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REGULAR ARTICLE

Association of ambient air pollution and meteorological factors with primary care visits at night due to asthma attack

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Abstract

Aim The association of outdoor air pollution and meteorological elements with primary care visits at night due to asthma attack was studied.

Methods A case–crossover study was conducted in a primary care clinic in Himeji City, Japan. The subjects were 956 children aged 0–14 years who visited the clinic with an asthma attack between the hours of 9 p.m. and 6 a.m. Daily concentrations of particulate matter, ozone, nitrogen dioxide, and a number of meteorological elements were measured, and a conditional logistic regression model was used to estimate odds ratios (ORs) of primary care visits per unit increment of air pollutants or meteorological elements. The analyses took into consideration the effects of seasonality.

Results Of the 956 children, 73 (7.6 %) were aged <2 years and 417 (43.6 %) were aged 2–5 years. No association between daily ozone levels and primary care visits due to asthma attack at night in the spring or summer was found. An inverse relation between suspended particulate matter and primary care visits due to asthma attack was detected in the winter. ORs in the summer per degree increment in daily mean temperature was 1.31 [95 % confidential interval (CI) 1.09–1.56], and ORs in the autumn per hourly increment in daily hours of sunshine was 0.94 (95 % CI 0.90–0.99).

Conclusion The findings of our study fail to support any association between daily mean concentration of air pollutant and primary care visits at night. However, we did find evidence indicating that certain meteorological elements may be associated with primary care visits

Keywords Air pollution · Asthma · Ozone · Meteorological elements · Particulate matter

Introduction

Children's exposure to air pollution is of special concern because their immune system and lungs are not fully developed, thereby potentially putting them at risk of developing asthma or worsened pulmonary function. Further, children spend a significant amount of time outdoors, where concerns of exposure to pollution from traffic, power plants, and other sources are generally higher than indoors. Exposure to ambient air pollutants, such as particulate matter (PM), ozone, and nitrogen dioxide (NO_2), is associated with many adverse health outcomes ranging from increased symptoms of allergic airway disease to increased mortality [1–3]. Children are considered to be more sensitive to air pollution than adults [4], and asthmatic children are particularly vulnerable to the adverse health effects of air pollution. Studies of asthmatic children have concluded that exposure to high concentrations of ozone or PM significantly enhances the risk of respiratory symptoms, asthma medication use, and reduced lung function,

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such as decline in peak expiratory flow or forced expiratory flow in a short time [5–10]. However, while a number of studies have been conducted in the field of air pollution epidemiology, few have examined the association between meteorological elements and asthma attack, and the adverse health effects of low-level exposure to air pollutants remain unclear.

Previous studies have shown that the meteorological risk factors of care visits due to asthma attack are high temperature [11, 12], large changes in temperature [13, 14], high atmospheric pressure [13, 15], low relative humidity [13], and large changes in humidity [14]. However, these data may suffer from publication bias.

In this study, we collected and analyzed data on the mean levels of air pollutants and meteorological elements to determine whether there was an association between any of these environmental factors and primary care visits of children at night due to asthma attack.

Methods

Subjects

The setting of this study was Himeji City Emergency Clinic, Himeji, Japan, which had been established for the purpose of treating emergency cases between 9 p.m. and 6 a.m. on weekdays. Himeji City is located in the western part of Japan, within 100 km of central Osaka, and faces the Setonaikai Sea. The city is 534 km^2 in area, and its population is approximately 540,000. The subjects of our study were city residents aged 0–14 years with a past history of asthma attack who had visited the municipal emergency primary care clinic between 9 p.m. and 6 a.m. at some point between 1 April 2010 and 31 March 2012.

We excluded patients who visited the clinic on national holidays for reasons discussed in the Statistical methods section. The medical records of all patients were provided retrospectively, and subjects' age, gender, diagnosis, and date of visit were recorded. Eligible subjects were patients diagnosed with asthma by their primary care physician and for whom bronchodilators were prescribed. The study was approved by the Himeji local government with respect to using personal identification information obtained from the municipal clinic (Himeji City Emergency Clinic, Himeji, Japan).

Air pollutants and meteorological elements

Data on daily concentrations of suspended PM (SPM), NO_2, and ozone from 1 April 2010 through to 31 March 2012 were obtained from the Himeji local government. SPM is defined in the Japanese Air Quality Standard as any particle collected with an upper 100 % cut-off point of an aerodynamic diameter of 10 μm. The 50 % cut-off diameter for SPM is assumed to be approximately 7 μm; we therefore refer to this variable as PM_7. The monitoring station where these air pollutants were measured was located on a residential street in the city. We also measured hourly concentrations of PM with a 50 % cut-off aerodynamic diameter of $\leq$2.5 μm ($PM_{2.5}$), PM with a 50 % cut-off aerodynamic diameter of $\leq$10 μm (PM_{10}), and organic black carbon (OBC) using the R&P TEOM-1400 ambient particulate monitor (Rupprecht & Patashnick Co., Albany, NY) at a point nearby the monitoring station from April 2010 through March 2012. Meteorological elements such as daily mean values for atmospheric pressure, relative humidity, temperature, wind speed, as well as total hours of daylight were also assessed. These data were obtained from the Japan Meteorological Agency.

Statistical methods

The study design was that of a time-stratified case–crossover analysis, which is an accepted technique for assessing brief changes in risk associated with transient exposures [16, 17]. Case–crossover analyses require exposure data for cases only and can be regarded as a special type of case–control study in which each case serves as its own control. This design has the advantage of inherently controlling for potential confounding caused by fixed individual characteristics, such as sex, race, diet, and age. "Time-stratified" indicates the method by which the control periods were chosen. Specifically, we stratified time into months to select days for control periods that fell on the same day of the week within the same month as the date of the primary care visit (day of the index period). For example, if the primary care visit at night due to asthma attack occurred on September 18, the three control days were September 4, 11, and 25. Therefore, this approach also controls for long-term trends, seasonality, and day of the week. The merits of case–crossover designs in studies of health effects of air pollution have been discussed in detail by Schwartz [18].

We excluded patients who visited the clinic on national holidays because of bias in control selection. That is, if patients whose visits occurred on holidays were included as subjects, the estimated relative risks were lower than expected because the concentration of air pollutants on holidays (days for the index periods) was usually/systematically lower than that on non-holidays (days for control periods) [19].

We examined associations between daily mean concentrations of each air pollutant and the risk of primary care visits at night due to asthma attack. These concentrations were subject-specific values averaged over the day of the indexing. We estimated odds ratios (ORs) of primary care visits at night due to asthma attack per 10 μg/m^3 difference in SPM in a single-pollutant model adjusted for 1-day mean atmospheric pressure (hPa), relative humidity (%), temperature (°C), wind speed (m/s), hours of daylight (h). Similarly, we also estimated ORs of primary care visits per 10-ppb difference in NO_2 and in ozone. In addition, we estimated ORs of primary care visits at night due to asthma attack per 10 μg/m^3 difference in SPM, per 10 ppb difference in NO_2, and per 10 ppb difference in ozone in a multi-pollutant model adjusted for the same variables as the single-pollutant model. We also assessed the association between primary care visits due to asthma attack and the concentrations of air pollutants or meteorological elements 1 day before the visits.

All models took into consideration the effects of season and unusually high and low temperatures; modified effects were examined using a four-level indicator variable for the spring (April through June), summer (July and August), autumn (September through November), and winter months (December through March).

The PHREG procedures of SAS release 9.2 (SAS Institute, Cary, NC) were used to perform the conditional logistic regression. All tests were two-tailed, and alpha was set at 0.05. We computed ORs and their 95 % confidence intervals (CIs). Given that several test procedures were used in our study, multiple testing issues arose. However, we did not devise any countermeasures for these issues as we believed that elevated risks of air pollutants in this study should be demonstrated by the precautionary principle.

Table 1 Age and gender of subjects enrolled in the study

Age group (years)	Gender		Total
	Boys	Girls	
0–1	49	24	73
2–5	277	140	417
6–14	341	125	466
Total	667	289	956

Gender data for two subjects were missing

Results

Characteristics of the subjects enrolled in our study are shown in Table 1. Of the 956 children evaluated, 73 were aged <2 years, 417 were preschool children aged 2–5 years, and 466 were school children aged 6–14 years. Figure 1 shows the number of cases in each month of the study period.

The daily mean concentrations of air pollutants and other meteorological data are shown in Table 2. The mean concentration of ozone was higher in the spring months than in the other months.

Table 3 shows the association between air pollutants and primary care visits at night due to asthma using the single-pollutant model. We noted no association between air pollutants and primary care visits, other than SPM in winter. When we analyzed these data according to three age groups, namely, children aged 0–1 year, 2–5 years, and 6–14 years, the results were almost the same as those obtained for the whole study cohort (data not shown).

Table 4 shows the results for the multi-pollutant model. We noted statistical significance in the inverse relation between ozone levels and primary care visits in winter, as well as between SPM and primary care visits in winter. With respect to meteorological elements, we observed an association between temperature increase and primary care visits in the summer, and between decline in hours of daylight and primary care visits in he autumn. No

Fig. 1 Number of nighttime primary care visits of children by age group in each month

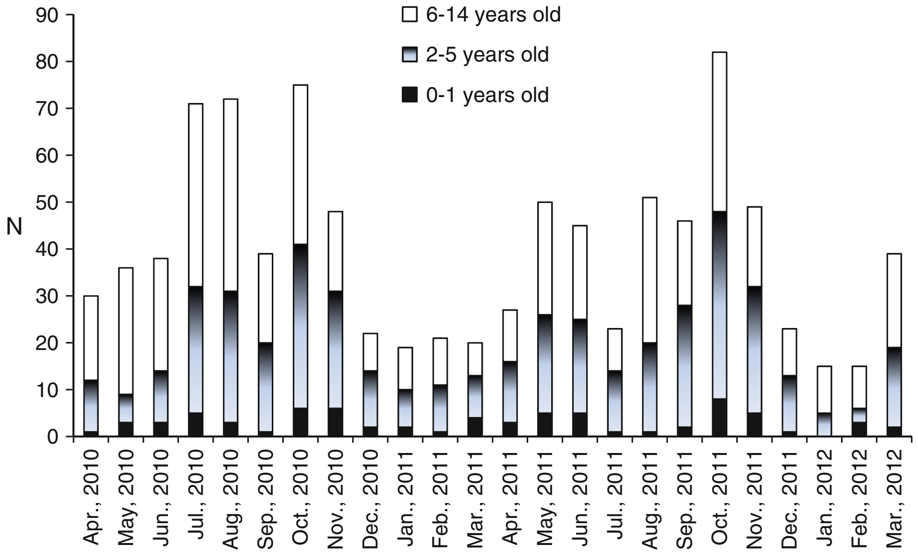

Table 2 Summary statistics of daily concentration of air pollutants and meteorological indices

Meteorological elements/ air pollutants	April–June ($N = 182$ days)			July–August ($N = 124$ days)			September–November ($N = 182$ days)			December–March ($N = 243$ days)		
	Mean	SD	Maximum	Mean	SD	Maximum	Mean	SD	Maximum	Mean	SD	Maximum
Atmospheric pressure (hPa)	1,008.2	5.6	1,022.8	1,005.9	5.4	1,015.1	1,011.7	6.4	1,024.6	1,013.9	5.5	1,025.1
Relative humidity (%)	69.8	12.3	93.0	74.4	6.9	94.0	71.5	8.3	92.0	66.9	8.7	92.0
Temperature (°C)	17.7	5.0	28.6	27.7	1.9	31.0	18.5	5.9	30.5	5.4	3.1	13.5
Wind speed (m/sec)	2.7	0.8	5.8	2.6	0.8	7.5	2.4	0.9	7.7	2.7	0.9	5.8
Daylight hours (h)	5.6	4.5	13.4	6.5	3.9	12.9	5.4	3.7	12.2	5.2	3.2	11.3
NO_2 (ppb)	12.5	4.8	27.8	8.6	2.6	16.8	10.7	4.2	23.6	12.9	5.9	40.1
Ozone (ppb)	36.2	11.0	62.4	22.5	10.6	58.3	21.5	8.4	46.7	23.0	9.0	46.6
SPM (μg/m^3)	27.3	11.6	99.2	24.0	8.1	46.3	18.7	8.4	47.4	17.2	11.0	132.4
$PM_{2.5}$ (μg/m^3)	22.5	12.7	81.3	21.3	9.8	43.1	19.8	12.6	69.5	21.1	11.2	73.6
PM_{10} (μg/m^3)	41.0	29.8	289.1	34.2	12.4	60.3	32.6	21.9	206.4	29.5	15.0	103.1
OBC (μg/m^3)	0.5	0.3	1.6	0.5	0.3	1.4	0.5	0.3	1.7	0.5	0.4	2.8

NO_2 Nitrogen dioxide, *SPM* suspended particulate matter, *$PM_{2.5}$* Particulate matter (PM) with a 50 % cut-off aerodynamic diameter of ≤2.5 μm *PM_{10}* PM with a 50 % cut-off aerodynamic diameter of ≤10 μm, *OBC* organic black carbon, *SD* standard deviation

Table 3 Associations[a] between air pollutants and primary care visits at night due to asthma attack by seasonal subgroups (single-pollutant model)

Air pollutants	Unit increment	April–June			July–August			September–November			December–March		
		OR	95 % CI		OR	95 % CI		OR	95 % CI		OR	95 % CI	
NO_2	10 ppb	0.881	0.594	1.306	1.110	0.557	2.214	1.125	0.784	1.614	0.874	0.607	1.259
Ozone	10 ppb	1.003	0.847	1.187	1.118	0.934	1.337	0.984	0.794	1.221	0.903	0.694	1.174
SPM	10 μg/m^3	0.942	0.828	1.072	1.021	0.829	1.256	1.006	0.882	1.148	0.726	0.552	0.956
$PM_{2.5}$	10 μg/m^3	0.998	0.882	1.129	0.958	0.776	1.182	0.991	0.885	1.109	1.039	0.883	1.222
PM_{10}	10 μg/m^3	0.988	0.936	1.043	0.968	0.818	1.146	0.971	0.900	1.047	1.022	0.902	1.158
OBC	0.1 μg/m^3	1.019	0.961	1.079	1.058	0.965	1.160	1.023	0.973	1.075	0.984	0.937	1.033

Data are adjusted for daily mean atmospheric pressure, relative humidity, temperature, wind speed and hours of daylight

[a] Associations are shown as odds ratios (ORs) and their 95 % confidence intervals (CIs) per unit increment of each pollutant

Table 4 Associations between air pollutants and primary care visits at night due to asthma attack by seasonal subgroups (multi pollutant model)

Meteorological elements/air pollutants	Unit increment	April–June			July–August			September–November			December–March		
		OR	95 % CI		OR	95 % CI		OR	95 % CI		OR	95 % CI	
Atmospheric pressure	1 hPa	1.020	0.985	1.058	1.025	0.985	1.067	1.004	0.972	1.037	1.013	0.969	1.058
Relative humidity	10 %	1.239	0.981	1.564	1.319	0.800	2.172	0.787	0.608	1.018	1.183	0.847	1.652
Temperature	1 °C	1.029	0.96	1.103	1.306	1.092	1.561	0.980	0.938	1.023	1.043	0.970	1.121
Wind speed	1 m/s	1.001	0.801	1.252	1.019	0.796	1.304	0.878	0.713	1.082	0.965	0.710	1.312
Hours of daylight	1 h	1.015	0.959	1.073	0.963	0.888	1.044	0.939	0.895	0.986	1.046	0.974	1.123
NO_2	10 ppb	0.953	0.606	1.497	1.158	0.494	2.713	1.274	0.718	2.263	0.466	0.202	1.072
Ozone	10 ppb	1.012	0.853	1.201	1.128	0.933	1.365	1.043	0.807	1.346	0.495	0.284	0.862
SPM	10 μg/m^3	0.948	0.817	1.101	0.951	0.726	1.246	0.948	0.782	1.151	0.724	0.524	0.999

Associations are shown as ORs and their 95 % CIs per unit increment of each indices statistically significant associations were noted between primary care visits due to asthma attack and the concentrations of air pollutants or meteorological elements 1 day before the visits except for the association between temperature and primary care visits in the summer (OR 1.36, 95 % CI 1.08–1.70).

Discussion

To ascertain whether there is an association between ambient air pollution/meteorological factors and primary care visits at night due to asthma, we examined these factors among children with a past history of asthma attack who had visited the municipal emergency primary care clinic in Himeji, an industrial city in the western part of Japan, between 9 p.m. and 6 a.m. at some point between 1 April 2010 and 31 March 2012. We noted no association between 1-day ozone levels and primary care visits due to asthma attack at night in the summer, nor did we note any association between other air pollutants and primary care visits, except for an inverse relation between ozone and SPM and primary care visit due to asthma attack in the winter season. However, we did find evidence indicating that several meteorological elements, such as temperature and hours of daylight, may be associated with primary care visits due to asthma attack. The OR in the summer months per degree increment of daily mean temperature was 1.31 (95 %CI 1.09–1.56), and that in the autumn per hourly increment of hours of daylight was 0.94 (95 % CI 0.90–0.99).

Ozone and primary care visits due to asthma attack

Our findings regarding a potential association between ozone and physician visits due to asthma attack were not consistent with those of previous studies. A recent U.S. Environmental Protection Agency analysis of ambient ozone health effects concluded that children with asthma suffer acute adverse health consequences at current ambient levels of ozone [3], and Babin et al. [20] and Moore et al. [21] also observed an association between pediatric emergency room visits for asthma exacerbation and outdoor ozone levels. In a previous Japanese study as well, Yamazaki et al. [10] noted an association between ozone and physician visits due to asthma attack in the summer.

However, the findings in our study show no association between ozone levels and primary care visits in the warmer months. We propose that a number of factors could explain these results. First, compared to the previous Japanese study by Yamazaki et al. [10], in which investigators analyzed the association between hourly concentrations of air pollutants and hourly records of primary care visits due to asthma attacks, we analyzed *daily* concentrations and primary care visit data. As such, we were unable to detect any effects of acute hourly high-level exposure of air pollutants. For example, in our study, the maximum concentration of ozone in the warmer months (April through September) was a daily high of 62 ppb (Table 2), compared with a value of 224 ppb/h in Yamazaki et al.'s study [10]. Second, outcomes such as "emergency room visit" or "primary care visit" might not be appropriate in studies on adverse health effects of air pollution conducted in developed nations, as attentive asthma medication for the prevention of these attacks is relatively widely available in these countries. With respect to our finding of an inverse association between ozone and primary care visits in the winter, we speculate that results from the multi-pollutant model may suffer from the effect of multilinearity among air pollutants. Pearson's correlation coefficients between ozone and NO_2, ozone and SPM, and NO_2 and SPM were −0.69, −0.12, and 0.44, respectively. Finally, the detection of this inverse association may be the result of an alpha error of the test.

PM and NO_2 and primary care visits due to asthma attack

Our findings failed to support any association between daily mean concentration of PM/NO_2 and primary care visits at night. Moreover, the inverse relation of SPM on primary care visits with asthma attack was detected in the winter. We speculate that this was an alpha error detection because we did not find an association of $PM_{2.5}$ and PM_{10} with primary care visits in the winter in our study.

Meteorological data and primary care visits due to asthma attack

With respect to the relationship between primary care visits due to asthma attack and temperature, several studies have examined respiratory morbidity effects of heat waves with consistent findings [22, 23]. Our results support a positive association between high temperature and trigger of primary care visits for asthma attack. To our knowledge, ours is the first study to examine the relationship between primary care visits for asthma attack and hours of daylight. Further studies will be needed to examine the association between change in meteorological risk factors and respiratory outcomes.

Limitations

A number of limitations to our study warrant mention. First, the significance of the association between air pollution and primary care visits at night due to asthma attack is diminished because primary care visits due to asthma attack are a surrogate measurement for asthma exacerbation. The time lag between exposure to elevated concentrations of air pollutants and asthma exacerbation can vary, with an equal variation in time lag between asthma exacerbation and time of primary care visit. These variations in time lag affect the statistical association between air pollutants and primary care visits at night due to asthma attack. Second, we were unable to evaluate the effect of indoor air pollution on primary care visits. In Japan, indoor space heaters are usually used in the winter, particularly December through February, and as such the concentrations of indoor air pollutants are reported to be considerably high in the winter [24]. The observed inverse association between outdoor air pollutants and primary care visits in winter may therefore have been confounded by these space heater-generated indoor air pollutants. Third, selection of subjects for this study may have been subject to issues with external validity, as we restricted our population to nighttime patients. Fourth, the estimated ORs in this study may suffer from non-differential misclassification, causing our results to be biased toward null.

In conclusion, while we noted no association between daily concentration of ozone and primary care visits with asthma attack at night in the summer, we did find evidence suggesting that meteorological elements such as temperature and hours of daylight might be associated with primary care visits due to asthma attack.

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Conflict of interest All authors declare that they have no competing financial interests.

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