ or higher as very poor. In this study, the number of days with poor and very poor PM grades in 17
metropolitan cities and provinces from August 2019 to July 2020, before the 16th KYRBS was conducted in August 2020, were summed to evaluate the air quality level. Subsequently, the annual PM exposure of each participant was estimated by the total number of days with poor and very poor PM grades based on the address of each participant’s cities and provinces.

**Statistical analysis**

The $\chi^2$ test was used to analyze the relationship between school absence due to asthma and the general characteristics of the study participants and the total number of days with poor and very poor PM grades. The calculated data of the dependent variables were expressed as numbers, estimated numbers, estimated standard errors, and estimated percentages for each categorical variable. The estimated values for the dependent variable were obtained using complex sample analysis that uses an estimation formula that applies strata, clusters, and weights. In the sampling process, the population was stratified to minimize sample error, and the regional group and school level were divided into stratification variables and used as the strata. The weight was obtained by multiplying the reciprocal extraction rate by the reciprocal response rate and the weight post-correction rate. The sampling rate was calculated reflecting the sampling process of the sample design, and the response rate was calculated using the response rate by grade of the sample school and was calculated to be the same as the number of middle and high school students nationwide as of April 2020. An estimation formula reflecting the stratification, clustering, and weight information of the complex sampling was used. The details have been described elsewhere.23

Among 3,238 adolescents diagnosed asthma, a logistic regression model was used to calculate the odds ratios (ORs) and 95% confidence intervals (CIs) between absence from school due to asthma and total number of days with poor and very poor PM grades. Statistical analyses of the data were conducted in 2 ways. First, the OR of school absence due to asthma was calculated when the total number of days with poor and very poor PM grades increased by 1 day. After that, the median values of the exposure frequency of poor and very poor PM grades and OR of school absence due to asthma were calculated by setting the median as a reference point for dividing the independent variable in the 2 groups. The results of both methods mentioned above were presented before and after adjusting for confounding factors. The covariates that might confound the association between the total number of days with poor and very poor PM grades and school absence due to asthma included sex,27 BMI,28,29 school year (age),15 smoking history,30-32 diagnosis of allergic rhinitis,33 diagnosis of atopic dermatitis34 and city size.35

As an additional analysis, subgroup analysis was performed on patients who received treatment within the last 12 months using complex logistic regression. In response to the question, “Have you taken or inhaled medicine to treat asthma in the last 12 months?” Students who responded that “I was treated regularly even if I had no symptoms” and “I was treated only when I had symptoms” were classified into one group and “I was not treated” into another group. In addition, complex ordinary logistical regression analysis was conducted by placing dependent variables mentioned above as ordinal variables (“None,” “1–3 days,” “4–6 days,” and “7 days or more”) presented by raw data of KYRBS.

The $\chi^2$ test and logistic regression analysis were performed using the weights presented in the original dataset. IBM SPSS version 27.0 for Windows (IBM Corp., Armonk, NY, USA) was used to perform all statistical analyses, and a $p$-value of < 0.05 was considered significant.
Ethics statement
This study was approved by the Institutional Review Board (IRB) of Yeungnam University Hospital (IRB No. 2022-01-052) and waived the requirement for informed consent.

RESULTS

Participants' characteristics
Among the 54,948 respondents of the 16th KYRBS, 3,238 were selected as participants of this study. Table 1 shows the comparison between the general characteristics and school absences due to asthma. Among the adolescents diagnosed with asthma, 1,834 (56.8%) were men and 1,404 (43.2%) were women. A total of 129 (7.2%) men and 85 (6.3%) women were absent due to asthma, showing no significant difference between the sexes (p = 0.306). When classified according to BMI, 2,565 patients (79.9%) had normal weight, while 674 (20.1%) were obese. No significant difference was observed in the prevalence of school absence due to asthma between 169 (6.8%) patients with normal weight and 45 (6.7%) patients with obesity (p = 0.863). A total of 1,504 middle school students (43.2%) and 1,734 (56.8%) high school students were found to have asthma. When middle and high school students were compared, 125 (8.6%) and 89 (5.5%), respectively, were absent due to asthma, with the prevalence of school absence significantly higher among middle school students (p = 0.001). Among the students diagnosed with asthma, 2,834 (87.5%) had no smoking experience, while 404 (12.5%) had smoking experience. No significant differences were observed in the prevalence of school absences due to asthma between 180 (6.6%) students in the non-smoking group and 34 (8.4%) students in the smoking group (p = 0.162). Of the 2,004 patients (62.9%) diagnosed with allergic rhinitis, 143 (7.3%) were absent due to asthma. This ratio was higher than that of 71 (6.0%) students who were absent due to asthma among the 1,234 (37.1%) participants who were not diagnosed with allergic rhinitis, but the difference was not significant (p = 0.191). Of the 2,000 patients (61.5%) who had not been diagnosed with atopic dermatitis in their lifetime, 136 (7.1%) were absent from school due to asthma exacerbation. However, no significant difference was observed between the two groups (p = 0.434). Of the students diagnosed with asthma, 1,388

Table 1. General characteristics of the study participants and absence from school due to asthma

| Variable            | Category | Total No. | Total SE | Total Estimated % | Absent from school due to asthma No. | Absent from school due to asthma SE | Absent from school due to asthma Estimated % | p-value |
|---------------------|----------|-----------|----------|-------------------|-------------------------------------|-----------------------------------|--------------------------------------|---------|
|                     |          |           |          |                   |                                     |                                   |                                      |         |
| Sex                 | Men      | 1,834     | 89,672   | 3,266             | 56.8                                | 1,705                             | 83,380                               | 3,089   | 92.8  | 129 | 6,499 | 597 | 7.2  | 0.306 |
|                     | Women    | 1,404     | 68,389   | 2,688             | 43.2                                | 1,319                             | 64,110                               | 2,566   | 93.7  | 85  | 4,279 | 486 | 6.3  |
| BMI                 | Normal   | 2,564     | 126,492  | 3,201             | 79.9                                | 2,395                             | 117,834                              | 2,982   | 93.2  | 169 | 8,565 | 677 | 6.8  | 0.863 |
|                     | Obese    | 674       | 31,769   | 1,296             | 20.1                                | 629                               | 29,656                               | 1,229   | 93.3  | 45  | 2,113 | 335 | 6.7  |
| School year         | Middle   | 1,504     | 68,344   | 2,585             | 43.2                                | 1,379                             | 62,496                               | 2,401   | 91.4  | 125 | 5,848 | 511 | 8.6  | 0.001 |
|                     | High     | 1,734     | 89,918   | 2,662             | 56.8                                | 1,645                             | 84,995                               | 2,491   | 94.5  | 89  | 4,923 | 569 | 5.5  |
| Smoking             | No       | 2,834     | 138,519  | 3,417             | 87.5                                | 2,654                             | 129,408                              | 3,196   | 93.4  | 180 | 9,111 | 695 | 6.6  | 0.162 |
|                     | Yes      | 404       | 19,742   | 1,075             | 12.5                                | 370                               | 18,082                               | 1,041   | 91.6  | 34  | 1,660 | 276 | 8.4  |
| Allergic rhinitis   | No       | 1,238     | 58,744   | 1,858             | 37.1                                | 1,163                             | 55,220                               | 1,754   | 94.0  | 71  | 3,523 | 451 | 6.0  | 0.191 |
|                     | Yes      | 2,004     | 99,518   | 2,701             | 62.9                                | 1,861                             | 92,270                               | 2,560   | 92.7  | 143 | 7,247 | 613 | 7.3  |
| Allergic dermatitis | No       | 2,000     | 97,381   | 2,724             | 61.5                                | 1,884                             | 90,476                               | 2,530   | 92.9  | 136 | 6,905 | 636 | 7.1  | 0.434 |
|                     | Yes      | 1,238     | 60,880   | 1,947             | 38.5                                | 1,160                             | 57,014                               | 1,842   | 93.6  | 78  | 3,866 | 443 | 6.4  |
| City size           | Large    | 1,388     | 66,889   | 2,342             | 42.3                                | 1,309                             | 62,988                               | 2,221   | 94.2  | 79  | 3,902 | 454 | 5.8  | 0.163 |
|                     | Medium to small | 1,612 | 82,630   | 2,830             | 52.2                                | 1,490                             | 76,372                               | 2,623   | 92.4  | 122 | 6,257 | 579 | 7.6  |
|                     | County   | 238       | 8,742    | 899               | 5.5                                 | 225                               | 8,130                                | 789     | 93.0  | 13  | 612   | 217 | 7.0  |

SE: standard error; BMI: body mass index.
(42.3%) lived in large cities, 1,612 (52.2%) lived in medium-to small cities, and 238 (5.5%) lived in counties. No significant differences were observed in the prevalence of school absence due to asthma among 79 (5.8%) students in the large city group, 122 (7.6%) students in the medium-to small city group, and 13 (7.0%) in the county group (p = 0.163).

**PM results by region**

Table 2 shows the comparison between the total number days with poor and very poor PM grades within 1 year and prevalence of school absence due to asthma in 17 metropolitan cities and provinces nationwide. The total number of days with poor and very poor PM\(_{10}\) grades was the lowest in Gwangju and Jeollanam-do (1 day), followed by Daejeon, Jeollabuk-do, and Gyeongsangnam-do (2 days). Meanwhile, Gyeonggi-do had the highest total number of days with poor and very poor PM\(_{10}\) grades (9 days), followed by Chungcheongnam-do (8 days), and Seoul Metropolitan City (7 days). In terms of PM\(_{15}\), Gyeongsangnam-do had the lowest total number of days with poor and very poor PM grades (6 days), followed by Ulsan Metropolitan City and Jeollanam-do (8 days). By contrast, Chungcheongbuk-do had the highest total number of days with poor and very poor PM grades (45 days), followed by Gyeonggi-do and Chungcheongnam-do (43 days). Of the 17 metropolitan cities and provinces, the prevalence of asthma was highest in Chungcheongnam-do (7.6%), followed by Chungcheongbuk-do (6.9%), Daegu (6.8%), and Jeju-do (3.6%). The ratio of school absences due to asthma was highest in Chungcheongbuk-do (9.4%), followed by Jeollanam-do (9.3%) and Busan and Gyeonggi-do (8.7%). On the contrary, Daegu and Sejong had the lowest ratio of school absences due to asthma (2.2%).

**Association of PM exposure and asthma exacerbation-related absence**

Table 3 shows the OR of school absence due to asthma when the total number of days with poor and very poor PM grades increased by 1 day. In terms of PM\(_{10}\), the OR before adjusting for confounders was 1.07 (95% CI: 1.01–1.14, p = 0.024) when the total days with poor and very poor PM\(_{10}\) grades increased by 1 day. After adjusting for confounding factors, the OR
remained significant at 1.06 (95% CI: 1.00–1.13, \( p = 0.045 \)). In the analysis of PM2.5, the OR before adjusting for confounders was 1.01 (95% CI: 1.00–1.03, \( p = 0.017 \)) when the total number of days with poor and very poor PM grades increased by 1 day. After adjusting for confounding factors, the OR remained significant at 1.01 (95% CI: 1.00–1.02, \( p = 0.041 \)).

Sensitivity analysis
Table 4 shows the OR of absence from school due to asthma by setting the median exposure frequency of poor and very poor PM concentrations. First, the median values of the total number of days with poor or very poor PM10 concentrations divided into 1–6 days and 7–9 days were 48.6% and 51.3%, respectively. The OR for 1–6 days was 1.69 (95% CI: 1.28–2.23, \( p < 0.001 \)) before adjusting for confounders. After adjusting for confounding factors, the OR remained significant at 1.66 (95% CI: 1.25–2.19, \( p = 0.001 \)) when the total number of days with poor and very poor PM10 grades increased by 1 day. After adjusting for confounding factors, the OR remained significant at 1.01 (95% CI: 1.00–1.02, \( p = 0.041 \)).

Subgroup analysis
As an additional analysis, subgroup analysis of the group treated within 12 months and ordinal logistic regression was performed with the number of days of school absence due to asthma as the dependent variable. Supplementary Table 1 shows that 1,993 (62.5%) students received regular or irregular asthma treatment within 12 months, and 1,245 (37.5%) students did not receive treatment. A total of 137 students were absent for 1–3 days, 31 students for 4–6 days, and 46 students for \( \leq 7 \) days. Supplementary Table 2 shows the group that received regular or irregular asthma treatment within 12 months. School absences increased significantly as the total number of days with poor and very poor PM increased. (adjusted OR of PM10: 1.11, 95% CI: 1.03–1.18, \( p = 0.004 \), adjusted OR of PM2.5: 1.01, 95% CI: 1.00–1.03, \( p = 0.032 \)). Supplementary Table 3 shows the group that received regular or irregular asthma treatment within 12 months.

Table 3. OR of school absence due to asthma when the total number of days with poor and very poor PM grades increased by 1 day

| PM   | Crude OR\(^a\) | 95% CI         | \( p\)-value | Adjusted OR\(^b\) | 95% CI         | \( p\)-value |
|------|----------------|---------------|--------------|------------------|---------------|--------------|
| PM10 | 1.07           | 1.01–1.14     | 0.024        | 1.06             | 1.00–1.13     | 0.045        |
| PM2.5| 1.01           | 1.00–1.03     | 0.037        | 1.01             | 1.00–1.02     | 0.041        |

PM: particulate matter; OR: odds ratio; CI: confidence interval; PM10: particulate matter of 10 microns in diameter or smaller; PM2.5: particulate matter of 2.5 microns in diameter or smaller.

\(^a\)OR of school absence due to asthma when the total number of days with poor and very poor PM grades increased by 1 day.

\(^b\)OR of school absence due to asthma when the total number of days with poor and very poor PM grades increased by 1 day, adjusted for sex, BMI, school year, smoking, allergic rhinitis, atopic dermatitis, and city size.

Table 4. OR of school absence due to asthma by setting the median exposure frequency of poor and very poor PM concentrations

| PM   | Day\(^a\) | Estimated (%) | Crude OR\(^d\) | 95% CI | \( p\)-value | Adjusted OR\(^d\) | 95% CI | \( p\)-value |
|------|----------|---------------|----------------|--------|--------------|------------------|--------|--------------|
| PM10 | 7–9      | 51.3          | 1.69           | 1.28–2.23 | < 0.001  | 1.66             | 1.25–2.19 | < 0.001    |
|      | 1–6      | 48.6          | Ref.           |         |             |                  |        |             |
| PM2.5| 36–45    | 55.6          | 1.66           | 1.25–2.11 | 0.001   | 1.60             | 1.19–2.15 | 0.002      |
|      | 6–31     | 44.3          | Ref.           |         |             |                  |        |             |

PM: particulate matter; OR: odds ratio; CI: confidence interval; PM10: particulate matter of 10 microns in diameter or smaller; PM2.5: particulate matter of 2.5 microns in diameter or smaller.

\(^a\)Total number of days with poor and very poor PM grades.

\(^d\)Adjusted for sex, BMI, school year, smoking, allergic rhinitis, atopic dermatitis, and city size.

\(^e\)Among the variables adjusted for PM10, the adjusted OR of smoking was 1.47 (95% CI: 1.00–2.15, \( p = 0.049 \)) and the adjusted OR of school year was 1.72 (95% CI: 1.29–2.28, \( p < 0.001 \)).

\(^f\)Among the variables corrected for PM2.5, adjusted OR of school year was 1.71 (95% CI: 1.29–2.27, \( p < 0.001 \)).
treatment within 12 months, school absences increased significantly in the group with 7–9 days of poor and very poor PM$_{10}$ grades and 36–45 days of poor and very poor PM$_{2.5}$ grades (adjusted OR of PM$_{10}$: 1.99, 95% CI: 1.44–2.77, \(p < 0.001\), adjusted OR of PM$_{2.5}$: 1.78, 95% CI: 1.27–2.49, \(p = 0.001\)). **Supplementary Table 4** shows a significant increase in the total number of days of school absence when the total number of days with poor and very poor PM grades increased by 1 d. (adjusted OR of PM$_{10}$: 1.06, 95% CI: 1.00–1.13, \(p = 0.039\), adjusted OR of PM$_{2.5}$: 1.01, 95% CI: 1.00–1.02, \(p = 0.038\)). **Supplementary Table 5** shows significantly increased total days of school absence in the group with 7–9 days of poor and very poor PM$_{10}$ grades, and 36–45 days of poor and very poor PM$_{2.5}$ grades (adjusted OR of PM$_{10}$: 1.66, 95% CI: 1.26–2.20, \(p < 0.001\), adjusted OR of PM$_{2.5}$: 1.60, 95% CI: 1.20–2.15, \(p = 0.002\)).

**DISCUSSION**

This study investigated whether adolescents with asthma were absent from school due to worsening of asthma symptoms using the AirKorea data and the 16th KYRBS. A significant positive association was found between the total number of days with poor and very poor PM grades and school absences due to asthma.

PM, can be naturally generated, such as dust, pollen, soil particles, and forest fires, or artificially created, such as industrial, construction, mining, smoking, and fossil fuels of urban transportation and power plants, is a representative air pollutant of which the human body is frequently exposed to. Depending on the size of the PM, the degree of invasion and health effects on the respiratory system differ. PM$_{10}$, which is 2.5 μm in size, acts on the nasal cavity, pharynx, and primary bronchi. PM$_{2.5}$, which is 0.1–2.5 μm in size, acts on the peripheral bronchi and alveoli. PM affects the human respiratory system through several mechanisms, including innate/acquired immunity, oxidative stress, and bronchial remodeling. Diesel exhaust particles, known as PM$_{10}$, can worsen the allergic symptoms by increasing the levels of proinflammatory cytokines in epithelial cells and inducing the release of neutrophils and eosinophils. Furthermore, PM$_{10}$ induces antigen-presenting cell-mediated responses that modulate macrophages to contribute to innate immunity and T helper (Th) cell-mediated responses to secrete cytokines, such as interleukin (IL)-10. In terms of PM$_{2.5}$, high concentrations of PM$_{2.5}$ increases the production of IL-13 and IL-17 and cause an imbalance between Th1 and Th2 cells by regulating their cytokines. Airway damage and inflammation due to oxidative stress also occur. PM produces oxidants and free radicals. They oxidize the airway cells and damage the DNA, thereby causing airway damage. Through these mechanisms, it has been hypothesized that PM is associated with the development and exacerbation of asthma and other allergic diseases.

In this study, as the total number of days with poor and very poor PM grades increased, the correlation between school absence due to asthmatic symptoms significantly increased. These results are consistent with those of previous studies. Iskandar et al. reported that exposure to higher concentrations of PM could trigger hospitalization due to asthma in the Danish 0–18-year-old study group. Every time the interquartile range of the average concentration of PM$_{10}$ and PM$_{2.5}$ for 5 days increased by 1 quartile, the ORs of hospitalization due to asthma were 1.07 (95% CI: 1.03–1.12) for PM$_{10}$ and 1.09 (95% CI: 1.04–1.13) for PM$_{2.5}$. Samoli et al. reported that air pollution in Greece affects the rate of pediatric hospitalization due to acute exacerbation of asthma. When the concentration of PM$_{10}$ increased by 10 μg/m$^3$, the number of pediatric asthma hospital admissions increased by 2.54% (95% CI: 2.00–3.10).
Lee et al.\textsuperscript{17} reported a relationship between air pollution and asthma exacerbation in children with asthma in Seoul. The estimated relative risk of hospitalization due to asthma was 1.07 (95% CI: 1.04–1.11) for PM ≤ 10 μm, while every interquartile range increased (interquartile range = 40.4 μg/m\textsuperscript{3}). Meng et al.\textsuperscript{45} reported that the increased ORs of experiencing daily or weekly asthma symptoms were 1.29 (95% CI: 1.05–1.57) for PM\textsubscript{10} and 1.82 (95% CI: 1.11–2.98) for PM\textsubscript{2.5} when the PM concentration increased by 10 μg/m\textsuperscript{3} after adjusting for age, sex, race/ethnicity, poverty level, and insurance status.

Several studies have reported that respiratory diseases including asthma may affect academic productivity and increase the frequency of school absenteeism. Zhang et al.\textsuperscript{22} reported that the moving average of PM\textsubscript{2.5} for 3 days was significantly associated with school absence, and the OR of school absence was 1.37 (95% CI: 1.07–1.74). Geng et al.\textsuperscript{21} reported that the ORs of respiratory-related school absence were 1.021 (95% CI: 1.019–1.024) and 1.015 (95% CI: 1.014–1.017) for each 10 μg/m\textsuperscript{3} increase in PM\textsubscript{2.5} and PM\textsubscript{10}, respectively, in Qingdao. Kim et al.\textsuperscript{46} reported school absence due to asthma and other allergic diseases based on the previous KYRBS. This study showed that asthma was negatively correlated with better school performance. School performance was divided into five groups, and the ORs for school absence due to asthma from the highest to the lowest grade were 0.74 (95% CI: 0.66–0.83), 0.87 (95% CI: 0.79–0.96), 0.83 (95% CI: 0.75–0.91), and 0.93 (95% CI: 0.85–1.02), respectively (p < 0.001).

This study has several limitations. First, although the association between the total number of days with poor and very poor PM grades and absence from school due to asthma was significant, it was difficult to determine causality because the KYRBS is a nationwide cross-sectional study. Second, rather than measuring the exposure level individually, exposure was assessed using an ecological approach, assuming the CAI in the cities and provinces as personal exposure. Therefore, the evaluation of each individual’s exposure to PM was crude. Although this exposure assessment was not ideal, it was necessary for this study because KYRBS sampling was created by integrating several cities and counties and it is difficult to match the AirKorea data to a single city, county, or district. However, previous studies have been conducted in a similar method, which covered a broad area and used an air quality index\textsuperscript{47,48} and CAI is an indicator designed to easily inform the public of their daily exposure to PM, so it is thought to be a reasonable substitute for personal exposure. Third, asthma symptoms were assessed indirectly using a self-reported questionnaire without any clinical data or hospitalization records. Therefore, it was difficult to objectively distinguish the grade of asthma exacerbation and could not evaluate the correlation between the total number of days with poor and very poor PM grades and the severity of asthma symptoms. Lastly, this study could not reflect the individual factors, such as previous medical history, family history, and living environment because it was conducted using secondary data.

Despite its limitations, this study has some strengths; it was conducted based on the KYRBS and the AirKorea data. KYRBS was aggregated from a large study population in Korea, and the AirKorea data were collected from different stations for PM measurement installed nationwide. In addition, it has the advantage of being able to observe health behaviors due to their worsening asthma while objective medical access to asthma symptoms is difficult. Therefore, this study could confirm the significant relationship between absence due to worsening of asthma and period with exceeding PM concentration based on the standard for Korean adolescent population, compared with other studies that were conducted in a limited area. The approach used in this study could help promote the health of adolescents with asthma.
CONCLUSIONS

In this study, a significant correlation between total number of days with poor and very poor PM$_{10}$ and PM$_{2.5}$ grades and school absence due to asthma was observed, which showed that the PM in the atmosphere increases the likelihood of asthma exacerbation among Korean adolescents diagnosed with asthma and can affect their academic life. However, further studies are needed to determine the possible effects of PM on worsening asthma in children and adolescent patients and their lifestyle and academic performance.

ACKNOWLEDGEMENTS

The authors wish to thank the Ministry of Education, Ministry of Health and Welfare, and Korea Centers for Disease Control and Prevention, which provided the raw data.

SUPPLEMENTARY MATERIALS

Supplementary Table 1
Detailed characteristics of the asthma questionnaire among the study participants

Click here to view

Supplementary Table 2
Odds ratio of school absence due to asthma when the total number of days with poor and very poor PM grades increased by 1 day, grouped by asthma treatment within 12 months

Click here to view

Supplementary Table 3
Odds ratio of school absence due to asthma by setting the median exposure frequency of poor and very poor PM concentrations, grouped by asthma treatment within 12 months

Click here to view

Supplementary Table 4
Odds ratio of school absence due to asthma when the total number of days with poor and very poor PM grades increased by 1 day, using complex ordinary logistic analysis

Click here to view

Supplementary Table 5
Odds ratio of school absence due to asthma by setting the median exposure frequency of poor and very poor PM concentrations using complex ordinary logistic analysis

Click here to view
REFERENCES

1. AirKorea. Overseas air pollution status [Internet]. https://www.airkorea.or.kr/web/contents/contentView?pMENU_NO=127&cntnts_no=4. Updated 2021. Accessed March 28, 2022.

2. Tonne C, Wilkinson P. Long-term exposure to air pollution is associated with survival following acute coronary syndrome. Eur Heart J 2013;34(17):1306-11.

3. Nishiwaki Y, Michikawa T, Takebayashi T, Nitta H, Iso H, Inoue M, et al. Long-term exposure to particulate matter in relation to mortality and incidence of cardiovascular disease: the JPHC Study. J Atheroscler Thromb 2013;20(3):296-309.

4. Raaschou-Nielsen O, Andersen ZJ, Beelen R, Samoli E, Stafoggia M, Weinmayr G, et al. Air pollution and lung cancer incidence in 17 European cohorts: prospective analyses from the European Study of Cohorts for Air Pollution Effects (ESCAPE). Lancet Oncol 2013;14(9):813-22.

5. Turner MC, Krewski D, Pope CA 3rd, Chen Y, Gapstur SM, Thun MJ. Long-term ambient fine particulate matter air pollution and lung cancer in a large cohort of never-smokers. Am J Respir Crit Care Med 2011;184(12):1374-81.

6. Klooog I, Ridgway B, Koutrakis P, Coull BA, Schwartz JD. Long- and short-term exposure to PM$_2.5$ and mortality: using novel exposure models. Epidemiology 2013;24(4):555-61.

7. Kelly FJ, Fussell JC. Size, source and chemical composition as determinants of toxicity attributable to ambient particulate matter. Atmos Environ 2012;60:504-26.

8. Manisalidis I, Stavropoulos E, Stavropoulos A, Bezirtzoglou E. Environmental and health impacts of air pollution: a review. Front Public Health 2020;8:14.

9. Sompornrattanaphan M, Thongngarm T, Ratanawatkul P, Wongsa C, Swigris JJ. The contribution of particulate matter to respiratory allergy. Asian Pac J Allergy Immunol 2020;38(1):19-28.

10. Jang AS. Impact of particulate matter on health. J Korean Med Assoc 2014;57(9):763-8.

11. Kim SH, Yang HJ, Jang AS, Kim SH, Song WJ, Kim TB, et al. Effects of particulate matter in ambient air on the development and control of asthma. Allergy Asthma Respir Dis 2015;3(5):313-9.

12. Bräbäck L, Forsberg B. Does traffic exhaust contribute to the development of asthma and allergic sensitization in children: findings from recent cohort studies. Environ Health 2009;8(1):17.

13. Brauer M, Hoek G, Smit HA, de Jongste JC, Gerritsen J, Postma DS, et al. Air pollution and development of asthma, allergy and infections in a birth cohort. Eur Respir J 2007;29(5):879-88.

14. Silverman RA, Ito K. Age-related association of fine particles and ozone with severe acute asthma in New York City. J Allergy Clin Immunol 2010;125(2):367-373.e5.

15. Ko FW, Tam W, Wong TW, Lai CK, Wong GW, Leung TF, et al. Effects of air pollution on asthma hospitalization rates in different age groups in Hong Kong. Clin Exp Allergy 2007;37(9):1312-9.

16. Iskandar A, Andersen ZJ, Bonnelykke K, Ellermann T, Andersen KK, Bisgaard H. Coarse and fine particles but not ultrafine particles in urban air trigger hospital admission for asthma in children. Thorax 2012;67(3):252-7.

17. Lee JT, Kim H, Song H, Hong VC, Cho YS, Shin SY, et al. Air pollution and asthma among children in Seoul, Korea. Epidemiology 2002;13(4):481-4.

18. Samoli E, Nastos PT, Paliatsos AG, Katsouyanni K, Priftis KN. Acute effects of air pollution on pediatric asthma exacerbation: evidence of association and effect modification. Environ Res 2011;111(3):418-24.

https://aoemj.org

https://doi.org/10.35371/aoem.2022.34.e21

11/13
19. Moonie S, Sterling DA, Figgs LW, Castro M. The relationship between school absence, academic performance, and asthma status. J Sch Health 2008;78(3):140-8.
   PUBMED | CROSSREF

20. Moonie SA, Sterling DA, Figgs L, Castro M. Asthma status and severity affects missed school days. J Sch Health 2006;76(1):18-24.
   PUBMED | CROSSREF

21. Geng X, Liu X, Li X, Wang T, Zhang J, Zheng Y, et al. Impact of ambient particulate matter on respiratory-related school absence: a case-crossover study in China. Air Qual Atmos Health 2021;14(8):1203-10.
   CROSSREF

22. Zhang Y, Cui L, Xu D, He MZ, Zhou J, Han L, et al. The association of ambient PM$_{2.5}$ with school absence and symptoms in schoolchildren: a panel study. Pediatr Res 2018;84(1):28-33.
   PUBMED | CROSSREF

23. Korea Disease Control and Prevention Agency. Korea youth risk behavior survey [Internet]. https://www.kdca.go.kr/yhs. Updated 2021. Accessed March 28, 2022.

24. Kim Y, Choi S, Chun C, Park S, Khang VH, Oh K. Data resource profile: the Korea Youth Risk Behavior Web-based Survey (KYRBS). Int J Epidemiol 2016;45(4):1076-1076e.
   PUBMED | CROSSREF

25. National Institute of Environmental Research. Standard methods for examination of air [Internet]. https://nier.go.kr/NIER/cop/bbs/selectNoLoginBoardArticle.do?menuNo=13001&bbsId=BBSMSTR_0000000000031&nttId=29208&Command=READ. Updated 2022. Accessed June 3, 2022.

26. National Institute of Environmental Research. Annual report of air quality in Korea, 2020 [Internet]. https://library.me.go.kr/#/search/detail/5858242. Updated 2021. Accessed April 5, 2022.

27. Almqvist C, Worm M, Leynaert B; working group of GA2LEN WP 2.5 Gender. Impact of gender on asthma in childhood and adolescence: a GA2LEN review. Allergy 2008;63(1):47-57.
   PUBMED | CROSSREF

28. Sutherland ER. Linking obesity and asthma. Ann N Y Acad Sci 2014;1311(1):31-41.
   PUBMED | CROSSREF

29. Weiss ST. Obesity: insight into the origins of asthma. Nat Immunol 2005;6(5):537-9.
   PUBMED | CROSSREF

30. Flodin U, Jönsson P, Ziegler J, Axelson O. An epidemiologic study of bronchial asthma and smoking. Epidemiology 1995;6(5):503-5.
   PUBMED | CROSSREF

31. Plaschke FP, Janson C, Norrman E, Björnsson E, Eilbjär S, Järvhholm B. Onset and remission of allergic rhinitis and asthma and the relationship with atopic sensitization and smoking. Am J Respir Crit Care Med 2000;162(3 Pt 1):920-4.
   PUBMED | CROSSREF

32. Piipari R, Jaakkola JJ, Jaakkola N, Jaakkola MS. Smoking and asthma in adults. Eur Respir J 2004;24(5):734-9.
   PUBMED | CROSSREF

33. Kwon EB, Baek JH, Kim HY, Yoon JW, Shin YH, Lee HM, et al. Relationship between the asthma and rhinitis in asthmatic children: comparison of allergic rhinitis and nonallergic rhinitis. Allergy Asthma Respir Dis 2013;1(3):241-7.
   CROSSREF

34. Pyun BY. Relationship between atopic dermatitis, wheezing during infancy and asthma development. J Korean Med Assoc 2007;50(6):533-8.
   CROSSREF

35. Kim MN, Lee WK, Park JY. The ecological analysis of asthmatic occurrence in patients: using the national health insurance data. JKDIS 2013;24(4):679-88.
   CROSSREF

36. Kim KH, Jahan SA, Kabir E. A review on human health perspective of air pollution with respect to allergies and asthma. Environ Int 2013;59:41-52.
   PUBMED | CROSSREF

37. Oztürk AB, Bayraktar R, Gogebakan B, Mumbuc S, Bayram H. Comparison of inflammatory cytokine release from nasal epithelial cells of non-atopic non-rhinitic, allergic rhinitic and polyp subjects and effects of diesel exhaust particles in vitro. Allergol Immunopathol (Madr) 2017;45(5):473-81.
   PUBMED | CROSSREF

38. McGee MA, Kamal AS, McGee JK, Wood CE, Dye JA, Krantz QT, et al. Differential effects of particulate matter upwind and downwind of an urban freeway in an allergic mouse model. Environ Sci Technol 2015;49(6):3930-9.
   PUBMED | CROSSREF
39. Alexis NE, Huang YC, Rappold AG, Kehrl H, Devlin R, Peden DB. Patients with asthma demonstrate airway inflammation after exposure to concentrated ambient particulate matter. Am J Respir Crit Care Med 2014;190(2):235-7.

40. Becker S, Soukup JM, Sioutas C, Cassee FR. Response of human alveolar macrophages to ultrafine, fine, and coarse urban air pollution particles. Exp Lung Res 2003;29(1):29-44.

41. Chan RC, Wang M, Li N, Yanagawa Y, Onoé K, Lee JJ, et al. Pro-oxidative diesel exhaust particle chemicals inhibit LPS-induced dendritic cell responses involved in T-helper differentiation. J Allergy Clin Immunol 2006;118(2):455-65.

42. Zhang X, Zhong W, Meng Q, Lin Q, Fang C, Huang X, et al. Ambient PM2.5 exposure exacerbates severity of allergic asthma in previously sensitized mice. J Asthma 2015;52(8):785-94.

43. Wang YH, Lin ZY, Yang LW, He HJ, Chen T, Xu WY, et al. PM2.5 exacerbate allergic asthma involved in autophagy signaling pathway in mice. Int J Clin Exp Pathol 2016;9(12):12247-61.

44. Gierszewicki J, Trivedi S, Kleeberger SR. Oxidants and the pathogenesis of lung diseases. J Allergy Clin Immunol 2008;122(3):456-68.

45. Meng YY, Rull RP, Wilhelm M, Lombardi C, Balmes J, Ritz B. Outdoor air pollution and uncontrolled asthma in the San Joaquin Valley, California. J Epidemiol Community Health 2010;64(2):142-7.

46. Kim SY, Kim MS, Park B, Kim JH, Choi HG. Allergic rhinitis, atopic dermatitis, and asthma are associated with differences in school performance among Korean adolescents. PLoS One 2017;12(2):e0171394.

47. To T, Shen S, Atenafu EG, Guan J, McLimont S, Stocks B, et al. The air quality health index and asthma morbidity: a population-based study. Environ Health Perspect 2013;121(1):46-52.

48. Wen XJ, Balluz L, Mokdad A. Association between media alerts of air quality index and change of outdoor activity among adult asthma in six states, BRFSS, 2005. J Community Health 2009;34(1):40-6.