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

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Abbreviations
BMI: body mass index; CAI: comprehensive air quality index; CI: confidence interval; IL: interleukin; KYRBS: Korea Youth Risk Behavior Survey; OECD: Organization for Economic Co-operation and Development; OR: odds ratio;

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 χ^2 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 (PM_{10}), 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 grades of PM_{10} (81 μg/m^3 or higher) increased by 1 day. In the analysis of particulate matter of 2.5 microns in diameter or smaller ($PM_{2.5}$), 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 $PM_{2.5}$ grades (36 μg/m^3 or higher) increased by 1 day.
Conclusions: A significant association was observed between the total number of days of poor and very poor PM_{10} and $PM_{2.5}$ 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 (PM_{10}) and particulate matter of 2.5 microns in diameter or smaller ($PM_{2.5}$) 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.

affect the cardiovascular system and cause ischemic heart disease,[2,3] cancer,[4,5] and increasing mortality.[6] PMs are particles suspended in the air and can affect the respiratory system[7-9] and cause asthma[10,11] when inhaled. According to the 2015 Global Burden of Disease Study, the number of asthma patients worldwide is estimated at 358.2 million, an increase of about 12.6% over 1990. Through this, it can be seen that the prevalence and burden of asthma are increasing worldwide. The risk of asthma occurrence and exacerbation can increase due to various environmental risk factors and can affect patients' daily lives. Several studies have reported an association between asthma and air pollution. Epidemiologically, several studies have reported an association between PM exposure and asthma incidence.[12,13] In a previous study, the occurrence of asthma symptoms among children and adolescents was related to exposure to PM,[14,15] and a significant positive correlation was found between national or regional air pollutant data and hospitalization due to worsening of asthma in children and adolescents in Denmark, Greece, and Seoul.[16-18] Beyond the primary health effects of PM, some studies have reported on the burden of life among adolescents due to asthma and PM exposure, such as increasing prevalence of school absence due to worsening of asthma symptoms[19,20] or exceeding concentrations of air pollutants such as PM.[21,22]

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.[23]

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/m^2 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 PM_{10} and $PM_{2.5}$. 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 SO_2, CO, O_3, NO_2 and PM based on the health risk of air pollution. In this study, only PM_{10} and $PM_{2.5}$ 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 PM_{10} levels, the daily average of 0–30 μg/m^3 was classified as good, 31–80 μg/m^3 as moderate, 81–150 μg/m^3 as poor, and 151 μg/m^3 or higher as very poor. In terms of $PM_{2.5}$ levels, the daily average of 0–15 μg/m^3 was classified as good, 16–35 μg/m^3 as moderate, 36–75 μg/m^3 as poor, and 76 μg/m^3 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 χ^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 dermatitis[34] 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 χ^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.

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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. Of the 1,238 patients (38.5%) who had been diagnosed with atopic dermatitis in their lifetime, 78 (6.4%) 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				Absent from school due to asthma								*p*-value
						No				Yes				
		No.	Estimated No.	SE	Estimated %	No.	Estimated No.	SE	Estimated %	No.	Estimated No.	SE	Estimated %	
Sex	Men	1,834	89,872	3,266	56.8	1,705	83,380	3,089	92.8	129	6,492	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	8,658	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	1,234	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	1,864	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	
Total		3,238	158,261	3,711	100.0									

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 $PM_{2.5}$, 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 Chungcheongnam-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

Table 2. Total number of days with poor and very poor PM grades in 17 metropolitan cities and provinces in Korea and school absence due to asthma

Region	PM_{10}[a]	$PM_{2.5}$[b]	Prevalence of asthma			Absent from school due to asthma							
						No				Yes			
			No.	Asthma (+)	Estimated %	No.	Estimated No.	SE	Estimated %	No.	Estimated No.	SE	Estimated %
Seoul	7	36	7,519	483	6.6	447	25,625	1,701	92.5	36	2,077	349	7.5
Busan	3	14	3,257	193	6.0	175	7,980	628	91.3	18	764	178	8.7
Daegu	6	31	2,700	185	6.8	181	8,309	505	97.8	4	184	80	2.2
Incheon	5	26	2,924	152	5.3	147	7,477	747	97.4	5	201	92	2.6
Gwangju	1	19	2,007	107	5.5	101	4,413	504	93.2	6	321	151	6.8
Daejeon	2	18	2,005	116	5.8	110	4,401	502	94.4	6	260	115	5.6
Ulsan	4	8	1,752	101	5.7	99	3,477	485	98.2	2	65	40	1.8
Sejong	6	41	875	51	6.1	49	1,306	300	97.8	2	30	18	2.2
Gyeonggi-do	9	43	11,971	766	6.5	694	41,097	1,998	91.3	72	3,939	480	8.7
Gangwon-do	5	16	2,000	115	5.7	107	4,019	415	93.6	8	276	100	6.4
Chungcheongbuk-do	5	45	2,041	145	6.9	137	5,148	498	93.5	8	358	117	6.5
Chungcheongnam-do	8	43	2,263	170	7.6	154	7,636	933	90.6	16	791	195	9.4
Jeollabuk-do	2	31	2,273	145	6.2	138	5,780	641	95.2	7	293	120	4.8
Jeollanam-do	1	8	2,184	97	5.0	91	4,097	626	90.7	6	418	199	9.3
Gyeongsangbuk-do	4	11	2,804	170	5.7	164	6,832	584	95.9	6	291	114	4.1
Gyeongsangnam-do	2	6	3,591	188	5.2	179	8,673	766	95.4	9	422	133	4.6
Jeju-do	5	10	1,332	54	3.6	51	1,221	142	93.8	3	81	46	6.2
Total	-	-	53,498	3,238	6.2								

PM: particulate matter; PM_{10}: particulate matter of 10 microns in diameter or smaller; $PM_{2.5}$: particulate matter of 2.5 microns in diameter or smaller; SE: standard error.
[a]Total number of days with poor and very poor PM_{10} grade; [b]Total number of days with poor and very poor $PM_{2.5}$ grade.

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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
PM_{10}[c]	1.07	1.01–1.14	0.024	1.06	1.00–1.13	0.045
$PM_{2.5}$[d]	1.01	1.00–1.03	0.017	1.01	1.00–1.02	0.041

PM: particulate matter; OR: odds ratio; CI: confidence interval; PM_{10}: particulate matter of 10 microns in diameter or smaller; $PM_{2.5}$: particulate matter of 2.5 microns in diameter or smaller; BMI: body mass index.
[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.
[c]Among the variables adjusted for PM_{10}, the adjusted OR of the smoking was 1.47 (95% CI: 1.00–2.14, $p = 0.047$) and the adjusted OR of the school year was 1.72 (95% CI: 1.30–2.29, $p < 0.001$).
[d]Among the variables corrected for $PM_{2.5}$, the adjusted OR of the school year was 1.71 (95% CI: 1.29–2.28, $p < 0.001$).

remained significant at 1.06 (95% CI: 1.00–1.13, $p = 0.045$). In the analysis of $PM_{2.5}$, 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 $PM_{2.5}$ 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 days with poor or very poor PM_{10} 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, $p < 0.001$). Second, the median value of the total number of days with poor or very poor $PM_{2.5}$ grades divided into 6–31 days and 36–45 days were 44.3% and 55.6%, respectively. The OR for 6–31 days was 1.66 (95% CI: 1.25–2.21, $p = 0.001$) before adjusting for the confounding factors. After adjusting for the confounders, the OR was still significant at 1.60 (95% CI: 1.19–2.15, $p = 0.002$).

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 ≤ 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 PM_{10}: 1.11, 95% CI: 1.03–1.18, $p = 0.004$, adjusted OR of $PM_{2.5}$: 1.01, 95% CI: 1.00–1.03, $p = 0.032$). **Supplementary Table 3** shows the group that received regular or irregular asthma

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[a]	95% CI	*p*-value	Adjusted OR[b]	95% CI	*p*-value
PM_{10}[c]	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.					
$PM_{2.5}$[d]	36–45	55.6	1.66	1.25–2.21	0.001	1.60	1.19–2.15	0.002
	6–31	44.3	Ref.					

PM: particulate matter; OR: odds ratio; CI: confidence interval; PM_{10}: particulate matter of 10 microns in diameter or smaller; $PM_{2.5}$: particulate matter of 2.5 microns in diameter or smaller.
[a]Total number of days with poor and very poor PM grades.
[b]Adjusted for sex, BMI, school year, smoking, allergic rhinitis, atopic dermatitis, and city size.
[c]Among the variables adjusted for PM_{10}, 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, $p < 0.001$).
[d]Among the variables corrected in $PM_{2.5}$, 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 was found association 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.[7,36] Depending on the size of the PM, the degree of invasion and health effects on the respiratory system differ. PM_{10}, which is 2.510 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 bronchus and alveoli.[7-9] PM affects the human respiratory system through several mechanisms, including innate/acquired immunity, oxidative stress, and bronchial remodeling.[10] 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.[37,38] Furthermore, PM_{10} induces antigen-presenting cell mediated responses that modulate macrophages to contribute to innate immunity[39,40] and T helper (Th) cell-mediated responses to secrete cytokines, such as interleukin (IL)-10.[41] 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.[42,43] 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.[44] 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.[16] 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.[18] 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:

0.06%–5.08%). Lee et al.[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 $\leq$ 10 μm, while every interquartile range increased (interquartile range = 40.4 μg/m^3). Meng et al.[45] reported that the increased ORs of experiencing daily or weekly asthma symptoms were 1.29 (95% CI: 1.05–1.57) for PM_{10} and 1.82 (95% CI: 1.11–2.98) for $PM_{2.5}$ when the PM concentration increased by 10 μg/m^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.[22] reported that the moving average of $PM_{2.5}$ 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.[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^3 increase in $PM_{2.5}$ and PM_{10}, respectively, in Qingdao. Kim et al.[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[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.

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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

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

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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[a]

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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[a]

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