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Evaluation of indoor air pollution in children with asthma

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ABSTRACT

OBJECTIVE: The unfavorable effects of air pollution on respiratory health have been shown in many studies. Exposure to air pollution can lead to developing asthma and losing control over existing asthma. In this study, we aimed to evaluate the investigation of indoor air pollution in children with asthma.

METHODS: 130300 measurement data obtained from all participants' home environments (29 patients diagnosed with asthma and 13 controls) were compared. The BLATN BR-SMART Multi-function Air Quality Monitor measured $PM_{2.5}$, CO_2, and formaldehyde (HCHO) levels.

RESULTS: The age and sex distributions of the patients and controls were similar. The median age of asthmatic patients was 14 years (IQR: 9), and the median age of controls was 13 years (IQR: 9). The number of household members in the homes of asthmatic patients (median: 4, IQR: 1) was significantly higher than the controls (median: 3, IQR: 1) (p=0.035). Asthmatic patients' houses were closer to the highway than the controls (p=0.019). The frequency of homes being closer than 100 meters to the main road was higher in asthmatics (n=17, 65.4%) than in controls (n=3, 23.1%) (p=0.019). Based on all measurements, indoor CO_2 and HCHO levels in the asthmatic patient group were higher than in the controls. Although the $PM_{2.5}$ levels were also higher in asthmatic patients, this difference was statistically insignificant. According to indoor air pollution parameters throughout the day, $PM_{2.5}$ levels were found to be higher in asthmatic patients, especially between 18.00 and 06.00, when the number of people in the house was the highest.

CONCLUSION: Indoor $PM_{2.5}$, CO_2, and formaldehyde levels in patients with asthma were higher than controls. Management of environmental factors along with medical treatment is also essential to achieve better asthma control.

Keywords: Air pollution; asthma; CO_2; HCHO; $PM_{2.5}$.

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Asthma is a common chronic inflammatory respiratory disease that has a prevalence of 1–18% in different countries and is characterized by symptoms such as cough, wheezing, chest tightness, shortness of breath, and variable expiratory airflow limitation [1]. The prevalence of physician-diagnosed asthma in Turkiye is 2.06% in adults and is reported to vary between 0.7–21.2% in children [2, 3]. Environmental factors play an important role in the development of asthma and the occurrence of exacerbations [1].

Today, air pollution is known as the most important environmental risk factor that has an impact on human health [4]. World Health Organization (WHO) reported that indoor air pollution has a role in 3.2 million

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deaths, while indoor and outdoor air pollution was associated with 6.7 million premature deaths in 2020 [5]. The most significant indoor air pollutants are environmental tobacco smoke, particulate matter (PM), nitrogen dioxide (NO_2), carbon monoxide (CO), and volatile organic compounds (VOC) [6].

PM is the main component of indoor air pollution in homes and comprises particles suspended in the air [7, 8]. They can be emitted from natural sources such as pollens, spores, bacteria, plants, and animal residues, as well as from anthropogenic sources such as motor vehicles, industrial emissions, and combustion by-products [5, 8]. Tobacco smoke, burning biomasses for cooking, heating or lighting, cleaning activities, and the outdoor particles that migrated inside are the main sources of indoor PM [3, 8]. PM can accumulate at various levels of the respiratory tract depending on its diameter: coarse particles smaller than 10 μm in diameter (PM_{10}) can enter the respiratory tract and be deposited in the upper airways, while particles smaller than 2.5 μm ($PM_{2.5}$) can reach the alveoli [9]. Long-term PM exposure can cause acute problems such as irritation of the eyes, nose, throat, and bronchi, as well as chronic diseases such as asthma, pulmonary fibrosis, and lung cancer [8]. Indoor $PM_{2.5}$ level is recommended to be below 12–15 μg/m^3 during a 24-hour period [10, 11].

Carbon dioxide (CO_2) is an important component of the atmosphere and a necessary metabolite for the human body. Indoor CO_2 levels are a common metric used to assess indoor air quality and ventilation control [12].

Formaldehyde (HCHO), the simplest member of aldehydes, formed by hydrogen bonding to two bonds of the carbonyl group, can cause cytotoxicity and genotoxicity by affecting cell proliferation and DNA-protein cross-links [13, 14].

There are limited studies on the impact of indoor air pollutants on asthma in pediatric population. This study aims to investigate indoor air pollution by measuring $PM_{2.5}$, CO_2, and HCHO levels in the homes of children with asthma.

MATERIALS AND METHODS

Participants

Patients who followed up with asthma in our clinic, which is a tertiary allergy center, were randomly selected and included in the study. The questionnaire prepared by us was filled out by the participants, and an air quality meter was given to them for at least 3 days and asked to keep it in the living room between 08.00–00.00 and in the child's bedroom between 00.00–08.00. It was requested to keep the device 1 meter above the ground.

> **Highlight key points**
>
> - Indoor air quality is lower in asthmatics than in healthy individuals.
> - Living less than 100 meters away from busy roads may be a risk factor for developing asthma.
> - Indoor air pollution levels are particularly high between 6:00 PM and 6:00 AM.

Asthma control test (ACT) and childhood ACT (c-ACT) were used to determine asthmatics control status.

Controls were randomly selected from families without asthma or any chronic respiratory disease history.

Air Quality Measurement

BLATN BR-SMART (BLATN Science & Technology, Beijing, China) Multi-function Air Quality Monitor was used to measure indoor air quality. The BLATN BR-SMART, which is a real-time air quality monitoring device with dimensions of 65×140×40 mm and a weight of 220 g, was used to detect $PM_{2.5}$, HCHO, and CO_2 pollutants. Light scattering (measuring range: 0–999 μg/m^3, resolution: 1.0 μg/m^3), nondispersive infrared sensor (NDIR) (measuring range: 400–2000 ppm, resolution: 1 ppm), electrochemical sensor (measuring range: 0–1.0 mg/m^3, resolution: 0.01 mg/m^3), and semiconductor sensor test (measuring range: 0–9.99 mg/m^3, resolution: 0.01 mg/m^3), used to measure $PM_{2.5}$, CO_2, and HCHO, respectively [15].

The device was kept in a well-ventilated environment for 8 hours for calibration on the first use and when not used for more than 7 days. The recording was started after at least 20 minutes of measurement to ensure that the readings were accurate [15].

The study was approved by the Ethics Committee of the Uludag University Faculty of Medicine (date: 15.04.2020, number: 2020-6/29). This research adhered to the ethical principles stated in the Declaration of Helsinki.

Statistics

Variables were expressed as mean±standard deviation and median [IQR (Q1–Q3)] values. The compliance

Table 1. General characteristics of patients (n=42)

	Diagnosis of asthma		p
	Asthma (n=29)	Control (n=13)	
Age (years)	14 (9:19–10)	13 (9:18–9)	0.342[a]
Gender (%)			0.485[b]
Female	37.9	23.1	
Male	62.1	76.9	
Place of residence (%)			0.719[b]
Downtown	65.5	76.9	
County	34.5	23.1	
The presence of asthma in the first-degree relatives (%)	55.2	15.4	0.016[e]
How many people live in the house?	4 (1:4–5)	3 (1:3–4)	0.035[a]
Monthly income of the family? (%)			0.419[c]
<2500 TL	6.9	0	
2.500–5.000 TL	31	23.1	
5.000–10.000 TL	41.4	69.2	
Over 10.000 TL	20.7	7.7	
Mother's educational background (%)			0.286[c]
Primary school	24.1	38.5	
High school	27.6	38.5	
University	48.3	23.1	
Father's educational background (%)			0.221[c]
Primary school	10.3	0	
Middle school	10.3	0	
High school	44.8	76.9	
University	34.5	23.1	

The data were expressed as median (IQR: Q1–Q3) and (%). a: Mann-Whitney U Test; b: Fisher's Exact Chi-Square Test; c: Fisher-Freeman-Halton Test; e: Chi-Square test; IQR: Interquartile range.

of continuous variables to normal distribution was assessed using the Shapiro–Wilk test. According to the normality test results, Mann Whitney U and Kruskal Wallis tests were used for comparisons between groups. Categorical variables were given as n (%). Categorical variables were compared between groups using the Chi-square test, Fisher's Exact Chi-square test, and Fisher-Freeman-Halton test. Analyses were made with the SPSS (IBM Corp. Released 2012. IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp.) program was used for statistical analysis, and $p<0.05$ was considered statistically significant.

Post-hoc power analysis was conducted to assess the reported findings of our study. Utilizing the chi-square analysis performed by considering the presence of asthma in the first-degree relatives among the study groups, we calculated the effect size measure to be w=0.44. Given a type 1 error rate of 5% and a study sample size of n=42 patients, the power of our study was established at 80%. Power analysis calculations were made using G*Power software [16].

RESULTS

29 children with asthma and 13 controls were included in the study. 130300 measurement data were recorded from all participants' home environments. The age and sex distributions of the patients and controls were sim-

TABLE 2. Indoor and outdoor features (n=42)

	Diagnosis of asthma		p
	Asthma (n=29)	Control (n=13)	
How many rooms are there in the house in total?	4 (1:3–4)	3 (1:3–4)	0.224[a]
How is the floor of the house? (%)			0.576[c]
Laminate flooring	3.4	0	
Solid parquet	89.7	92.3	
Mosaic or concrete	0	7.7	
Carpet flooring	6.9	0	
Is smoking allowed in the rooms inside the house? (%)	11.1	0	0.538[b]
Is smoking allowed on the balcony? (%)	65.4	83.3	0.444[b]
In which way do you provide heating for your home? (%)			>0.99[c]
Natural gas radiator	92.6	92.3	
Natural gas furnace	3.7	7.7	
Electric heater	3.7	0	
How many years ago did you change the furniture in your home? (%)			0.356[c]
0–2 years	14.8	7.7	
2–4 years	25.9	7.7	
Over 5–7 years	59.3	84.6	
What are the walls painted within your house? (%)			>0.99[c]
Lime paint	11.1	7.7	
Plastic paint	11.1	7.7	
Paper coating	77.8	84.6	
Are there any factories around your house? (%)	30.8	7.7	0.225[b]
Do you have a dust trap (thick) curtain in your home? (%)	51.9	53.8	>0.99[e]
Are there pets in your home? (%)	14.8	7.7	>0.99[b]
Do you have flowers in your home? (%)	59.3	61.5	>0.99[e]
Is there a flower ornamental plant in the child's room? (%)	11.1	7.7	>0.99[b]
How far is your house from the main road? (%)			0.019[c]
0–100 meters	65.4	23.1	
100–300 meters	19.2	53.8	
300–1.000 meters	7.7	23.1	
More than 1.000 meters	7.7	0	
On which floor is your house located? (%)			0.351[c]
0.–2. floor	0	7.7	
3.–5. floor	51.9	61.5	
6.–9. floor	37	30.8	
9. floor above	11.1	0	

The data were expressed as median (IQR:Q1-Q3) and (%). a: Mann-Whitney U Test; b: Fisher's Exact Chi-Square Test, c: Fisher-Freeman-Halton Test; e: Chi-Square Test; IQR: Interquartile range.

ilar. 62.1% (n=18) of asthmatic patients were receiving active treatment. The general characteristics of the patients and controls are given in Table 1.

Indoor $PM_{2.5}$ levels of 72.4% of asthmatics (n=21) and 76.9% of controls (n=10) were above the recommended short-term (24-hour) level (<15 μg/m³) (p=0.76). Ac-

Table 3. Comparison of $PM_{2.5}$. CO_2. and HCHO levels in the homes of asthmatic patients and controls

	Patient (n=94823)	Control (n=35477)	p[a]	Effect size
$PM_{2.5}$ (μg/m^3)	18 (27:9–36) 31±45.1	18 (14:12–26) 21.6±14.8	0.650	0.011
CO_2 (unit)	863 (776:529–1305) 1028.3±728.2	500 (179:433–612) 538.9±183.4	<0.001	0.107
HCHO (unit)	0 (0:0–0) 6±106.4	0 (0:0–0) 0.3±24.1	<0.001	0.001

The data were expressed as median (IQR: Q1–Q3) and mean±standard deviation; a: Mann-Whitney U Test; CO_2: Carbon dioxide; HCHO: Formaldehyde; $PM_{2.5}$: Particulate matter $_{2.5}$; IQR: Interquartile range.

Table 4. Distribution of air pollution parameters according to different hours of the day in asthmatic patients (n=94823)

	00:00–05:59 (n=26047)	06:00–11:59 (n=21879)	12:00–17:59 (n=21696)	18:00–23:59 (n=25201)	p[d]	Effect size
$PM_{2.5}$ (μg/m^3)	20 (26:10–36) 32.9±48.2	15 (22:8–30) 25.1±33.4	17 (26:9–35) 27.5±34.8	19 (33:10–43) 37.3±56.1	<0.001	0.011
CO_2 (unit)	1006 (895:614–1509) 1158.6±783.9	906 (680:594–1274) 1067.5±734.1	698 (650:442–1092) 833.4±582.3	887 (851:489–1340) 1027.4±740.8	<0.001	0.026
HCHO (unit)	0 (0:0–0) 0.26±23	0 (0:0–0) 0.75±39.8	0 (0:0–0) 3.9±95.5	0 (0:0–0) 19.6±186.4	<0.001	0.005

Data are given as median (IQR: Q1–Q3) and mean±st. deviation; d: Kruskal Wallis Test; CO_2: Carbon dioxide; HCHO: Formaldehyde; $PM_{2.5}$: Particulate matter $_{2.5}$; IQR: Interquartile range.

cording to the ACT, 77.8% (n=14) of controlled asthmatics and 66.7% (n=4) of uncontrolled asthmatics had $PM_{2.5}$ levels above the recommended short-term level (p=0.74).

Compared to control subjects (median: 3, IQR: 1 (Q1: 3, Q3: 4), asthmatic patients (median: 4, IQR: 1 Q1: 4, Q3: 5) resided in households with a statistically significant increase in the number of occupants (p=0.035). The frequency of houses being closer than 100 meters to the main road was higher in asthmatics (n=17, 65.4%) than in controls (n=3, 23.1%) (p=0.019). A comparison of the indoor and outdoor characteristics of patients and controls is given in Table 2.

Based on all measurements, indoor CO_2, and HCHO levels measured in the asthmatic patient group were higher than in the control group. While asthmatic patients exhibited elevated indoor $PM_{2.5}$ levels compared to non-asthmatic subjects, this difference did not reach statistical significance (Table 3).

When the daytime air pollution parameters were evaluated in asthmatic patients, indoor $PM_{2.5}$ levels were measured to be higher, especially between 18.00–06.00 when the number of people in the household was the highest (Table 4).

DISCUSSION

Effective asthma management necessitates consideration of environmental influences from both outdoor and indoor environments [1]. Most people do not have direct control over outdoor air pollution, but they can reduce the concentrations of certain pollutants in their homes, so they are more likely to reduce their exposure to indoor pollution than they are to outdoor pollution [1]. In a previous study conducted by our group, it was found that the asthma control levels were lower than desired in patients with childhood asthma [17]. In various studies conducted both in Turkiye and in the world, asthma control levels were stated to be low [18]. Although a variety of medications for the treatment of asthma are available today, inadequate asthma control may be due to negligence of the impact of air pollution. Consistent with previous research, our study found that indoor $PM_{2.5}$, CO_2, and HCHO levels were higher in patients with asthma than in controls.

Exposure to indoor air pollutants such as PM, NO_2, and passive cigarette smoke may cause the development of new asthma, worsen asthma symptoms, increase the risk of asthma attacks, and reduce respiratory function [15, 19, 20]. Many studies have shown that short-term exposure to $PM_{2.5}$ and PM_{10} leads to increased asthma symptoms in atopic children; in contrast, long-term exposure was associated with poor asthma control in children and reduced respiratory function in children and adults [21]. A large body of research also demonstrated that short- or long-term exposure to $PM_{2.5}$ or PM_{10} is associated with increased healthcare spending [22, 23]. A meta-analysis by Lim et al. [24] found that a 10 μg/m^3 increase in $PM_{2.5}$ concentrations was associated with a 4.8% increase in child's hospitalization and emergency room admission rates. In our sample, the median indoor $PM_{2.5}$ concentration (31.1 μg/m^3) in asthmatics was higher than in controls (21.5 μg/m^3), and the maximum value of $PM_{2.5}$ measured in asthmatic patients was 808 μg/m^3, while it was 276 μg/m^3 in the control group.

Indoor CO_2 concentrations are recommended to be maintained below 700 ppm to ensure human health [25]. Exposure to CO_2 concentrations above 3000 ppm increases the incidence of symptoms such as headache, drowsiness, fatigue, and difficulty concentrating [12, 26]. Our study found that the median indoor CO_2 level in the asthmatic group was higher than the recommended value while the median CO_2 level in the control group was below the recommended threshold.

Asthmatic patients experience worsening of their symptoms, especially at night and in the morning [1]. This condition is commonly associated with the circadian rhythm [27]. In our study, indoor $PM_{2.5}$ levels reached their highest levels, especially in the evening and night-early morning periods. This finding may be attributed to increased domestic activity and decreased ventilation, as supported by prior research [28]. Given these findings, we hypothesize that the low indoor air quality may contribute to the increase in the complaints of asthmatic patients at night and early in the morning. More studies are needed on this subject.

Traffic-related air pollution (TRAP) is a major health problem, especially for people living in urban areas, leading to the development of respiratory diseases such as asthma [21, 29]. TRAP is a mixture of major gas emissions including combustion products, non-combustible sources (e.g., road dust, tire and brake wear), and nitrogen oxides. These primary emissions lead to the production of secondary pollutants such as ozone, nitrates, and organic aerosols [30]. In a study conducted in 10 central European countries, 14% of asthmatic cases and 15% of asthma exacerbations were associated with TRAP [31]. NO_2, an important component of TRAP, is a known trigger of asthma attacks [20]. In addition, it has been shown that TRAP may cause an increase in asthma incidence, symptoms, severity, and TH2/Th17 inflammation, a decrease in response to bronchodilators, and lung functions [22, 32]. Several studies have shown that the place of residence's proximity to the highway poses a risk for the development of asthma. In two studies conducted by Lindgren et al. [29, 33], asthma frequency was found to be higher in the group living closer than 100 m to the highway. Considering that the TRAP density is higher on the highway sides, it is recommended that especially preschool children's living spaces should be away from highways to reduce the likelihood of developing asthma and alleviate symptoms in case of illness [20]. Our study found that 65.4% of asthma patients' homes were closer than 100 meters to the highway.

HCHO, a pungent-smelling, colorless gas released from building materials such as particle board, plywood, and adhesives, is one of the most common VOCs [12]. It is a highly reactive gas emitted during the incomplete reaction of hydrocarbons and is also produced by the oxidation of other VOCs by ozone or radiation [13]. Indoor HCHO sources are furniture and wood panels containing HCHO-based resins, adhesives, paints, paper products, cosmetics, electronic appliances, cleaning agents, and textiles [13]. The increasing importance of energy efficiency has led to shorter door and window opening times and significantly decreased indoor ventilation rates, resulting in higher HCHO pollution levels [34, 35]. Acute exposure to HCHO can cause irritation in the eyes and upper respiratory tract, headache, asthma, allergies, and eczema, while chronic exposure is a known risk factor for nasopharyngeal cancer and myeloid leukemia [8, 14, 36]. Exposure to HCHO for 150 minutes per week has been associated with a 1–1.5% decrease in forced expiratory volume in one second (FEV1) [36]. We found indoor HCHO levels were higher in asthmatic patients than in controls.

Low-cost air quality meters measure the size of particles with laser or infrared. Their low cost, small volume, and ease of use allow them to be widely used to measure indoor air quality [37, 38]. Continuous indoor air quality monitoring will enable practices to prevent indoor air pollution. Therefore, we think that the individual use of low-cost air quality measuring devices is important for public health in terms of increasing awareness of air pollution and taking preventative measures.

Limitations

Our study has some limitations. The first is that the sample is small. The characteristics, lifestyles, and environmental conditions of the individuals in the sample may differ from the general population of children with asthma. Hence, we recommend conducting new studies using a larger sample and more sophisticated measurement methods. The use of low-cost devices may also affect the reliability of the results. These devices may be less sensitive compared to more expensive devices and cause certain measurement errors. Leaving the control and measurement of the device to the patient can also affect the accuracy of the results. Therefore, using more sensitive devices and having the measurements taken by an experienced specialist will increase the accuracy of the results. Another important limitation of our study is that concurrent outdoor air pollution is not measured.

Conclusion

Indoor air pollution is a major health problem that requires attention and action. Better indoor air quality monitoring, control systems, and education on the importance of indoor air quality can help prevent respiratory illnesses and improve the overall health of individuals. To the best of our knowledge, this study is the first study in Turkiye to evaluate indoor air quality in children with asthma. As a result of the study, we found that the indoor air quality of asthmatic patients was worse than the controls. Studies involving a larger number of patients are needed in this regard.

Ethics Committee Approval: The Uludag University Faculty of Medicine Clinical Research Ethics Committee granted approval for this study (date: 15.04.2020, number: 2020-6/29).

Informed Consent: Written informed consent was obtained from the participants and their parents.

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