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The Relation between Ambient Temperature and Asthma Exacerbation in Children: A Systematic Review

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Abstract

Background: Asthma is one of the most common chronic non-communicable diseases which is seen more in the developed than developing countries of the world. Recurrence and exacerbations of the disease are common among patients and often lead to hospitalization and therapeutic interventions. Ambient air temperature might be related to the relapse of asthma. This review was conducted to investigate the relation between ambient temperature and exacerbations of asthma in children.

Methods: Related articles were searched in PubMed, Web of Science, Science Direct, and Scopus databases with appropriate keywords and no specific limitation on October 1, 2018. Initially, the relevance of the articles was examined using the title and abstract. Out of 2633 articles, 23 articles were eligible according to the inclusion and exclusion criteria.

Results: Fourteen studies had reported inverse relations; and showed as the temperature dropped, the number of asthma attacks increased in children. Nine papers observed a relation between hot weather and asthma attacks, 3 studies reported a relation between temperature differences and asthma attacks, and two studies did not show any relation. Some studies suggested the increased incidence of asthma in the 5-14 year old age group was associated with the start of the school year and probably due to the spread of viral diseases, not temperature changes.

Conclusion: Extreme temperatures are likely to cause exacerbation of childhood asthma.

Introduction

Asthma is one of the most common chronic airway and non-communicable diseases worldwide and its prevalence has increased in recent years[1]. This disease is characterized by chronic inflammation and obstruction of the airways. According to the WHO report, 235 million people suffer from this disease[2].

Recurrence and exacerbations of this disease are common among patients, which often leads to hospitalization and therapeutic interventions for improving lung function[3]. Several studies have been conducted to investigate the relation between air pollutants such as ozone and fine particulate matter and the progression and exacerbations of asthma. There is also evidence that exposure to environmental factors such as ambient temperature is associated with recurrence of asthma[4], and even deterioration and death due to respiratory failure[5, 6].

Average global temperature has increased 0.85 ∘C , between

1880 and 2012[7]. Nowadays all world countries are affected by global warming and its effect is not limited to a specific region of the world[8].

Air temperature may directly or indirectly be related to the recurrence of asthma. Cold air may directly affect airways and cause hyper-responsiveness. It might also indirectly trigger asthma by predisposing people to viral diseases, or air pollution. Air conditioners used in warm weather may also trigger the recurrence of asthma[9]. Several studies have been conducted in different countries to investigate the relation between ambient temperature variations and the incidence and/or recurrence of asthma. Studies have reported clusters of asthma recurrence and hospitalization in some seasons[10]. Children are one of the sensitive groups affected by environmental factors. These factors might cause asthma recurrence and hospitalization in sensitive children[11].

Understanding the environmental factors that trigger asthma recurrence and hospitalization in children can help prevent these attacks by modifying lifestyle or reducing exposure to these environmental factors[12]. Various studies have reported different results about the role of ambient temperature on the occurrence of asthma. These studies have been conducted in different geographic, social and racial regions and have examined the effect of low or high temperatures, or heat/cold waves, on the exacerbation of asthma[13, 14]. These studies have reported various associations and it is necessary to provide an overall conclusion from these studies to help public health policymaking. Although a systematic review was recently conducted about ambient temperature and childhood asthma by Xu et al[15], but this review did not include some articles[4, 16-29].

This review study was conducted to investigate the relation between ambient temperature and asthma focusing on recurrence and exacerbation of the disease in children.

Materials & Methods

Inclusion Criteria

Studies were included in this review if they had considered at least one temperature index as an exposure, had evaluated the age group under 17 years separately, the outcome was investigated in humans, and recurrence or hospitalization due to exacerbation of asthma was reported as a consequence. Also, papers were included which had included at least one year data.

Search Strategy

PubMed, Web of Science, Science Direct, and Scopus databases were searched for relevant articles. No time limit was implemented.

The keywords "temperature", "weather", "climate"," heat", "hot", "cold" and "ambient temperature" were used as exposure terms and "hospital*","admission*", "emergence*", "exacerbation" and "asthma" were used as outcome terms. The final search was done on October 1, 2018. In order to retrieve all related articles which included various age groups, we did not use "Children" as a keyword. Hence, we screened full-text articles to see if they had included children as a separate category.

Study selection

After searching different databases, the titles and abstracts of the retrieved articles were imported into EndNote software and duplicates were removed based on title, author and year of publication.

Initially, the relevance of the articles was examined based on title and abstract. Out of 2633 articles, 88 were selected for full-text evaluation. The full-text articles were evaluated using the inclusion and exclusion criteria.

The author's name, study period, population size, type of study, type of exposure variable and outcome, statistical analysis, and the main results were extracted from the finally selected articles.

Due to the differences in study methodologies, statistical analysis, and different temperature indices, conducting a meta-analysis was not possible.

Result

After screening through several steps, shown in Figure 1, 23 articles were selected for the review.

The characteristics of these articles are summarized in Table 1. The studies were from different parts of the world including Europe, America and Asia, but no study was conducted in Africa. The studies had been conducted in 12 countries.

In order to further examine the geographical distribution and the characteristics of the area in which the studies were conducted, the Köppen-Geiger climate classification was used, which includes 5 climate zones (figure 2). Three of the studies had been done in the equatorial region[17, 21, 22]. There were no studies from the arid and polar regions. The remaining studies were from the warm-temperate[4, 12, 16, 19, 20, 23-26, 28-35] and snow regions[18, 27, 36].

The studies included between one to nineteen years data. Studies had used different variables for measuring ambient temperature. Daily minimum, maximum and mean temperatures were the most common variables used in 16 studies[4, 12, 16-19, 21, 22, 24, 25, 28, 29, 31, 32, 34-36] followed by monthly minimum, maximum and mean temperature in 5 studies[20, 23, 26, 30, 33] and one article used hourly meteorological data[27].

Different definitions had been used to define the

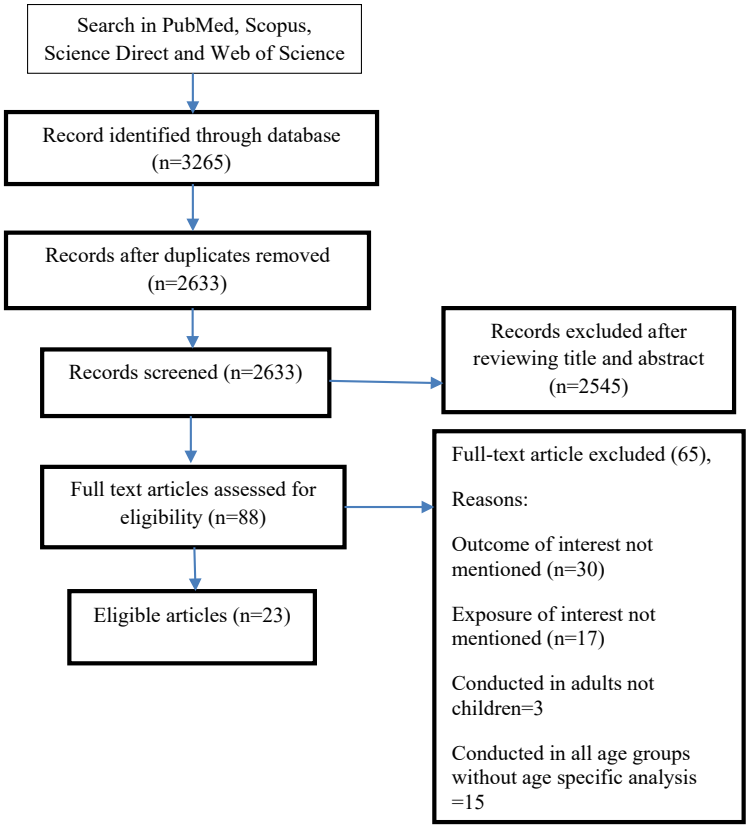

Figure 1: Search results and study selection

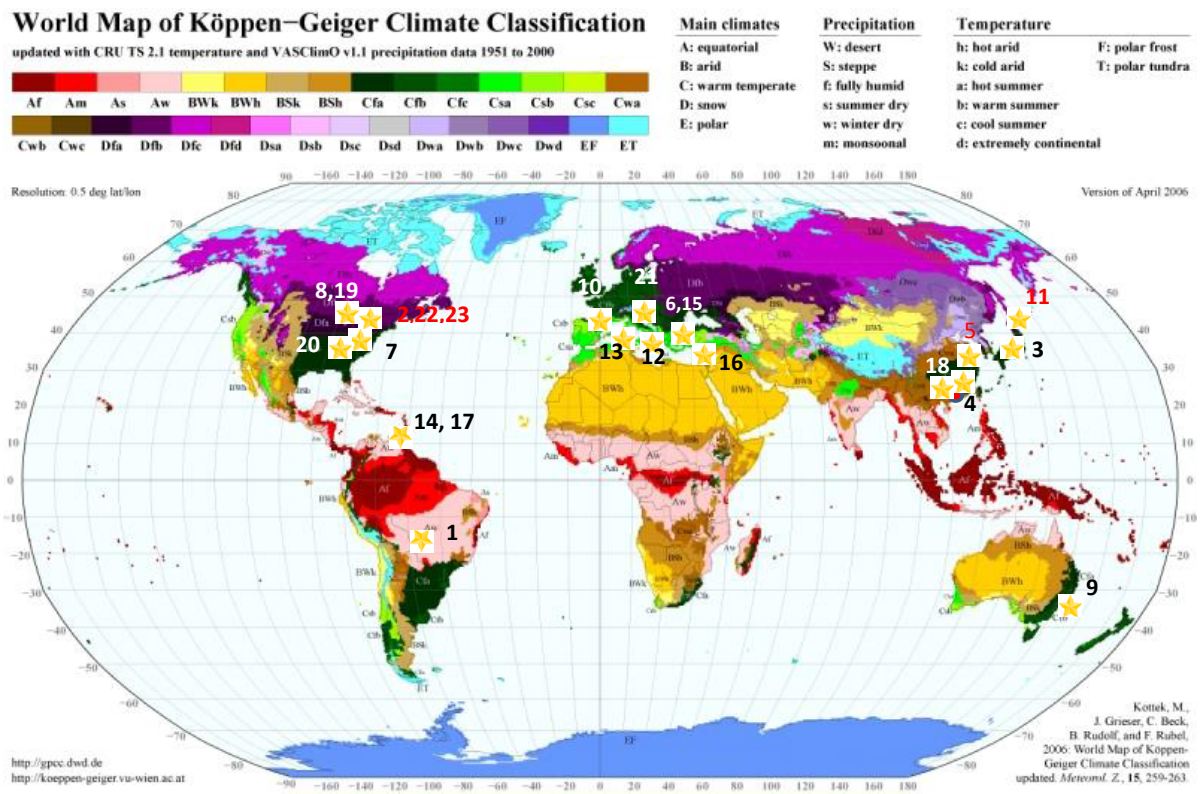

Figure 2: Distribution of studies across five Köppen Geiger climate zones (A–E). Study numbers on the map are defined in Table 1.

Table 1. Summary of the studies included in this systematic review

ID	First Author Year, location	Population size	Study period	Ages	Outcome definition	Exposure definition	Study type	Köppen–Geiger Climate Classification	Dominant gender	Lag time	Other variables included	Statistical analysis	Main results
1	De Souza, 2015, Brazil(17)	5844	2008-2010	<9	ICD10-(J45)	Daily Mean Temperature (DMT)	Ecologic	A	NR	0-30	Humidity, Rain fall, Wind Speed, O_3	Pearson Correlatio	Daily hospital admissions showed significant negative correlations with DMT (r=−0.214, *P<0.001*),
2	Fitzgerald, 2014, USA(4)	396043	1991-2007	<17	ICD9-(493.00)	Daily Mean Temperature	Ecologic	C	Female	0-4	PM2.5-Sex -Race	GAM	Decrease in admissions during a cold spell in the winter months for all subgroups. A mean decline of 4.9 % in asthma admissions happened statewide (95 % CI -7.8, -1.9 %).
3	Hashimoto, 2004, Japan(12)	5559	1998-2002	2-15	Physical findings such as dyspnea with wheezes	Daily Min, Max and Mean Temperature	Ecologic	C	NR	3	Barometric Pressure, Humidity/Vapor Pressure, Wind Speed	Logistic Regression	The rapid decrease of temperature within a 3-day period can increase the risk of asthma attacks. β=0.05, CI= 0.02–0.07
4	Lam, 2016, Hong Kong(31)	2402	2004-2011	<15	ICD9-(493.00)	Daily Mean Temperature	Time -Series	C	NR	20-30	Air Pollutants, Solar Radiation, Wind Speed	GAM, DLNM	Asthma admissions increased at high temperatures in the hot season and at low temperatures in the cold season RR=1.19
5	Liu,2007, China(23)	445	2000-2004	0-14	Diagnosis by clinicians	Monthly Mean Temperature	Historical Cohort	C	Male	NR	Air Pressure, Relative Humidity, Wind Speed	Linear Regression Analysis	Higher incidence was related with lower temperature, (r =-0.320 , P < 0.05)
6	Nastos,2006, Greece(24)	2764	2001-2003	0-14	Admitted with the diagnosis of “asthma”, “asthmatic bronchitis” or “wheezy bronchitis”	Daily Min, Max and Mean Temperature, Diurnal Temperature	Time-Series	C	Male	NR	Water Vapor Pressure and Cold Anti Cyclonic	Pearson Correlation	Low temperature, significantly correlated with an increase in the number of asthma admissions
7	Soneja,2016, USA(34)	119523	2000-2012	<17	ICD9-(493.00)	Daily Max Temperature, Extreme Heat	Case-Crossover	C	Female	0-2	Sex, Race	Conditional Logistic Regression	Exposure to extreme heat events was associated with a 3 % increase in the risk of hospital admission for asthma (Odds Ratio: 1.03)

8	Wasilevich, 2012, USA(27)	4804	2000-2001	3-18	ICD9-(493.00–493.99	Hourly Min, Max and Mean Temperature	Case-Crossover	D	Male	NR	Relative Humidity, Barometric Pressure, Wind Speed, Thunderstorm Activity and Air Pollutant	Conditional Logistic Regression	The case crossover study showed a statistically significant inverse relation between ED visits and maximum 24-hour temperature change after adjustment for climatic factors, RR=0.972, P = 0.01
9	Xu,2013, Australia(35)	13324	2003-2009	0-14	ICD10-(J45)	Daily Min , Max and Mean Temperature	Ecologic	C	Male	0-1, 0-13, 0-21	PM10, 03	Poisson Linear Regression	Male children and children aged 0–4 years were particularly sensitive to hot temperature (RR= 1.61 CI=1.22 to 2.14), and children aged 10–14 years were particularly sensitive to cold temperatures (RR=1.96 ,CI=1.03 to 3.50)
10	Altzibar, 2015, Spain (16)	59500	2004-2009	<15	ICD9-(493.00)	Daily Min , Max and Mean Temperature	Ecologic	C	Male	NR	Age, Sex, Air Pollutant, Relative Humidity and Flu Status	Pearson Correlation	Asthma exacerbations were correlated negatively with temperature. (r=-0.485 CI=-0.543;-0.423)
11	Ehara,2000, Japan(18)	205	1997	1-16	Asthmatic symptoms, such as wheezing and expiratory stridor	Daily Diurnal Temperature	Ecologic	D	Male	1	Barometric Pressure and relative Humidity	Mann–Whitney U-test	Diurnal difference between maximum and minimum temperatures of 1 day before admissions was larger than that of 1 day before days with no admissions P=0.02
12	Grech,2002, Malta(20)	2916	1994-1998	0-59	Diagnosis of asthma or wheezy bronchitis	Monthly Min , Max and Mean Temperature	Ecologic	C	NR	NR	Age Group	Spearman Correlation	Ranked mean monthly ambient temperatures correlated significantly with monthly admissions in the pediatric cohort (r= -0.71, p<0.0001)
13	Hervas,2015, Spain(30)	371	2007-2011	5-14	ICD9-(493.0-493.9)	Monthly Min, Max and Mean Temperature	Longitudinal Retrospective	C	Male	30-60	Water Vapor Pressure, Relative Humidity	Multivariate linear Regression	The Regression equation showed a 7.3% increase in the number of monthly asthma exacerbations for each degree decrease in temperature. (β=27.2, P<0.0001)
14	Ivey,2003, Trinidad and Tobago(22)	45842	1997-1999	0-65	Diagnosis of acute asthma and received bronchodilator nebulization	Daily Min and Diurnal Temperature	Ecologic	A	NR	1	Relative Humidity, , Barometric Pressure, Wind Speeds	Multiple Regression	Results of multiple regression indicated that temperature difference (P<0.001), and minimum temperature (P<0.001) were predictors of pediatric visits
15	Nastos,2008, Greece(33)	NA	1978-2000	0-14	Diagnosis of “asthma,” “asthmatic bronchitis” or ”wheezy bronchitis,”	Monthly Diurnal Temperature	Ecologic	C	NR	0-3	Relative Humidity, Absolute Humidity and Wind Speed	Generalized Linear Models	There was a negative relation mean monthly air temperature and asthma admissions in the age group 0 -4 years (B= −0.0376, P= <0.0001)

16	Garty,1998, Israel(19)	1076	1993	1-18	Diagnosed as having an acute asthma attack	Daily Min and Max Temperature	Ecologic	C	Male	NR	Barometric Pressure, Relative Humidity, Air pollutant	Pearson Correlation	ER visits showed a negative correlation with minimal temperatures (r = -0.45) and maximal temperatures (r = -0.41)
17	Ivey,2001, Trinidad and Tobago(21)	27848	1997	<16	Diagnosis of acute asthma and received bronchodilator nebulization	Daily Mean Temperature	Retrospective Ecologic Study	A	Equal	NR	Rainfall, Relative Humidity, Sex	Multiple Regression	Increased asthma visits in children were associated with increased temperature β= 0.14270, P= 0.009
18	Li,2016, China(32)	17022	2007-2013	0-14	Diagnosis by clinicians	Daily Min, Max and Mean Temperature and TVN*	Ecologic	C	Male	10	Sex, Relative Humidity	Poisson Generalized Linear Regression	A 1° C increase in temperature variation was associated with a 4.2% (95% CI 0.9-7.6%) increase in the number of hospital visits for childhood asthma
19	Mireku, 2009, USA (36)	25401	2004-2005	0-18	Diagnosis by clinicians	Daily Min, Max and Mean Temperature	Retrospective Ecologic Study	D	NR	0-5	Humidity, Barometric Pressure, Air pollutant	Time series	Interday changes in temperature from 1 day before asthma attack increased ED visits, with a 10°F increase being associated with 1.8 additional visits (P = 0.006).
20	O'Lenick, 2017, USA(25)	NR	1993-2012	0-19	ICD9-(493.0-493.9)	Daily Min, Max and Mean Temperature	Ecologic	C	Male	0-7	Sex, Race, Insurance Status	Poisson generalized linear models	Estimated RRs for T max and pediatric asthma ED visits were positive and significant for lag days 1–5, with the strongest single-day association observed on lag day 2 (RR=1.06, 95% CI: 1.03, 1.09)
21	Zaninovic, 2001, Croatia (29)	84	1984	Not Reported	Not Reported	Daily Min, Max and Mean Temperature	Ecologic	C	NR	0-7	Humidity, Barometric Pressure and Wind Speed	Spearman Correlation	Negative correlation coefficients between asthmatic attacks and mean, maximum and minimum air temperatures appeared on most days. The results considered together point at cold, clear and dry winter anticyclonic situations as dangerous for the asthmatics
22	Palusci, 1998, USA (26)	6741	1991-1995	<18	Not Reported	Monthly Min, Max and Mean Temperature	Historical Cohort	C	NR	NR	Dew point, Relative Humidity, Barometric Pressure and Wind Speed	Multiple Regression	No effect was seen with an average temperature
23	Witonsky, 2018, USA(28)	43729	2001-2008	All age groups	ICD9-(493.00)	Weekly Mean Temperature	Ecologic	C	NR	NR	NO2,O3,PM2.5, SO2, recipitation, air pressure, humidity, tree pollen, grass pollen, and weed pollen	Spearman Correlation	In pediatric patients, the multivariate coefficients for temperature and asthma related emergency department visits in the full year was –0.351 and in fall was–0.335

* TVN: Temperature variation between neighboring days
*NR: Not Reported

outcome in different articles. Although all studies were conducted after the release of the Ninth Revision of the International Classification of Diseases, only 8 studies had used ICD9[4, 16, 25, 27, 28, 30, 31, 34]. Five studies had used code 493.00 and 3 studies had used code 493.00 to 493.99. Also, two studies had used ICD10- (J45) as the outcome variable[17, 35]. The rest of the studies measured outcome based on physicians' assessment, the presence of asthma-related symptoms and the administration of nebulized bronchodilators. Two studies did not report how the asthmatic attack was diagnosed[26, 29].

The results of 10 studies showed that the number of cases of asthma exacerbation was higher in boys than girls, while two studies reported a higher number of cases of asthma in girls than boys[4, 27], and one study reported an equal number of cases[36].

Studies had considered different lag periods between exposure and outcome, which varied from 0 to 60 days, but 8 studies did not include lag time[19-21, 23, 24, 26-28]. In many studies, the temperature was not the only risk factor considered; and demographic factors such as sex, race and meteorological factors such as barometric pressure, relative humidity, wind speed, rainfall and air pollutants, such as PM_{10}, $PM_{2.5}$, O_3, NO_X, were also examined. But these variables were different in different studies.

Fourteen studies were simple ecological studies, and two were case-crossover studies[27, 34]. Two studies had used the time-series method[24, 31]. Seven studies had used correlation coefficients [16, 17, 19, 20, 24, 28, 29] and four studies had used relative risks to examine the relation between air temperature and asthma exacerbations[12, 25, 27, 31].

Fourteen studies had reported a relation between cold temperature and recurrence of asthma and showed as the temperature dropped, the number of asthma attacks or the number of visits to hospitals for asthma increased in children [12, 16, 17, 19, 20, 24, 28-35]. Nine papers observed a relation between hot weather and asthma attacks[4, 18, 21, 22, 25, 31, 32, 35, 36], and 3 studies reported a relation between temperature differences and asthma attacks [13, 18, 34]. Two studies did not show any relation between asthma attacks and temperature variables[26, 27].

Studies in Malta and Spain showed that the increase in the incidence of asthma in the 5-14 age group was associated with the school re-opening season, and with a two-week lag after the start of the school year, recurrence of asthma increased in this age group[19, 20, 22, 30].

Among the papers reviewed, 11 papers had examined the effect of seasons on the recurrence of asthma in children. Based on the Köppen–Geiger Climate Classification 16 studies were conducted in a warm-temperate climate[4, 12, 16, 19, 20, 23-26, 29-35]. Three articles were from the equatorial region[12, 25, 34] and three articles were from the snow region[13, 18, 37]. Study results were different, but mainly the highest frequency of asthma occurred in autumn and spring[4, 16, 20, 22, 24, 26, 28, 30, 34-36].

According to the World Economic Situation and Prospects[38], most studies (16 studies) had been conducted in developed countries; including Croatia, the US, Japan, Australia, Greece, Malta and Spain; and seven studies had been conducted in developing countries, including China, Trinidad and Tobago, Hong Kong, Israel and Brazil[17, 19, 21-23, 31, 32], while no study had been conducted in less developed countries.

Discussion

Most of the studies showed that extreme ambient air temperature has a relation with the recurrence or hospitalization of children due to asthma. For example, in Tokyo, as temperature decreased[12], and in New York, as temperature increased, the incidence of asthma attacks in children increased[4]. The average daily temperature in Tokyo is 11 ˚C, while in New York City during cold spells it is -15 ˚C[4] and New York has colder winters in comparison to Tokyo. Probably children with asthma during the winter season and during the cold spell, because of medical orders, changed their behavior and were less likely to expose themselves to the cold environment or use a mask to prevent asthma attacks.

Cold and hot temperatures affect the respiratory system through different mechanisms. Warm weather may cause microorganisms, mites and cockroaches to grow in the interior of human dwellings, or warm air can cause increased air pollution such as an increase in ozone and PM_{10}. This, maybe one of the factors associated with inflammation of the respiratory tract and the recurrence of asthma.

Studies have also shown that cold and dry air increases the risk of airway inflammation, reduces lung function and reduces lung capacity[37, 39-41]. Cold weather can decrease moisture in the mucosal membrane of the respiratory tract, predispose it to irritation by allergens, cause sensitivity to viral and bacterial infections and increase the risk of asthma attacks[42].

Studies conducted in Japan and America reported a direct relation between temperature changes, one day before the recurrence of asthma in children[18, 24, 26, 27, 29, 35, 36]. But, children under 5 years of age were less likely to be affected by air temperature changes due to less contact with the outside and environmental triggers[31, 34, 35].

However, the high recurrence rate of asthma in school age children can be due to temperature changes and the transition from summer to autumn and due to the easier transmission of respiratory diseases after school opens. Respiratory pathogens in these children affect the relation

between air temperature and the recurrence of asthma. Students can transmit these respiratory diseases to other family members, and a recurrence of asthma may be seen in other age groups as well[16, 20, 22, 30].

The reason for the difference in recurrence of asthma in different times of the year can be due to the effects of various climatic or demographic variables, air pollutants, viral infections, and indoor aeroallergens[43]. In spring, the increased incidence of asthma may be related to fungal spores and pollen grains, while in autumn it may be due to rapid changes in temperature[44, 45].

Most of the studies used in this review were ecological studies and one of the limitations of these studies was the assumption that the level of exposure was equal throughout the population and in different social and economic classes; and as well as the amount of time spent outdoors, and the use of air conditioner, heater and humidifiers. Also, in these studies, the reference population of patients visiting the hospitals under investigation was not clear. Only two studies used postal codes to determine the patients› location of residence and excluded children who were not living in that area[34, 36].

Another limitation was not using the same patient classification system in the studies, as only 10 studies used the International Classification of Diseases[4, 16, 17, 25, 27, 30, 31, 34, 35]. Other studies used physician's assessment, the presence of asthma symptoms, or a history of using asthma drugs; for diagnosing asthma attacks. Two studies did not report the criteria used for diagnosing asthma attacks[26, 29].

Conclusion

Ambient air temperature is probably related to the recurrence and hospitalization of child asthmatic patients. The results of some studies have shown that extremely hot and cold temperatures both increase the incidence of asthma in children. However, hot and cold temperature cause asthma attacks through different mechanisms.

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