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REGULAR ARTICLE

Correlation of light transmittance with asthma attack: fine water particles as a possible inducing factor of asthma

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Abstract
Background and objectives It has been postulated that air-borne fine water particles (or mist) can induce asthma attacks in asthmatic children. To date, no attempt has been made to quantify the density of air-borne fine water particles with the aim of relating particle density to the etiology of asthma among children. The aim of this study was to investigate the relation of asthma attack frequency and the particle density evaluated in terms of light transmittance.
Methods The density of fine water particles was quantified by measuring reductions in light transmittance at 250, 365 and 580 nm at an outdoor location when the surroundings were in darkness. The measurements were made at distances varying from 1 to 3 m from the light sources and performed every morning and evening for 1 year. Each day was separated into two half-day units [i.e., morning (from midnight to noon) and afternoon (from noon to midnight)]. The number of asthma attacks among 121 enrolled asthmatic children was counted for each unit. A possible correlation between the transmittance reduction and frequency of asthma attacks was assessed.
Results A significant difference was observed in the extent of reduction in light transmittance at 365 nm between the units with asthma attacks and those without attacks. Furthermore, the reduction in the transmittance was more evident when more asthma attacks were recorded among the patients. No difference was detected in the reduction in light transmittance at 250 or 580 nm.
Conclusions These results support the hypothesis that air-borne fine water particles are among the etiological factors that induce asthma attacks in asthmatic children.

Keywords Asthma attack · Fine water particles · Light transmittance · Temperature · Vapor pressure

Introduction

Many studies have been conducted to identify asthma-inducing factors, including allergy [1–3], viral infections [4, 5], atmospheric air pollutants [6, 7] among others. However, such associations have proven difficult to quantify, and a positive association of allergy, for example, was detected only in 4–11% of asthma cases [8].

In 1983, Anderson et al. [9] reported that fine water particles produced by ultrasonic nebulization could induce asthma attack in children. Working on this same line of research and based on analyses of weather charts and variations in vapor pressure, Kanaya suggested the possibility that fine water particles (or mist) may induce asthma attacks in many asthmatic children [10]. It was, however, not possible to measure the density of fine water particles in the atmospheric air.

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The aim of the study reported here was to investigate the relation of asthma attack frequency with particle density in the air, using decreases in light transmittance as an indicator of the density of air-borne fine water particles [10] after the method of Baron and Willeke [11]. As it is known that the decrease in light transmittance depends on light wavelength together with particle size, light of various wavelengths was tested in an attempt to identify whether light of certain wavelengths correlates more closely with asthma attack frequency than others.

Subjects and methods

Subjects studied

A total of 121 asthmatic children [72 boys (60%) and 49 girls (40%)] were enrolled in the study. All enrolled patients had visited the Kanaya Pediatric Clinic (Tanabe City, Wakayama prefecture, Japan) with bronchial asthma during the 1-year period from 1 November 2001 to 31 October 2002. The children ranged in age from 1 to 14 years (arithmetic mean age 6.1 years). On each visit, a clinical history was carefully taken to identify the time of onset of the asthma attack.

The diagnosis of bronchial asthma was clinically made by K.K. (as the doctor in charge) following the criteria of wheeze detection, chest tightness and shortness of breath [12]. Past history of having similar attacks was also taken into account [10]. The therapy given to the patients was basically palliative.

The number of asthma attacks among the 121 registered patients was counted on a half-a-day basis (1 unit); only the time of the first attack was counted when the symptoms/signs continued for more than two units. Thus, asthma a.m. or p.m. ('asthma a.m./p.m.') was defined as the morning (from midnight to noon of the day) or the afternoon (from noon of the day to midnight), respectively, when at least one attack took place in one or more of the 121 patients. Non-asthma a.m. or p.m. ('non-asthma a.m./p.m.') was defined as the morning or the afternoon, respectively, when none of the 121 patients had an asthma attack. The number of patients according to number of asthma attacks is listed in Table 1. A total of 204 attacks were observed in the 1-year period, with 46 patients having multiple attacks and the remaining 76 patients only making one visit to the clinic.

Table 1 Classification of patients according to number of asthma attacks during the 1-year study period

Parameters	Number of attacks (A)[a]					
	1	2	3	4	5	Total
Number of patients (P)[a]	75	26	8	7	5	121
A × P	75	52	24	28	25	204

[a] From 1 November 2001 to 31 October 2002

With regard to ethical issues, no application for approval of the study design was made prior to the study to an ethics committee simply because no such committee had been established at the time of the study, i.e. in 2001–2002. The privacy protection law was enacted in Japan in 2003 [13], and the establishment of medical ethics committees in various medical institutions followed the enactment. The Ethics Committee of the Kyoto Industrial Health Association approved the study protocol retrospectively in 2010.

Light transmittance measurement

Light transmittance was measured using the method of Baron and Willeke [11]. UD25UVR-2, UD36UVR-2 and Luxhytester (with a Se photocell) light meters (TOPCON, Tokyo, Japan) were used for measuring light at 250, 365 and 580 nm, respectively, at a distance of 0.05, 1, 2 and 3 m from the light source. The light sources were FA31191 (250 nm light; Matsushita Electric Ind. Co, Osaka, Japan), BLBV TCB30 (365 nm light; HYBEC Corp, Tokyo, Japan) and FL306EXN (580 nm light; Matsushita Electric Ind. Co).

Light transmittance ($T_{s,t}$), temperature and relative humidity were measured outdoors in the backyard of the clinic every morning before sunrise [sunrise varied from approx. 0500 hours (June) to 0700 hours (December)] and every evening after sunset [sunset varied from approx. 1700 hours (June) to 1900 hours (December)] when the surroundings were in darkness. Light transmittance, $T_{s,t}$, was defined as $T_{s,t} = I_{s,t}/I_{s,0}$, where $I_{s,t}$ and $I_{s,0}$ were light intensities measured at t ($t = 1$, 2 or 3 m) and 0.05 m from the light sources, respectively, at a light wavelength of s ($s = 250$, 365 or 580) nm; in practice, measurements were possible at distances of 1–3 m from the light source for the three wavelengths. T values were multiplied by 1,000 to facilitate reading. Relative humidity was measured with a hygrometer (Toyama Co, Toyama, Japan), and vapor pressure was calculated from the relative humidity and saturated vapor pressure at that temperature. The clinical records and records on climate and light transmittance were treated separately for the morning and the afternoon.

Statistical evaluation

Values of light transmittance (T), (irrespective of logarithmic transformation), temperature and vapor pressure did not follow a normal distribution when examined using the chi-square test, although the distribution of log T rather than the un-transformed T value was closer to normal. For

Table 2 Difference in light transmittance at 365 nm between the asthma and non-asthma a.m./p.m. units

Distance from light source	Observation period	Transmittance[a] at 365 nm × 1,000								*p* for difference by *t* test
		Asthma a.m./p.m.[b]				Non-asthma a.m./p.m.[b]				
		Number	GM	GSD	MED	Number	GM	GSD	MED	
1 m	The whole year	144	17.2	1.26	16.6	580	16.6	1.14	16.4	0.0084
	November 2001–January 2002	53	19.4	1.14	19.5	131	17.9	1.14	17.4	0.0003
	February 2002–April 2002	34	15.7	1.08	15.6	142	16.2	1.10	16.3	0.0657
	May 2002–July 2002	25	16.4	1.09	16.5	155	16.7	1.16	16.4	0.4983
	August 2002–October 2002	32	16.2	1.50	15.1	152	15.6	1.12	15.6	0.3630
2 m	The whole year	144	2.8	1.30	2.9	580	3.2	1.37	3.2	<0.0001
	November 2001–January 2002	53	3.1	1.17	3.0	131	3.3	1.13	3.4	0.0002
	February 2002–April 2002	34	2.8	1.14	2.9	142	3.1	1.15	3.1	0.0085
	May 2002–July 2002	25	3.0	1.33	2.7	155	3.8	1.58	3.7	0.0128
	August 2002–October 2002	32	2.1	1.37	1.9	152	2.8	1.35	2.8	<0.0001
3 m	The whole year	144	0.6	2.31	0.6	580	0.9	2.35	1.0	<0.0001
	November 2001–January 2002	53	0.8	1.55	0.8	131	1.0	1.39	1.0	<0.0001
	February 2002–April 2002	34	0.6	1.77	0.6	142	0.7	1.64	0.8	0.0165
	May 2002–July 2002	25	0.8	2.55	0.6	155	1.6	2.65	1.9	0.0006
	August 2002–October 2002	32	0.3	2.71	0.3	152	0.7	2.74	0.7	<0.0001

MED median, *GM* geometric mean, *GSD* geometric standard deviation

[a] For definition of transmittance, see "Subjects and methods"

[b] Asthma a.m./p.m., The morning (from midnight to noon of the day) or the afternoon (from noon of the day to midnight) when at least one attack took place in one or more of the 121 patients; non-asthma a.m./p.m., the morning or the afternoon when none of the 121 patients had an asthma attack

practical purposes, the distribution was expressed in terms of arithmetic means (AMs) ± arithmetic standard deviations (ASDs) together with medians (MEDs) in the case of temperature and vapor pressure. Transmittance was expressed in terms of geometric means (GMs) and geometric standard deviations (GSDs) together with MEDs. The distribution of asthma attack frequency (on the half-a-day basis) was markedly skewed by nature so that logarithmic conversion was insufficient to normalize the distribution.

The un-paired *t* test was used to detect possible significance in the difference between the values for asthma a.m./p.m. and those for non-asthma a.m./p.m. Multiple regression analysis was also conducted as necessary. When a normal distribution was not likely, the non-parametric Mann–Whitney test and Wilcoxon test (for paired data) were applied to detect a possible difference in the distribution.

Results

Comparison of *T* values at 365 nm between the asthma a.m./p.m. and the non-asthma a.m./p.m. units

The frequency of the asthma a.m./p.m. and the non-asthma a.m./p.m. units are summarized for an entire year and by the four seasons of the year in Table 2, together with the GM, GSD and MED for *T* values at 365 nm (T_{365}). The evaluation was made at distances of 1, 2 and 3 m from the light source.

At 3 m from the light source (Table 2), statistical examination on a whole-year basis by the *t* test showed that the value for asthma a.m./p.m. was significantly smaller ($p < 0.0001$) than that for non-asthma a.m./p.m. When classified by season, the difference between the pairs was significant ($p < 0.0001$) in three of the four seasons. In February–April, the difference was significant but less remarkable ($p = 0.0165$).

When the distance from light source was reduced to 2 m, the statistical difference between asthma a.m./p.m. and non-asthma a.m./p.m. persisted (Table 2). At 1 m from the source (Table 2), however, the asthma a.m./p.m. values were not always smaller than the non-asthma a.m./p.m. values, with $p = 0.0003$–0.4983. This lack of clear trend at 1 m may be due to the shorter light path.

Lack of difference in *T* values at 250 and 580 nm between the asthma a.m./p.m. and the non-asthma a.m./p.m. units

Similar calculations as those just described were conducted for a comparison of *T* values with light at 250 nm (1–3 m from the light source; Table 3) and 580 nm (at 3 m only;

Table 3 Difference in light transmittance at 250 nm between the asthma and non-asthma a.m./p.m. units

Distance from light source	Observation period	Transmittance at 250 nm × 1,000								*p* for difference by *t* test
		Asthma a.m./p.m.				Non-asthma a.m./p.m.				
		Number	GM	GSD	MED	Number	GM	GSD	MED	
1 m	The whole year	143	56.0	1.08	55.3	580	55.6	1.08	55.6	0.4112
	November 2001–January 2002	52	55.6	1.07	55.5	131	55.2	1.08	54.9	0.5453
	February 2002–April 2002	34	55.2	1.06	54.9	142	55.8	1.07	55.9	0.4415
	May 2002–July 2002	25	57.4	1.08	58.2	155	56.8	1.09	56.7	0.5544
	August 2002–October 2002	32	56.3	1.09	55.2	152	54.7	1.09	54.4	0.0872
2 m	The whole year	143	18.8	1.22	18.5	580	18.5	1.09	18.5	0.1727
	November 2001–January 2002	52	18.2	1.07	18.1	131	17.8	1.09	17.8	0.1220
	February 2002–April 2002	34	18.3	1.07	18.1	142	18.5	1.08	18.7	0.4449
	May 2002–July 2002	25	19.0	1.08	18.9	155	18.8	1.09	18.7	0.7345
	August 2002–October 2002	32	20.4	1.50	19.2	152	18.9	1.08	18.8	0.0338
3 m	The whole year	143	8.5	1.09	8.5	580	8.6	1.14	8.6	0.3820
	November 2001–January 2002	52	8.1	1.08	8.0	131	8.2	1.10	8.3	0.1670
	February 2002–April 2002	34	8.4	1.07	8.4	142	8.4	1.08	8.5	0.8789
	May 2002–July 2002	25	8.7	1.07	8.7	155	8.7	1.23	8.8	0.8947
	August 2002–October 2002	32	9.1	1.08	9.0	152	8.9	1.08	8.9	0.1769

Table 4 Difference in light transmittance at 580 nm between asthma and non-asthma a.m./p.m. units

Distance from light source	Observation period	Transmittance at 580 nm × 1,000								*p* for difference by *t* test
		Asthma a.m./p.m.				Non-asthma a.m./p.m.				
		Number	GM	GSD	MED	Number	GM	GSD	MED	
3 m	The whole year	142	53.2	1.10	53.8	571	53.6	1.11	53.8	0.4509
	November 2001–January 2002	51	53.3	1.10	53.8	123	52.9	1.10	53.8	0.6551
	February 2002–April 2002	34	54.7	1.08	57.1	142	55.3	1.10	57.1	0.5425
	May 2002–July 2002	25	53.9	1.11	57.1	154	54.2	1.10	53.8	0.7745
	August 2002–October 2002	32	51.0	1.12	50.0	152	51.9	1.12	53.8	0.3992

Table 4). As summarized in the right-most column in each table, no significant difference ($p > 0.10$) was detected between the asthma a.m./p.m. values and non-asthma a.m./p.m. values under most of the four measurement conditions.

Comparison on temperature and vapor pressure between the asthma a.m./p.m. and non-asthma a.m./p.m. units

Similar analyses as those described for light transmittance were carried out for temperature and vapor pressure between the asthma a.m./p.m. units and the matched non-asthma a.m./p.m. units (Tables 5, 6). These analyses revealed that the difference between the two groups was insignificant on a whole-year basis for temperature ($p = 0.5988$) and vapor pressure ($p = 0.1437$). When classified into four seasons, no significant difference ($p = 0.4306$ and 0.7160) was detected in two of the four seasons for temperature (Table 5). A significant difference was detected for vapor pressure in November (2001)–January ($p < 0.0001$) and February–April ($p = 0.0028$), and the value for vapor pressure for the asthma a.m. unit was higher than that for the non-asthma a.m. units; however, the trends were reversed for the two other seasons, although the differences were not statistically significant ($p = 0.3069$ and 0.5429, respectively) (Table 6).

Correlation of log T with asthma attack frequency

Simple linear regression analysis with the number of attacks on the horizontal axis and the log T on the vertical axis (Fig. 1) showed that log $T_{365,3}$ (Fig. 1c) and log $T_{365,2}$ (Fig. 1b) decreased ($p < 0.0001$ for both decreases) as a function of increasing number of asthma attacks. The decrease was more noticeable for log $T_{365,3}$ (Fig. 1c) than

Table 5 Difference in temperature between asthma and non-asthma a.m./p.m. units

Observation period	Temperature								*p* for difference by *t* test
	Asthma a.m./p.m.				Non-asthma a.m./p.m.				
	Number	AM	ASD	MED	Number	AM	ASD	MED	
The whole year	142	17.1	6.95	17	576	17.5	7.83	18	0.5988
November 2001–January 2002	53	11.7	4.12	12.5	130	8.9	3.53	9	<0.0001
February 2002–April 2002	33	15.4	5.21	15	141	12.3	5.05	12	0.0018
May 2002–July 2002	24	23.8	3.74	23	153	23.5	3.76	24	0.7160
August 2002–October 2002	32	22.8	5.54	23	152	23.5	4.70	24.5	0.4306

AM arithmetic mean, *ASD* arithmetic standard deviation

Table 6 Difference in vapor pressure between asthma and non-asthma a.m./p.m. units

Observation period	Vapor pressure								*p* for difference by *t* test
	Asthma a.m./p.m.				Non-asthma a.m./p.m.				
	Number	AM	ASD	MED	Number	AM	ASD	MED	
The whole year	142	18.4	7.37	17.3	576	19.6	8.67	18.8	0.1437
November 2001–January 2002	53	12.8	3.34	12.7	130	10.6	2.55	10.0	<0.0001
February 2002–April 2002	33	16.2	4.45	16.0	141	13.6	4.24	13.1	0.0028
May 2002–July 2002	24	25.4	5.57	24.1	153	26.2	5.62	24.9	0.5429
August 2002–October 2002	32	24.8	6.69	23.7	152	26.2	6.54	26.8	0.3069

for log $T_{365,2}$ (Fig. 1b). In contrast, the change in log $T_{365,1}$ as a function of the asthma attacks was minute with an insignificant increasing trend ($p = 0.143$).

Analysis of variance (ANOVA) followed by multiple comparison test (Scheffé) was performed to examine the decreasing trend in log ($T_{365,3} \times 1{,}000$) in Fig. 1c where the decay was most remarkable. As the numbers of a.m./p.m. cases with three and four attacks were small, namely, five and one, respectively, the trend was examined after combining cases of three and four attacks together (i.e. $3 + 4$; $n = 6$) or with the addition of cases with two attacks (i.e., $2 + 3 + 4$; $n = 39$). With Groups 0, 1, 2 and $3 + 4$, the p for ANOVA was <0.0001. The Scheffé test showed that the decrease in log ($T_{365,3} \times 1{,}000$) from Group 0 to Group 1 and that from Group 0 to Group 2 were statistically significant ($p < 0.0001$). When Groups 0, 1 and $2 + 3 + 4$ were compared ($p < 0.0001$ for ANOVA), the decrease from Group 0 to Group $2 + 3 + 4$ was significant ($p < 0.0001$) in addition to that from Group 0 to Group 1.

Identification of influential factors on asthma attack frequency

In order to identify factors that had a large effect on the frequency of asthma attacks, multiple regression analysis was performed taking the logarithm of ($T_{365,3} \times 1{,}000$), temperature, vapor pressure and a.m./p.m. (a.m. = 1, p.m. = 0) as four independent variables and asthma attack frequency (in a range of 0–4) per half-day unit (i.e., a.m. or p.m.) as a dependent variable (Table 7). The results of these analyses suggest that log ($T_{365,3} \times 1{,}000$) was a factor significantly influential to asthma attacks frequency among the four parameters tested but that temperature or vapor pressure were not. a.m./p.m. was also a significantly influential factor. Analysis with the Mann–Whitney test showed that there was a significant difference ($p < 0.0001$) in asthma attack frequency and that the attacks came more frequently in the afternoon (p.m.) than in the morning (a.m.). However, the R^2 for this difference was as small as 0.075, although the correlation coefficient ($r = 0.274$) was statistically significant ($p < 0.0001$), probably due to the large number of cases ($n > 700$).

To examine further the significant difference between the a.m. and p.m. units in terms of asthma attack frequency in relation to $T_{365,3}$, the total observation period was classified into the four seasons of the year, and the frequency of asthma attacks and $T_{365,3}$ were evaluated (Table 8). As the distribution of asthma attack frequency was extremely skewed (Fig. 1), the maximum attack per half-day and the sum of the attacks per season were taken as the representative parameters. $T_{365,3}$ was presented after logarithmic conversion in terms of GM and GSD. Whereas the sum for p.m. (i.e., 135 attacks) was almost twofold higher than that for a.m. (69 attacks), the comparison by four seasons had a significance of $p = 0.0656$ when examined by the

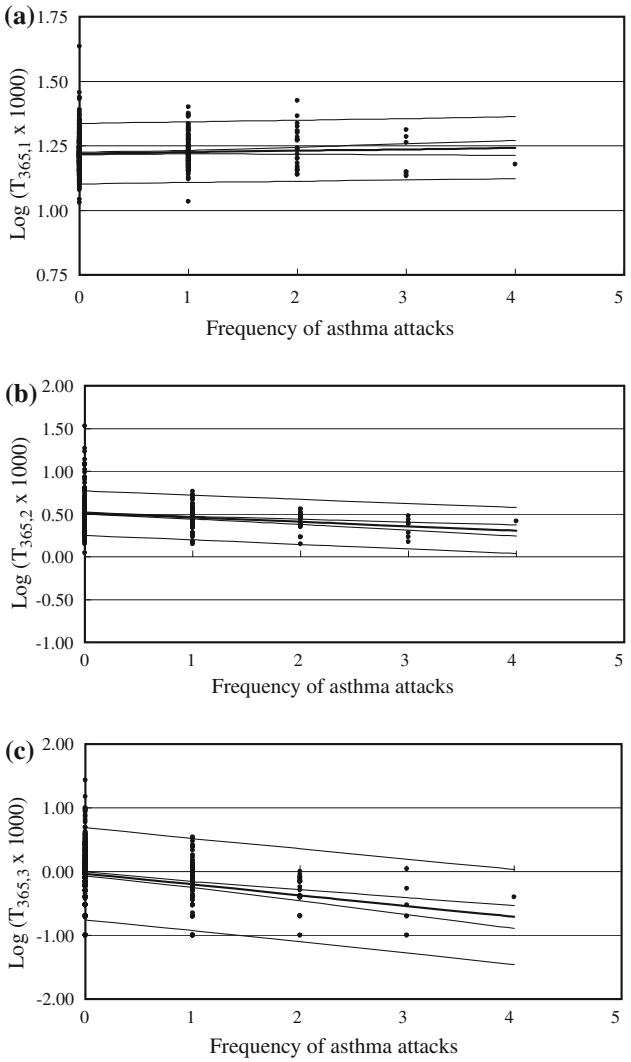

Fig. 1 Simple regression analysis of the decrease in light transmittance at 365 nm (T_{365}) as a function of increasing number of asthma attacks. The number of asthma attacks among 121 asthmatic child patients was counted for 1 year on a half-day basis, i.e., in the morning and in the afternoon, respectively. T_{365} at distances of 1, 2 or 3 m from the light source (**a**, **b**, and **c**, respectively) was measured twice a day, before sunrise and after sunset, respectively, and the T_{365} values were multiplied by 1,000 to facilitate reading. *Darker middle line* Calculated regression line, *two lines immediately above and below middle line* 95% confidence limits for the mean, *two outer-most curves* 95% limits for the individual values. *Each dot* shows one case. The equation for the calculated regression line is $Y_1 = 1.22 + 0.006X$ ($r = 0.055$, $p = 0.1427$) (**a**), $Y_2 = 0.51 - 0.051X$ ($r = 0.217$, $p < 0.0001$) (**b**), and $Y_3 = -0.033 - 0.170X$ ($r = -0.237$, $p < 0.0001$ (**c**), where X the number of asthma attacks in a half-day and $Y_i = \log (T_{365,i} \times 1{,}000)$ ($i = 1$, 2 or 3). Note the heavy congestion of dots on the *vertical axis* (i.e., $X = 0$). The numbers of cases for $X = 0$, 1, 2, 3 and 4 are 583, 112, 24, 4 and 1, respectively, with a total of 724 cases

Wilcoxon test. The comparison of four pairs of GMs for $T_{365,3}$ by the same test also gave $p = 0.0679$, indicating borderline significance.

Discussion

The results of the present study over an entire year period show that the $T_{365,2}$ and $T_{365,3}$ values were significantly lower during those a.m./p.m. units when children had asthma attacks than during those when there were no attacks (Table 2). This observation suggests that the density of air-borne fine water particles correlate with asthma attacks. This study is therefore the first one to report a quantitative relation between fine water particle density and asthma among children. The difference was, however, insignificant when $T_{250,1-3}$ or $T_{580,3}$ was subjected to similar analyses (Tables 2, 3).

Kanaya [10] analyzed weather charts and vapor pressure variation in relation to asthma attacks among his asthmatic pediatric patients. Based on the analyses, Kanaya hypothesized that air-borne fine water particles induce asthma attacks among asthma patients. The effects of climate factors on asthma attacks among children have been a focus of attention for many years, with Anderson et al. [9] reporting in 1983 that fine water particles produced by ultrasonic nebulization induced asthma attack among children. In line with the hypothesis of Anderson et al., Kashiwabara et al. [14] observed that the visits of children with bronchial asthma to a clinical emergency department(s) increased significantly on misty or foggy nights, suggesting that air-borne fine water particles may stimulate bronchoconstriction and induce asthma. In contrast, Weiland et al. [15] summarized the results of a large-scale questionnaire survey and reported that annual variation in outdoor temperature and relative humidity was negatively associated with asthma symptoms among children. Similarly, Nastos et al. [16] reported that pediatric asthma admissions to three main children's hospitals in Athens, Greece, were correlated negatively with air temperature and absolute humidity (implying vapor pressure) and positively with cooling power (a sensation scale) and relative humidity.

Studies on the relation between asthma attacks and climate conditions are still limited in Japan [17], where the climate is generally rather warmer and more humid than in Europe or North America. Ito et al. [18] early in 1990s observed that emergency asthma visits in large hospitals were more frequent when temperature and vapor pressure (recorded by local meteorological observatories) were high, and that the observation was reproducible in two cities of different geographical locations in Japan. Similarly, Tanaka et al. [19] found that naturally occurring acid fog increased hospital visits of adult asthmatic patients and that the fog effects were more evident among non-atopic asthmatics than among atopic patients. They added that gaseous air pollutant levels were lower on foggy days than on fog-free days. Considering the possible implication on the present observation, however, the effects of climate

Table 7 Factors influencing asthma attack frequency

Dependent variable	Independent variables				R^2	r	(p for r)
	Log ($T_{365,3}$ × 1,000) SRC (p)	Temperature SRC (p)	Vapor pressure SRC (p)	a.m./p.m. SRC (p)			
Asthma attack frequency	−0.197 (<0.001)	0.114 (0.518)	−0.947 (0.344)	−0.152 (<0.001)	0.075	0.274	(<0.01)

SRC standardized regression coefficient

Table 8 Asthma attack frequency and transmittance at 365 nm

Observation period	Asthma attack frequency				Transmittance at 365 nm × 1,000			
	a.m.		p.m.		a.m.		p.m.	
	Maximum	Sum	Maximum	Sum	GM	GSD	GM	GSD
The whole year	3	69	4	135	0.95	2.23	0.85	2.38
November 2001–January 2002	3	33	3	39	0.92	1.49	0.90	1.47
February 2001–April 2002	3	13	4	29	0.71	1.65	0.64	1.75
May 2002–July 2002	1	7	2	23	1.60	2.59	1.37	2.74
August 2002–October 2002	2	16	3	44	0.79	2.57	0.65	2.97

Medians and minima for number of asthma attack per a.m./p.m. were all zero in the four seasons of the year

The a.m. and p.m. difference in the sum of asthma attack frequency in each of the four seasons, and the difference in seasonal GM of the transmittance at 365 nm were of borderline significance (p = 0.06–0.07) when examined by Wilcoxon test

(e.g. temperature) and air pollutants (e.g. ozone) may be different between the child and adult asthmatic patients [7]. Nevertheless, Kashiwabara et al. [14] confirmed that the visits of asthmatic children to an emergency room of a hospital were significantly more frequent at foggy or misty nights.

Kashiwabara et al. [20] analyzed the relation of visits by asthmatic children and meteorological factors on foggy or misty nights and compared these with such factors on fine nights. They not only confirmed their previous observation [14], but went further to suggest that the saturated density of airborne water droplets may stimulate bronchial constriction to provoke asthma attack. Probably implying the same, Hashimoto et al. [21] found that the number of visits per night of children (due to asthma attack) to an emergency room in a large urban hospital was elevated when there was a rapid decrease in barometric pressure, temperature and humidity as well as low wind velocity. In this sense, it is highly probable that $T_{365,3}$ and $T_{365,2}$ are the measures of density of fine water particles in air which may induce asthma attacks among children. $T_{365,1}$ may not be a reliable measure simply because of the shorter light path.

There are several limitations to the present study. The most important of these are that only 121 pediatric patients were studied and the survey covered only 1 year. Thus, although asthma attack tended to come more frequently in the afternoon (possibly at night) rather than in the morning, as the multiple regression analysis showed, attacks in the morning and those in the afternoon could not be analyzed separately from each other if sufficient statistical power was to be achieved in the analysis. It may have been possible to treat the data on the morning and afternoon cases separately if the study had been conducted for 2 years (rather than 1 year), but the longer time period was not possible due to practical reasons, including limitations in personnel.

Due to technical limitations, the measurement of light transmittance was possible only when the surroundings were in darkness. This necessitated that the transmittance be measured before sunrise or after sunset, i.e., early in the morning and late in the evening. The T values thus obtained were taken as representative for the half-day unit (i.e., a.m. or p.m.). Nevertheless, it is also conceivable that the transmittance (and therefore possibly the fine water particle density) may vary depending on the time of the day (i.e. daytime and night), thereby inducing a limitation on the measured transmittance being representative of half-day conditions.

The number of patients may be small when compared with those in some other studies, such as that performed by Ito et al. [18] in which several thousand cases were studied. However, the number of patients in other studies such as that by Tanaka et al. [19] was only comparable to that of the present study. The relatively small number of cases was primarily due to the fact that the study was based on patients in a private clinic; however, the bond between the treating physician (i.e., K.K.) and patients was quite close so that there was only a very small risk for cases that would

remain unreported and uncounted. As such, one major advantage of this study is that the time of attack was carefully identified in the medical history so that the light transmittance at the time of attack could be compared with the time of the attack onset. The time of the visit may differ from the time of the onset of the attack. Clinical experiences show that the lapse in time between the initiation of attack and the visit to a clinical facility varies substantially, from within half a day to over 2 days. This difference may explain, at least to some extent, the existing differences in the conclusions drawn by researchers on the relation of asthma attack and climate conditions.

As discussed above, based on his estimations of the density of air-borne particles (assumed to be fine water particles or mist), Kanaya [10] proposed a close association between the density of these particles and the frequency of asthma attacks among pediatric patients of asthma. The decay in the transmittance of light due to the presence of air-borne particulate matters is known to depend both on the wavelength of light and on the size of the particles concerned and that it will be modified as a complex function of absorption, scattering, refraction and other factors [11].

Because the characteristics (including size) of the air-borne particles under study remains unknown, light of various wavelengths (250, 365 and 580 nm) was employed in the present study. Of these, T_{365} (transmittance of light at a wavelength of 365 nm) and $T_{365,3}$ (or T_{365} at 3 m from light source) in particular showed a close relation with asthma attack frequency (because the distance from light source should affect the decay in transmittance), but T_{250} or T_{580} did not (e.g., Tables 2, 3, 4; Fig. 1). This observation suggests that air-borne particles (assumed to be water particles [10]) of certain diameters may play an important role in provoking asthma attacks. To estimate the particle sizes, however, experimental studies are necessary with monochromatic light of various wavelengths, and measurements should be conducted under strict conditions [11]. Such research is beyond the scope of the present study, and further elaborations are apparently necessary to explain the observed correlation and to determine the effect of particle size.

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