Impact of Particulate Air Pollutants on Allergic Diseases, Allergic Skin Reactivity and Lung Function

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SUMMARY Elevated levels of particulate matter can exacerbate existing asthma and atopy, while evidence that it can promote the induction of atopy and asthma is limited. A cross sectional study was taken to compare the prevalence of eye, nose, ear and airway allergic symptoms, allergic skin sensitivity and lung function in 290 high school students with a history of high 24 hour average exposure to particulate matter less than 10 μm in diameter (PM10) = 170 μg/m^3 versus low PM10 of 36 μg/m^3 in central Bangkok. Multivariate analysis revealed an increased risk of eye and airway symptoms in groups exposed to higher PM10 levels (p = 0.003, and 0.05, respectively). Positive skin prick tests and a history of having a lawn at home were associated with nasal symptoms (p = 0.008 and 0.04, respectively). Mean $FEF_{25-75\%}$ (forced expiratory flow that occurs during the middle 50% of the forced expiratory effort) was significantly lower in those who were exposed to higher PM10 levels (3.89 ± 1 *vs* 4.42 ± 0.9 l/sec, $p < 0.001$). A significant increase in days of school absence and medical expenses was associated with high PM10 exposure. It is concluded that chronic exposure to high PM 10 levels was significantly associated with increased prevalence of eye and airway symptoms and a decrement of $FEF_{25-75\%}$ resulting in increase of school absence and medical expense.

In the past decade, the prevalence of allergic rhinitis, conjunctivitis, and asthma has increased worldwide. The prevalence especially increases continuously in most industrialized cities. In Bangkok, the prevalence of children with asthma increased from 4 to 12% within the past decade.[1] Moreover, almost 50% of the population in Bangkok suffered from some form of rhinitis and/or conjunctivitis. There was great concern that air pollution exposure was one of the factors that was responsible for the alarming asthma statistics.[2] Outdoor air pollution levels have been associated with adverse health effects including pulmonary function decrement, increased bronchial hyperresponsiveness, visits to emergency departments, hospital admissions, increased medication use and symptom reporting.[3] Pollution was considered an inducer of allergic sensitization and allergic asthma. For example, it was reported that sensitization to cedar pollen was more frequent among the residents of an area exposed to automobile exhaust than among the residents living in a cedar forest with less traffic.[4] Several studies have associated particulate matter less than 10 micrometers in diameter (PM10) with increased in mortality and morbidity rate from respiratory and cardiovascular diseases.[5,6]

According to a report from the Department of Health, Ministry of Public Health and the Department of Pollution Control, Ministry of Sciences, Technology and Environment, the air quality (as per monitoring PM10 and carbon monoxide

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levels) in most areas of Bangkok has exceeded the acceptable limits for more than 7 consecutive years. The air pollution causes eye, nose and airway irritation to those individuals walking on the pavement along the roads in every afflicted district especially in congested areas.[7] Even though the Environmental Protection Agency (EPA) has set the standard for PM10 levels at 120 μg/m^3, it was indicated that no safety margin for PM10 could be derived, for each additional 10 μg/m^3 of PM10, the mortality rate for cardiorespiratory diseases could be increased by 0.7-1%.[5,6,8] Concern over adverse effects of high PM10 levels in Bangkok prompted us to study the impact on students who attended a school, which was located in a central business area with a 24-hour average PM10 level of 170-190 μg/m^3.

METHODS

Air quality in front of and inside the school located at a congested area of central Bangkok was monitored from 28 February 1999 to 8 March 1999. Total suspended particulate and PM 10 levels were measured by means of Gravimetric-High Volume, the carbon monoxide level was measured by Gas Filter Correlation, SO_2 was measured by UV-fluorescence, NO_2 was measured by chemiluminescence and ozone was measured by ultraviolet photometry. Air quality measurement was performed by the Department of Pollution Control, Ministry of Sciences, Technology and Environment, Thailand.

Two hundred and ninety students aged 15-18 years participated in the cross-sectional study during February to October 1999. Trained physicians completed survey questionnaires on the eye, nose, ear, throat, airway and sinus symptoms and signs. Indoor home environmental background including carpeting, lawn, pet, passive smoking, air-conditioning was obtained. The parental and sibling atopic histories were also included.

Working definitions of the clinical survey: In regards to eye symptoms, itching of the eyes, redness, watery eyes, conjunctival edema, irritation and/or swelling of eyelids of more than 2 weeks/year were recorded. The symptoms of purulent eye discharge or eye infection were excluded. Nasal symptoms included clear nasal discharge, blockage, itching, and loss of smell and/or sneezing especially on exposure to allergens or irritants. The following symptoms of nasal congestion, purulent rhinorrhea, postnasal drip, paranasal aching with headache and cough more than 10 days were recorded as sinusitis. Itching of ear canals, earache popping and reduced hearing were recorded as positive ear symptoms. Chronic irritation and itching of the throat with secretion were defined as positive throat symptoms. As for airway symptoms, difficulty in breathing, chronic recurrent cough, tightness of the chest and/or wheezing were recorded.

Physical examination was done by trained allergists. Appearance of a pale, swollen, congested nasal mucosa, hypertrophic nasal turbinate or polyp were recorded as abnormal findings consistent with rhinitis. A tympanic membrane that looked injected, retracted or hazy was also recorded as positive ear finding. Signs of conjunctival edema, congestion, papillary hypertrophy, puffiness of eyelids, and allergic shiners were recorded as conjunctivitis. Wheezing, decreased air entry and/or rhonchi were reported as positive chest findings.

Allergy skin prick test to house dust mite, Southern grass, Bermuda, cockroach, dog, cat, *Alternaria* and *Hormodendrum* were done with positive and negative controls. The peak expiratory flow rate, FEV1, percent of FEV1 to the predicted value, FVC, maximal mid-expiratory flow rate or $FEF_{25-75\%}$ of forced vital capacity and percent of $FEF_{25-75\%}$ to the predicted value were recorded.

Quality of life and economic impact which was reflected by days of absence from school and amount of medical expenses due to the rhinoconjunctival, respiratory or sinus problems were also reported.

RESULTS

The results in Table 1 indicated that the main problem of the air quality in front of the school was the high level of 24 hour average PM10 which exceeded the standard most of the time, while CO levels exceeded standard 3 out of 11 times. The lowest levels were recorded on Sunday, when the traffic was less congested. The other parameters were well below standard level.

The average level of PM10 measured in March 1999 at the roadside in front of the school was 170 μg/m^3 whereas average PM10 measured during 18 November to 10 December 1998 was 194 μg/m^3.

Demographic characteristic of the subjects involved in the study are shown in Table 2. All students are female. Of 290 students, 185 spent 16 ± 1.02 minutes a day waiting for public transportation at the roadside where the 24 hour average PM10 was 170-190 μg/m^3. The others (n = 105) waited inside the school for private transportation. The 24-hour average PM10 inside the school was 35- 40 μg/m^3. The students who attended the school were mainly from middle

Table 1 Ambient air quality at the roadside in front of the school and inside the school from 28 February to 8 March 1999

Pollutants	Standard	Roadside in front of School			Inside School		
		Range	Average	Exceeding standards	Range	Average	Exceeding standards
TSP (24 hr; mg/m^3)	0.33	0.18-0.32	0.26	0/11	0.04-0.17	0.08	0/11
PM10 (24 hr; $\mu g/m^3$	120.00	118-239	170	10/11	22-79	36.00	0/11
CO (8 hr; mg/m^3)	10.26	4.9-10.69	7.8	3/11	0.57-1.19	0.09	0/11
NO_2 (1 hr; $\mu g/m^3$)	320.00	0-110.92	75	0/8	18-126	92.00	0/11
SO_2 (24 hr average; $\mu g/m^3$)	300.00	3.96-19.88	8.2	0/8	33.49-71.57	53.50	0/9
O_3 (1 hr; $\mu g/m^3$)	200.00				1.96-148	92.00	0/11

TSP = total suspended particle
PM10 = particulate matter with diameter less than 10 μm
SO_2 = sulfur dioxide
ppm = parts per million
CO 8 hr = carbon monoxide, 8 hours in average
NO_2 = nitrogen dioxide
O_3 = ozone
$\mu g/m^3$ = microgram/cubic meter

Table 2 Characteristics of the two groups of students (N = 290)

Characteristics	% of all subjects (N = 290)	Waiting site for transportation at school		p-value
		Waiting inside (n = 105)	Waiting outside (Roadside; n = 185)	
Average PM10 ($\mu g/m^3$)		36	170	< 0.001**
Gender: female	100	100	100	ns*
Family history of atopy (%)	49	51.9	46.1	ns*
Home environment				
-**cigarette smoking in family** (%)	30	32	30	ns*
-**living on sideroad** (%)	71	75	70	ns
-**living near factory** (%)	7.1	4	9	ns*
-**lawn at home** (%)	45	62.4	34.6	< 0.001**
-**carpet in house** (%)	35	42	31	ns*
-**pet at home** (%)	50	57.6	43.8	ns*
-**air conditioning**	88.8	94.1	87.4	ns*
Positive skin prick test (%)	51	50	53	ns*

ns* = not significant, **statistical significant

class and higher socioeconomic background.

Forty nine percent of the subjects had a family history of atopy. Passive smoking in the family was recorded in 30% of the subjects. Seventy one percent of the subjects lived on roadsides. Thirty five percent of the subjects' home had carpeting. Half of the subjects had pets at home, 88% of the home were air-conditioning, and 45% of the subjects had a lawn at home. As shown in Table 2 almost all of the parameters were comparable among students who usually waited inside the school to be picked by their

Table 3 Respiratory and eye symptoms among the students in the past year

Clinical symptoms	% of total subjects (N = 290)	Waiting site for transportation at school (pollution exposure) %		Odd ratio (95% CI)	*p*-value
		Inside school (low) (n = 105)	At roadside (high)(n = 185)		
Nose	55.7	55.0	57.0	1.0 (0.7-1.7)	ns*
Eye	50.0	38.1	55.7	2.0 (1.3-3.3)	< 0.01
Ear	5.5	3.9	7.1	2.6 (0.7-9.3)	ns*
Throat	23.8	24.0	23.8	1.0 (0.6-1.8)	ns*
Airway	21.7	17.1	24.0	2.0 (0.8-2.8)	ns*
Sinusitis	15.0	14.0	16.5		ns*

*ns = not significant

parents versus those who were waiting at the roadside outside the school for commuting. The average PM10 at the roadside area outside the school was significantly higher than that of the area inside school (170 *vs* 36 $\mu g/m^3$, $p < 0.001$). A record of a lawn at home was significantly higher in the group of students who waited inside the school indicating their socioeconomic status being relatively higher.

The clinical symptoms reported within the last year are shown in Table 3. Fifty-five percent of the subjects reported symptoms consistent with rhinitis in the past 12 months. Fifty percent reported symptoms of itching of the eyes, redness, watery eyes, conjunctival edema, irritation and/or swelling of eyelids. Twenty three percent complained of throat irritation. Twenty one percent of the subjects reported airway symptoms of difficulty in breathing, chronic recurrent cough, tightness of the chest and/or wheezing. Twenty four percent complained of recurrent headache especially during or after a long walk on the pavement. History of sinusitis was reported in 15 percent of the students and teachers. Five and a half percent having had ear symptoms in the past 12 months. Seventy three percent reported having upper respiratory tract infection in past 12 months.

Thirty-eight percent of the students who waited inside the school for private transportation, where the average PM10 was 35-40 $\mu g/m^3$ experienced ocular symptoms compared to 55.7% of those who waited at the roadside with an average PM10 of 170-190 $\mu g/m^3$ (p = 0.0042 with odd ratio of 2 [1.3-33]). There was no significant increase in nasal, ear, throat and airway symptoms in the group that waited for transportation at the roadside.

Risk factors and clinical symptoms (Fig. 1 and Table 4)

Eyes: Multivariate analysis revealed a significantly increased risk of eye symptoms in the group exposed to pollution with higher PM10 levels, passive smoking, and the group with lawn at home with odd ratios of 2.7 (95% CI 1.5-4.9), 1.8 (95% CI 1.0-3.1) and 1.9 (1.1-3.3); the *p*-values were < 0.01, < 0.05 and < 0.05, respectively, as shown in Table 4.

Noses: Increased prevalence of nose symptoms were correlated with those who had positive allergy skin prick tests and lawn at home with odd ratios of 2.0 (1.2-3.5) and 1.7 (1.0-2.9); *p*-values were < 0.1 and < 0.05, respectively. A family history of atopy was associated with nasal symptoms only in univariate analysis but not in multivariate analysis.

Throat and airway: Increased throat symptoms were associated with passive smoking with odd ratios of 1.9 (univariate 95% CI 1.1-3.3) and 2.0 (multivariate 95% CI 1.1-3.7), respectively (*p*-value < 0.05). Whereas multivariate regression analysis showed that airway symptoms were correlated with positive skin prick tests and a high PM-10 pollution exposure (waiting at the roadside for the transportation) with odd ratios of 2.2 (1.1-4.2) and 2.2 (1.1-4.2), and a *p*-value < 0.05, respectively.

Physical examination: Six and seven-tenth percent of the students who waited inside the school and 9% of those who waited at the roadside showed positive clinical signs consistent with allergic blepharo-onjunctivitis. The clinical sign of allergic rhinitis was reported in 10% of the subjects who waited inside the school and 11% of the subjects who waited at the roadside, whereas abnormal granular pharynx and enlarged tonsils were reported in 7.2% of the subjects inside the school and 7.8% in the other group, abnormal ear findings were recorded in 10% of the subjects who waited inside and 6% of those who waited at the roadside. There was a significant increase in abnormal chest findings on auscu-

Table 4 Risk factors and clinical symptoms of eye, nose and respiratory system by univariate and multivariate analysis

Possible factor	Clinical symptoms	Univariate regression analysis		Multivariate regression analysis	
		Odd ratio (OR)	*p*-value	Odd ratio (OR)	*p*-value
Waiting at the roadside (high PM10 exposure)	Eye	2.0 (1.2-3.3)	< 0.01*	2.7 (1.5-4.9)	< 0.01*
	Nose	1.1 (0.7-1.7)	ns**		ns
	Throat	1.0 (0.6-1.8)	ns		ns
	Airway	2.0 (0.8-2.8)	ns	2.2 (1.1-4.2)	< 0.05*
Family history of atopy	Eye	1.2 (0.7-1.9)	ns		ns
	Nose	2.1 (0.3-0.8)	< 0.01*		ns
	Throat	1.2 (0.7-2.1)	ns		ns
	Airway	1.5 (0.9-2.7)	ns		ns
Positive skin prick test	Eye	1.1 (0.7-1.8)	ns		ns
	Nose	2.1 (1.3-3.6)	< 0.01*	2.0 (1.2-3.5)	< 0.01*
	Throat	1.2 (0.7-2.2)	ns		ns
	Airway	2.3 (1.2-4.4)	0.01*	2.2 (1.1-4.2)	< 0.05*
Lawn at home	Eye	1.3 (0.8-2.1)	ns	1.9 (1.1-3.3)	< 0.05*
	Nose	1.9 (1.2-3.1)	< 0.01*	1.7 (1.0-2.9)	< 0.01*
	Throat	1.0 (0.6-1.7)	ns		ns
	Airway	1.1 (0.6-1.8)	ns		ns
Smoking in the family	Eye	1.7 (1.0-2.9)	< 0.05*	1.8 (1.0-3.1)	< 0.05*
	Nose	1.2 (0.7-2.0)	ns		ns
	Throat	1.9 (1.1-3.3)	< 0.05*	2.0 (1.1-3.7)	< 0.05*
	Airway	1.1 (0.6-2.0)	ns		

*statistical significant, **ns=not significant

Table 5 Pulmonary function tests among the students who usually waited inside and outside of their school (N = 230)

Pulmonary function	Waiting inside the school Low PM10 exposure (n = 80)	Waiting outside the school High PM10 exposure (n = 150)	*p*-value
PEF	434.49 ± 35.3	429.25 ± 40.77	ns*
FVC	2.81 ± 0.25	2.88 ± 0.33	ns
FEV_1	2.79 ± 0.31	2.77 ± 0.38	ns
FEF_{25-75}	4.42 ± 0.92	3.89 ± 1.00	< 0.001**

*not significant, **statistical significant

tation in the subjects who waited at the roadside from 1% to 2%.

Quality of life: Students in the group that waited for transportation in the high PM 10 level area had an average of 0.84 ± 1.86 school ab sent days within 12 months while those in the group that waited for transportation in the low PM10 level area had an average 0.45 ± 1.27 school absent days ($p < 0.01$). The average amount of medical expenses for eye and respiratory symptoms in subjects who were exposed to low PM 10 levels was 538 Baht/ year in comparison to 724 Baht/year for those who were exposed to higher PM10 levels. There was a statistically significant difference in the percentile according to Mann-Whitney U test statistics ($p = 0.001$).

Lung function: There was a significant decrement in the mean $FEF_{25-75\%}$ of forced vital capacity in the group that waited for transportation at the roadside ($p = 0.001$) as shown in Table 5.

There was no significant

decrement of the mean peak expiratory flow rate, FEV1 and FVC. The mean peak expiratory flow in those who waited at the roadside was 424 l/min while of those who waited inside the school was slightly higher at 430 l/min ($p < 0.001$).

Allergy skin prick test reactivity: Positive allergy skin test reactivity was noted in over 50% of the students. There was a slight increase in positive allergy skin prick tests in those who waited outside the school but not statistically significant. Positivity to house dust mite allergen was recorded in 44% and 48% in those waiting inside and outside, respectively. Cockroach skin test positivity was noted in 21% in those waiting inside and 27% in those waiting at the roadside. Allergy to grass was recorded in 15%, positivity to dog and cat was noted at 4 and 7%, respectively.

DISCUSSION

Epidemiological studies re-vealed an increase in the prevalence of allergic diseases, especially in industrialized countries in the past two decades. Modernization and industrialization have created environmental changes to Bangkok's overcrowded population of 10 millions. High buildings and traffic problems lead to higher levels of air pollution. With increased emissions from a higher numbers of vehicles and higher usage, diesel exhaust particles (DEP) became the major air pollutants in modernized and industrialized cities. DEP consist of fine particles sized from 2.5-10 μm and several components of polyaromatic hydrocarbons. DEP was shown *in vitro* and *in vivo* to enhance the production of IgE from B cells as well as production and release of inflammatory Th2-type cytokines.[9] DEP can act as mucosal adjuvants at the molecular and cellular level,[10,11] hence they may augment IgE production[12] and contribute to an increase in allergic sensitivity in the population who live in big cities. Half of the population we studied had a positive allergic skin reactivity to common pollen inhalants. In our other study done in 103 low socioeconomic background children aged 13-18 years in central Bangkok, positive allergic skin tests were found in 49%. Twenty-three and six-tenth percent had a family history of atopy, 13.8% with eye symptoms, 29% with nose symptoms, 7.8% with ear symptoms, 20% with throat symptoms, 10.8% with airway symptoms and 21% had a history of upper respiratory tract infection in the past 12 months (unpublished data). Even though small particulate matter such as PM10 promotes the allergic sensitization of the whole population of Bangkok, the prevalence of allergic eye and respiratory diseases in children from affluent families is double of that from poorer families. This may imply that affluent lifestyle poses a greater risk for the development of allergic diseases than air pollution. A high prevalence of atopic diseases and asthma have also been reported in the affluent Western society.[13] Other studies have also demonstrated that urbanization, outdoor air pollution from vehicle emissions and westernized lifestyle is correlated with an increasing prevalence of allergic diseases and asthma.[14]

In this study, half of the children from affluent socioeconomic background who were exposed to air pollution exceeding standard levels in a central business area in the metropolitan city of Bangkok were found to have allergic rhinitis, conjunctivitis and almost twenty percent had airway symptoms. Those who were exposed to higher PM10 levels at the roadside demonstrated higher prevalence of eye symptoms and an exacerbation of existing allergic diseases leading to an increase in medical expenses and days of absenteeism. Therefore, clinicians should alert their patients that air pollution is one factor that can aggravate allergic diseases and asthma.[15]

Differences in air pollutants across the population were associated with decrements of their lung function. An increase of 54 days/yr when PM10 exceeded 100 μg/m^3 was associated with a 7.2% decrement in FEV1, as percent of predicted comparing to the normal subjects of the same sex, age and height.[16] Other studies showed that PM10 and PM2.5 were each significantly associated with lower FVC, FEV1 results and maximal midexpiratory flow rate.[17,18] In this study, we have shown a significant decrement in the mean $FEF_{25-75\%}$ in subjects who were exposed to higher PM10 levels while waiting for transportation at the roadside. This indicates that the small airway function may be a sensitive indicator for the effect of particulate matter less than 10 μm in air pollution. There was no statistical difference in peak expiratory flow rate and FEV1. The explanation might be that we did not perform a series peak expiratory flow rates during the day. Besides, the PEF and FEV1 were recorded before the exposure period, not 15-30 minutes after exposure to air pollution.

It was concluded that this study showed that allergy skin test positivity, affluent lifestyle, and family history of atopy pose a greater risk for the development of allergic nasal and airway diseases than air pollution. Particulate air pollutant increased the development of eye symptoms and decrement of small airway function. An increase in medical expenses and days of absence from school in the group that was exposed to higher levels of particulate matter (PM10) was noted as economic impact. This implies that even though exposure to high PM10 levels by itself did not directly increase prevalence of nasal symptoms, but it could exacerbate the existing atopic conditions as shown by the increase in medical expenses and days of absenteeism.

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